Water Quality in the Americas

Risks and Opportunities

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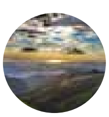

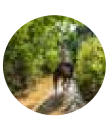

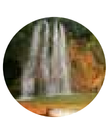

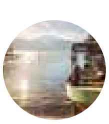

Foreword

This volume is the product of a collaborative effort between the Water Committee of the InterAmerican Network of Academies of Science (IANAS) and the International Hydrology Program of UNESCO. It is the latest of three publications resulting from this ongoing collaboration. Earlier efforts include a comprehensive overview of the water resources of the Americas entitled *Diagnosis of Water in the Americas*, published in 2013 and a study of urban waters entitled *Urban Water: Challenges in the Americas*, published in 2015. All these works have been published in both English and Spanish to make them widely available to water managers, scholars and the public throughout the Americas and globally. There is every reason to expect that this collaboration will continue and build on its successful past in the future. The editors of this volume are grateful for the support of their colleagues from UNESCO in bringing this volume and its predecessors to fruition and look forward to the continued success of the collaboration.

In the present book, focused on the problems and management of **Water Quality**, there has been close collaboration with the Regional Bureau for Sciences in Latin America and the Caribbean of UNESCO in Montevideo, specifically with the International Hydrological Program for Latin America and the Caribbean (IHP-LAC) and the IHP Regional Hydrologist for LAC, Dr. Miguel de Franco Doria. It is important to mention that a series of meetings were held to support the preparation, organization and publication of this book: the IANAS Water Program and UNESCO in Irvine, California (USA, September 2015, Water Quality in the Americas Workshop); the International Water Fair in November 2016 in Medellín, Colombia hosted by the Centro de Ciencias y Tecnología de Antioquia (Center of Science and technology of Antioquia) and the Colombian Academy of Exact, Physical and Natural Sciences; the Meeting of the Water Program in Ottawa hosted by the Royal Society of Canada, The Academies of Arts, Humanities and Sciences of Canada and Carlton University (August, 2017); Sharing Water: From Local to Global focusing on Water Quality in the Americas (Ipatinga, Brazil, February, 2018) hosted by UNESCO-IHP; the World Water Forum, Brasilia, the Presentation of Urban Waters Challenges in the Americas (March, 2018) supported by the Brazilian Academy of Sciences and the UNESCO Latin America-Caribbean Regional Training Workshop on Emerging Pollutants in Water Resources organized by the UNESCO-IHP International Initiative on Water Quality (IIWQ) in Campinas, Brazil, in December, 2018.

We would like to acknowledge the support from the Conferencia de Directores del Agua (Spanish acronym-CODIA), which is active in promoting the dissemination of technical, scientific, social and environmental knowledge in water resources for supporting this publication, particularly as regards the production of various promotional materials linked to this publication.

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A General Overview of Water Quality in the Americas

Co-Chairs of the IANAS Water Program
Katherine Vammen (Nicaragua) and Henry Vaux (USA)

Water resources are a key component supporting and strengthening sustainable development in the American hemisphere and globally. ***"Water Quality in the Americas: Risks and Opportunities"*** brings together a unified effort by the Academies of Sciences from 21 countries of the Americas. A team of 148 authors from all 21 countries, experts in different aspects of water science, produced this assessment from the perspective of the Academies of Science, with the objective of analyzing specific problems of water quality and offering suggestions for better management. The book provides an overview of surface and groundwater quality and impacts on human consumption, agriculture and ecosystem services in each country, thereby creating a hemisphere-wide picture of the current status and future challenges for the quality of essential water resources. This overview will facilitate the creation of new management concepts and the introduction of best practices in our diverse hemisphere. The book considers areas of abundance and scarcity of water resources, ranging from temperate to tropical conditions and puts water resource development in the context of the great diversity of economic and social development in the Americas. It deals with the different impacts of industrial and human activity in both urban and rural areas, problems involved in potable water and wastewater treatment, and in particular, each country´s institutional and professional capacities to improve water governance.

In the beginning, management concepts were focused more on water balance in the different watersheds; but today, availability is clearly being influenced by anthropogenic impacts that affect water quality, and in turn the availability of the resource, for different uses leading to problems of water security for the human population and for ecosystems. The restoration of water quality involves many aspects from the protection of watersheds at all levels to assuring improved environmental laws and their enforcement, all aimed at reducing risks and vulnerability to assure water security. Science has a key role in developing evidence-based recommendations to assure water quality leading to better policies and their timely implementation. It is imperative to improve the management of water resources throughout the Americas and to improve and better adapt governance to the specific resource conditions of each country as they address their particular water quality problems.

Globally, the deterioration of water quality has gone through a process of change parallel to changes in human activities, population growth, urbanization, industrialization and progressive shifts in land use. Pollutants are continuously more complex and can be directly related to human health and significant impacts on the environment. This results in an increase in costs for treatment for purification of water and wastewaters and affects ecosystem services. Water quality deterioration is due to human impacts, which began with fecal and organic contamination at a time when water treatment was extremely limited in the 1800s and was followed by an increase in metal pollution with special characteristics of bioaccumulation in aquatic ecosystems into the 1900s. Beginning in the 1960s with the increasing input of nutrients into receiving waterbodies, eutrophication processes were observed throughout the continent, which eventually reached levels causing cyanobacteria blooms resulting in cyanotoxin release into the water of lakes and reservoirs. From the Great Lakes of North America to reservoirs and lakes in South America, public concern was growing, and the rapid proliferation of algal blooms was increasingly subject to studies. (Tundisi, 2015; Schindler, 1977). "These studies were aided by rapid developments in chemical methods and equipment" (see chapter on Canada) and these advances were quickly adopted by research teams looking to identify and solve water pollution throughout the Americas, from the north of Canada to South America.

It became increasingly clear after some decades of studies that both point and non-point sources are important causes of pollution: (1) point sources (e.g. factories, sewage outfalls) without adequate waste treatment were causing eutrophication; and (2) non-point sources and run off from agriculture were the sources of the input of phosphorus, nitrogen and other agrochemical into major waterbodies. Organic chemicals became widely used in agriculture. Persistent organic pollutants (POPs), herbicides and insecticides and the increase of uncontrolled use of fertilizers became a major source of pollution in water resources, surface- and groundwater. Changes in land use, which promoted deforestation for expansion of agriculture and livestock production, also created widespread sedimentation into surface waters: lakes, reservoirs, rivers and coastal lagoons. All these processes affected water for human consumption and led to a "reduction in quality of ecosystems which support water resources and maintain their quality" (Tundisi, 2015). Additionally, the integrity of key zones of protection for water bodies such as riparian zones, wetlands and others such as the extremely delicate areas of recharge for groundwater and pristine sources of hydrological systems was compromised.

The American continent has many special areas of global importance for climate and great hydrological significance. One feature, the Amazon River, stands out as it flows for "6,992km and discharges close to 20% of all the freshwater that reaches all marine environments of the world" and covers an "area of seven million square kilometers" (see Chapter on Brazil). The adaptation of the aquatic biota due to the diversity of water types together with seasonal variation throughout the evolutionary process has produced a unique combination of biodiversity. Human impacts on the water quality of the Amazon basin are threatening water quality and biodiversity due mainly to certain mining activities, urban impact and changes in land use (see Chapter Brazil for more details. The situation in other watersheds in the region is, in many cases, similar or worse. Targeting the Amazon basin when there are worse cases-in North and South America-could be misinterpreted

There are new emerging risks for water quality that need special attention and are the subject of evaluation in some chapters. Emergent contaminants are present in surface and groundwater sources which originate from drugs, cosmetics, antibiotics, hormones, nanomaterials and other inputs which present new threats to human health, biodiversity and ecosystems. These need closer analyses in the near future. Certain industrial mining extraction methods initiated in the last decades such as sand tar mining and fracking in vulnerable areas are producing new risks for water resources that could have consequences for water quality and therefore for human health.

Global climate change also has multiple effects on water quality. Extreme events mean that water sources which were once perennial now suffer from drought periods leading to a greater concentration of pollutants with consequences for aquatic biota and public water supplies. Insufficient water quantity in some areas has meant the use of the same water source for both water withdrawals for human consumption and irrigation and at the same time for waste disposal (see Chapter on Canada). On the other hand, flooding brings in large quantities of sedimentation and extreme events such as hurricanes tend to destroy hydrological systems due to massive deforestation and extreme changes (sedimentation and siltation) in river and lake basins drastically affecting flow regimes. Metals and nutrients which are weakly bound in sediments can be released into the water in these events. Increases in the temperature of surface waters have already caused an intensification of cyanobacterial blooms as these species adapt rapidly to higher water temperatures and dominate the biodiversity of phytoplankton in the aquatic ecosystems. Climate warming also influences metal contamination, for example, mercury can be released to downstream waters after forest fires or disappearance of permafrost environments (for example in Canada, and warming can also lead to reconcentration of contaminants).

This volume of Water Quality in the Americas is intended to contribute to a greater understanding of current threats and impacts to water resources. The analyses therein are summarized in the following sections.

Water Quality Problems of the Americas

Eutrophication

Virtually every country in the Americas experiences some degree of artificial eutrophication in its waterways and water bodies. Frequently, the eutrophication in question is characterized as cultural eutrophication meaning that the phenomena is artificially established by an excess of nutrients in the waters that are discharged by agricultural and industrial activities rather than occurring exclusively from natural sources. The results are varied and include algal blooms that are sometimes toxic and deplete dissolved oxygen. Cultural eutrophication can render the water unsuitable for drinking and other purposes and destabilize the aquatic ecosystem in question. Such destabilization frequently results in algal blooms with the subsequent release of toxins and explosive growth of unwanted species. Greenhouse gas production in water reservoirs should also be noted.

Non-point source pollution. Eutrophication is often, though not always, caused by non-point source pollution, which by itself creates vexing water quality problems in virtually every country of the Americas. Non-point source pollution involves pollutants that originate from diffuse sources that are difficult to regulate directly because it is impossible to identify points of origin. By contrast, point source pollution emanates from an identifiable location making it relatively easy to enforce regulatory standards. Non-point source pollution includes run-off from watershed lands that have been eroded or otherwise heavily modified or denuded; run-off from agricultural lands that contains the residues of agricultural chemicals including fertilizers and pesticides; run-off and particularly storm water run-off from urban landscapes that contains all manner of chemicals including hydrocarbons and sediment.

Agricultural Chemicals. Agricultural chemicals – mainly fertilizers and pesticides – are difficult to control both because the chemicals themselves may be damaging to the environment or human health and are frequently not evaluated prior to commercial release. In addition, decisions relating to how much of a chemical to apply tend to be decentralized and there is a tendency to apply more than is needed with the result that the quantities of chemicals in the run-off can be even greater than if the quantities applied were optimal. Run-off from agricultural lands has been implicated as the cause of "dead zones" found in waters where cultural eutrophication is especially severe.

Cyanobacterial Blooms and Toxins. A particularly insidious manifestation of eutrophication involves cyanobacteria, which are photosynthesizing bacteria, found naturally in terrestrial and aquatic habitats around the world. Under conditions that include extreme levels of eutrophication and featuring specific strains of cyanobacteria, the associated algal blooms release toxins that are dangerous to animals, some forms of plant life and humans. These toxins have been known to cause death in humans. The potential for such blooms exists throughout the Americas and is one extreme of the sort of contamination that severe cultural eutrophication can lead to.

Chemical Contamination

The number of chemicals with the potential to contaminate waterways and water bodies is almost limitless. Contamination of water with chemicals is ubiquitous and is found throughout the Americas in varying degrees of severity.

Emerging Contaminants. New chemicals emerge every day in the agricultural, industrial and technology sectors. Although these products are intended to offer solutions to various problems, many appear soon afterwards in waterways and water bodies as well as on the land. This appearance occurs before much is known about their health and environmental impacts. No country in the Americas currently has the capacity to evaluate emerging contaminants either before or after their release into the environment. The ultimate implications of this situation are totally unknown but it is clear that the prospects for dangerous and even deadly waterborne health impacts rise with each passing day.

Toxic Chemicals. The lack of capacity to evaluate emerging new contaminants means that the inability to discriminate between toxic and non-toxic chemicals increases the threat to human health and well-being. There is particular concern about the fact that newly emerging chemicals or their metabolites may react with chemicals already in the environment to produce toxins that are even more dangerous than the original chemical. In addition, the failure to evaluate the impacts of discharging toxic chemicals into water means that the potential long-term impacts are poorly understood or not understood at all. The resources needed to assess the long-term implications of chemicals that may not be immediately toxic are simply not available in most of the countries of the Americas.

Acid Rain. It is well established that emissions from the combustion of fossil fuels released into the atmosphere can cause increases -and perhaps significant increases – in the acidity of precipitation. Increasing the acidity of precipitation has adverse effects on aquatic habitats and may result in biological destabilization of those habitats. Acid rain can also cause significant damage in urban areas through destruction of protective paints and other coatings. Significantly, the impacts of increasing acidic rain are often felt at locations that are remote from the places where the causative emissions occur. This means that the emitting party frequently has no incentive to ameliorate the offending discharges. This problem is more pronounced in regions of the Americas that rely exclusively on the burning of fossil fuels with a high sulphur content and the generation of NOx (Nitrogen Oxides) for production of electricity and other commodities.

Salinization. All naturally occurring waters contain some salts. When water is evaporated, or transpired in the case of agriculture, the salts remain. In irrigated agriculture, some salinization is evitable and unless it is attended to it will ultimately reduce the productivity of the soils in question ending with a total loss of soil productivity. The remedy is to leach periodically the salts from the root zone. This requires water in addition to that necessary to support the crop. In arid regions throughout the Americas salinization of agricultural lands is a threat. The waters to counteract salinization through leaching may not be available in arid and semi-arid regions. Sea water intrusion, which occurs when coastal and near coastal aquifers are overdrawn, is another form of water quality degradation. This is dealt with in the section on groundwater below.

Contamination due to Urban Waste. The inadequate disposal of urban solid waste and untreated industrial residue in garbage dumps can lead to contamination of groundwater due to leaching processes. Rain and the humidity of residues accelerate this process, transmitting various substances harmful to human health, including carcinogenic and toxic substances.

Mining and Other Industrial Wastes. Mining and other industrial wastes pose high risks to water quality because of the concentration of metallic and other compounds which can be mobilized by precipitation and water transport through the soil. These wastes can be particularly vexing to manage because sources are sometimes diffuse – as with acid mine drainage – and it is often difficult to identify the ownership of them. In countries with developed economies, such wastes are typically cleaned up at very high cost. Countries with less robust economies will rarely be able to defray the costs of clean-up.

Natural Contamination. Natural contamination also creates threats to water quality. Among the most prominent of the contaminants are fluorides, boron and arsenic. These contaminants are usually found in soils and rocks and are mobilized through rainfall and other weathering events. Fluorides are ubiquitous in the soil and water environment and are relatively harmless at low concentrations. However, they can be toxic at higher concentrations even in nature. Boron is typically present in soil and water and at higher concentrations can be toxic to plants including crop plants. Arsenic is toxic to humans and body burdens of arsenic are cumulative so even the ingestion of water with low arsenic concentrations over time can have significant toxic impacts. Natural contaminations of all sorts are difficult to manage because they typically come from diffuse sources and from specific geological formations, such as volcanic origins.

Biological and other non-Chemical Contaminants

Microbes and other biological contaminants are well known. There are other contaminants that may or may not have biological properties that pose threats to water quality.

Invasive Species. The advent of transportation technology resulted in an ever more tightly linked globe. In such circumstances it was almost inevitable that organisms could move from the accustomed habitats where they had evolved to more distant habitats that they could colonize. The more distant habitats lacked the predators and/or environmental conditions that had tended to keep population numbers stable in the original habitat. The result was frequently a population explosion in the new habitat that continued until it could no longer be supported, and the population numbers crashed. Modified landscapes and aquatic environments also invite the invasion of other species for a variety of reasons. Invasive species can do significant damage to the environmental integrity of an aquatic habitat affecting trophic levels in the ecosystem, leading in some cases to the extinction of important species. Significant resources have already been devoted to the management of invasive species to counteract the substantial damage that they can inflict. The advent of global warming and other environmental changes suggests that invasive species will appear throughout the Americas (and the rest of the globe) with increasing frequency and attendant increases in the cost of control. Such invasion will affect aquatic habitats.

Sedimentation. Sedimentation is a natural process of wearing down the landscape and transporting the material. However, mismanagement of watershed lands and waterways can lead to excessive mobilization of sediments and accelerated rates of sediment transport. Excessive amounts of sediment can destroy aquatic habitats, shorten the life of dams by prematurely filling reservoir space that would otherwise be available to store water and render the water unsuitable for some uses. Indiscriminate land conversion as with the development of agricultural lands, clear cutting and modifying land surface in ways that increase water flow runoff can all lead to excessive sedimentation. Activities that increase the rate of sedimentation occur on lands throughout the Americas with the result that sediment mobilization and transport will increase and cause degradation of surface water quality.

Microbial contamination. In spite of significant gains in the provision of potable water supplies, microbial contamination continues to threaten the quality of many of these supplies. Modification and mismanagement of watershed lands threatens the qualitative integrity of water from those lands. The absence of well-functioning and operated treatment facilities and the failure to maintain and renew existing facilities increases the possibilities for microbial contamination. No country in the Americas is free of concerns about eliminating microbial contamination of potable water supplies although the situation is worse in some countries than others. Both bacterial and viral pollution need to be considered in monitoring programs. This situation deteriorates further due to exposure to untreated liquid urban waste and agriculture.

Adequate sanitation. Many countries in the Americas have made impressive gains in the provision of sanitation service over the past decades. This has entailed the construction of wastewater treatment facilities and the development of a cadre of workers who can operate them. Still many countries of the Americas are behind in the coverage of sanitation in urban areas and when existent lack adequate treatment before the effluents enter into receiving bodies and therefore cause further pollution to important waterbodies. Rural sanitation remains a problem, even in countries where total coverage is reasonably high. Maintenance and renewal of sanitation facilities may become a significant problem over time because of high cost and popular apathy.

Groundwater

The importance of groundwater as a potential source of supply and the management of it to protect both available quantities and good quality has been largely neglected throughout the Americas. It is not widely appreciated that it is almost always cheaper to protect groundwater quality than it is to clean it up after it has been contaminated. Groundwater quality protection is made difficult by the fact that most contaminants come from diffuse sources and that contamination moves underground at different rates which are difficult and expensive to monitor. In general, groundwater quality must be managed indirectly by specifying a set of best management practices to govern activities that are undertaken in recharge areas. A well-designed set of practices will minimize or eliminate the possibility of contaminants from reaching the aquifer in question. Well-head protection programs are especially important inasmuch as contaminants can reach the groundwater almost instantaneous if they flow down wells.

A special problem occurs where coastal aquifers are overdrafted (more is extracted than recharged) and the level of the water table drops. When that level falls below sea level, sea water may intrude into the aquifer. Progressive salinization of the aquifer then results if remedial actions are not taken. The obvious remedy is to eliminate the overdraft and allow the water table to recover. Other methods of hydrologic manipulation, which require additional water supplies have been employed successfully. Artificial desalination is another potential remedy, but it is very costly.

Managing Water Quality in the Americas

No country in the Americas is totally successful in managing water quality. This finding includes the developed countries as well as those that are developing. The ingredients of a successful management program are well known and are summarized below.

Recycling and Reuse

The Principle of Materials Balance, derived from the Law of Conservation of Mass, holds that the mass of material discharged as waste to the environment is approximately equal to the mass of material that enters into production processes. This means that there are only two ways in which the volume of pollutants can be reduced: 1) reduce the throughput or 2) recycle and reuse the materials that are being discharged into the environment. Recycling is practiced to one degree or another throughout the hemisphere, but the scale of recycling programs needs to be increased. Similarly, it is important to note that waste sinks – water, air and land – are interconnected so that a reduction of quality in one sink implies an increase in quality in the others. Programs that are sink specific – such as some of those in the United States – simply move the wastes around and fail to acknowledge the fact that sinks are essential, yet largely absent throughout the Americas.

Monitoring

No pollution management program can be successfully mounted without some information on the state and quality of the aquatic environment. A minimum of data is needed about water flows and water quality. In spite of this fact the level of monitoring in virtually every country of the Americas is inadequate. Where data is inadequate the management problem becomes one of managing risk and uncertainty. Risk management also requires some monitoring as well as research to determine the risk associated with different pollutants. Monitoring and data generation must usually be undertaken by the central government because of the interdependency of waters flowing between States and Provinces. The difficulty is that programs of data collection and analyses lack political appeal and therefore are usually inadequate to the task at hand.

Research Programs

Effective management programs should be based upon the science of water quality. As economic and population growth proceed, the water quality management problem becomes more extensive and more complicated. This requires more scientific research in order to understand both the nature of the problem and appropriate measures to combat it. Research programs require public investment. Such investment is inadequate in virtually every country of the Americas. At stake is the cost and effectiveness of existing and future programs of pollution management and abatement. A robust program of research has the advantage of keeping scientists in contact with their colleagues throughout the hemisphere so that scientific knowledge generated in other countries is available to all.

Policy Making and Governance

Programs of effective pollution management require explicit statements of policy goals and policies and rules for achieving those goals. Thus, for example, the statement of goals needs to enumerate whether the pollution control strategy will entail direct government controls, a more indirect incentive based system or some mixture of the two. It is important to recognize that merely developing a standard is not sufficient. Policies must be devised to select the level of the standard and solve the problems of compliance and enforcement. Comprehensive pollution control policies will normally have components covering: 1) education; 2) price based incentives such as tradable pollution permits: 3) a system of standards and 4) a hierarchy of enforcement mechanisms.

Managing water quality also requires an effective array of institutions to establish the policies, monitor the results and enforce the resultant standards and policies. Institutions include laws, public agencies, appropriate policies and appropriate enforcement mechanisms. Strong institutions that are reliable, and with adequate human and financial resources, are an essential part of any effective pollution control programs, yet they are largely absent in the Americas.

Sustainable Development Goal 6: Target 6.3 Water Quality

Target 6.3 deals with reducing contamination, illegal waste disposal and hazardous chemical materials with a special mention to cutting untreated wastewater by half and increasing recycling and safe reuse. Each country chapter deals with these challenges and includes some examples of efforts to promote reuse especially efforts in countries with less abundance of water.

The Dimensions of Water Quality: Society, Health, Women, Energy and Monitoring

As water quality depends on human activities and directly acts on human health, this book contains subchapters dealing with these important aspects: “Water and Society: The Multidimensions of Water Quality” and “Water and Health”. As mentioned above, in order to understand the state of water quality in the different resources and its levels it is essential to develop improved monitoring programs. Two subchapters on special monitoring aspects have been included: “Biological Monitoring of Water Quality and “Application of new methodologies in monitoring and zoning plans for waterbodies” which give examples of important components and methodologies for future monitoring programs.

The importance of the role of women in securing water quality in the home and in industry and agriculture, is a topic which is not always dealt with and therefore the Women in Science program of IANAS, which is also in line with the priority of UNESCO related to gender equality, have contributed a special feature chapter “Gender, Women and the Quality of Water” dealing with experiences in several developing countries of Latin America and the Caribbean, which demonstrate the importance of water quality and the treatment of wastewaters in the lives of women.

The Energy Program carried out small studies in most countries represented in IANAS to determine whether there has been progress on the use of renewable energy in assuring water quality. These findings have been presented in a special feature chapter which illustrate some examples in the Americas.

Referencias

Schindler, D.W. (1977). Evolution of phosphorus limitation in lakes. *Science* 195, pp. 260-262.

Tundisi, J.G.; Matsumuro-Tundisi, T.; Ciminelli, V.S. & Barbosa, F.A. (2015). Water availability, water quality water governance: the future ahead. Hydrological Sciences and Water Security: Past, Present and Future. (Proceedings of the 11th Kovacs Colloquium, Paris, Francia, June 2014). *IAHS Publ.* 366, 2015.

Important Aspects Related to Water Quality

Water and Society
The multidimensionality of water quality

María Luisa Torregrosa (Mexico), Daniela de las Mercedes Arellano Acosta (Cuba) and Karina Kloster (Mexico)

Introduction

Addressing problems related to water quality in the region is not an easy task. Despite the many efforts made by various governments since the 1970s, the delay of many countries in expanding water and sanitation services in sufficient quantity and quality, particularly in the peri-urban and rural communities, remains. Particularly in Latin America, there is enormous heterogeneity in the forms of access to water. There is still a large sector of the population located in marginal and peri-urban areas that access water through tanker trucks, low-cost plastic carboys from nearby unsafe sources, among others, all of which are unreliable regarding water quality (Jiménez, 2009),[1] without mentioning the risks to which the rural population is subject due to the high degree of contamination of sources due to problems of eutrophication or other types of pollution that are increased by the absence of drainage and the forms of final disposal of gray water and sewage.

In urban settlements, this final disposal is a problem that persists in Latin American countries, in addition to those derived from the lack of investment to maintain and improve infrastructure. Many cities still lack drainage and sanitation systems, and when they do exist, they are often either not operated correctly or never begin operating.

Likewise, the absence or limitation of regulatory frameworks and their application in terms of sanitation persists, together with the final disposal of wastewater from cities, industries -particularly extractive industries-, and agriculture, which has had major consequences for the water quality of our countries.

Another important obstacle to improving the water quality of many of our countries is the delay in or, at worst, absence of reliable data indicating the current quality. Data on sanitation services often only refer to the sewage disposed through sewerage services without considering its treatment, that of gray water and its safe final disposal in the receiving bodies. This has significant consequences and an incidence that is reflected in the amount of contaminated sources and high rates of waterborne diseases in the population.

These deficiencies in the quality of the water supplied to the population, whether it is connected to networks or obtained by other means, has led people to resort to the purchase of bottled water, which is unregulated and for which there is no certainty about the quality that it distributes (Pacheco-Vega, 2017). Alternatively, they purchase home water purification systems, which increases the cost of this resource by 30 or 50% over the official price,

1. Independent studies undertaken by academic institutions reveal that, although a high percentage of water is chlorinated, of the water received in homes, only 30% of the cases meet the requirements established for the presence of microorganisms and chlorine residues (Jiménez *et al.*, 2002).

which is generally assumed by the more disadvantaged sectors of the population or, failing that, they pay the health costs of being unable to purify water.

Looking at these results, we should ask ourselves: Why is it so difficult to obtain good water quality in our countries? What do we need to achieve this? What are the crucial factors for reducing the water and sanitation deficit? What is the relationship between water and sanitation services and the availability of water and technologies, economic status, legal framework, institutional capacity and water policies?

There are multiple formal and informal water supply strategies that have proven to be successful in both developed and developing countries, ranging from state or municipal public management, public-private participation and cooperative models to community management, among others (Torregrosa and Jiménez 2009:348, Hukka and Katko, 2009, Pietilä *et al.*, 2009, Muradian *et al.*, 2013). In the case of the final disposal of gray and black water and sanitation, the problems we face are even more complex and often transcend the possibilities of being resolved at the community level. There have been significant experiences of working with wastewater removal at the community level but very few of coping with and solving sanitation problems. This is reflected in water quality.

This suggests that the problem of water quality lies in the multiplicity of factors that determine it. We are used to addressing water-related problems in a fragmented way, from different specialties or fields of experience. But solving problems related to water quality is complex and multidimensional. In this respect, they are not only economic, technological or institutional issues. It is important to explore other rarely considered aspects, which may be affecting the obtainment of better water quality.

This also raises the question or institutional issues Why is it so difficult to interact with different ways of understanding, seeing and solving problems related to water and sanitation and to make these differences part of public policy?

One way to approach the issue may be from the perspective of the ***social nature of water***, which would give us the possibility of thinking about the quality of water produced socially from the culture, knowledge, practices, ideas, meanings and values that provide it and confront it with the unilateral institutional construction of what is considered water and its quality.

This leads us to consider issues that could shed light on the difficulties this implies, such as the relationship between water and society , the forms of water governance and the power relations embedded in them.

Box 1

Access to water in quantity and quality for all sectors of society can only be achieved by adopting an integrated, multidimensional approach in which the provision of water and sanitation services is organized through a wide array of institutional, formal and informal arrangements , which take into account the various characteristics and local conditions.

How do we conceive the relationship between water and society?

One of the ways in which the relationship between water and society has been conceived is through the idea of governance. The idea would be that a good water government would pay for the existence of institutions that make it possible to guarantee water in sufficient quantity and quality for all inhabitants, based on the idea that governance is provided by the way policies regulate and coordinate the management of natural, economic and social resources and, on this basis, assuming the proposal made by UNESCO[2] that "water governance is defined by the political, social, economic and administrative systems that are operating and directly or indirectly affect the use, development and management of water resources, as well as the distribution of water supply services at various levels of society" (Global Water Partnership, 2003). The following is a reflection on inclusion, responsibility, participation, transparency, predictability and receptivity, as necessary conditions for good governance and an effec-

2. http://www.waterhistory.org/histories/nile and www.theoi.com/Titan/Titanokeanos.html

tive relationship between water and society, rarely observed in Latin America today.

1. Necessary conditions for water governance

1.1 Inclusion

A review of the contents of the Hague Ministerial Declaration held at the beginning of this century (2000) referred to this aspect and called for "*wisely governing water in order to ensure good governance, so as to involve the public and ensure that the interests of all stakeholder groups are included in water resource management*".

This rules out any initiative establishing borders for the guarantee of water service in quantity and quality, among those living in marginal areas, indigenous communities or suburban areas and residing in neighborhoods or any other type of property owned by more affluent social sectors.

1.2 Responsibility

Water resource management entails responsibilities for society as a whole, which must be included in the principles and legal bases on which this management is based. This responsibility includes the prevention of pollution by all social actors, and aspects related to the financial sustainability of the system adopted. The responsibility associated with effective water governance demands that the roles of these actors be defined.

Without justifying those governments whose interest in sustainable water resource management is only evident in their discourse in electoral processes and campaigns, there is generally a limited perception of individual responsibilities in terms of the management and protection of water resources.

1.3 Participation

Water resource management is carried out on the basis of the interests and participation of society as a whole, regardless of the social strata of its members. Accordingly, governments at all levels must develop an inclusive approach during the formulation and implementation of policies related to these resources. In terms of effective water governance, participation is developed on the basis of social mobilization and the ability to exercise this constructively.

1.4 Transparency

Transparency is one of the principles of effective governance, as shown in the following quote: "*Institutions should work openly. They should use language that is understandable and accessible, so that the general public has more confidence in complex institutions. In addition to being open, good governance requires that all policy decisions be transparent, so that both those who are directly involved and those who are not can easily follow the steps taken in policy design. This is particularly important as regards financial transactions*" (Alcocer *et al.*, 1988). For these transactions, transparency is vital, since it contributes to overcoming the challenge societies face for dealing with corruption. One cannot ignore the fact that transparency is built on the basis of the free flow of information.

1.5 Predictability

Having representative, reliable and sufficient information about all the scenarios linked to water resource management, constitutes the basis for conducting the analyses (technical economic, cost/benefits, budgetary and financial, etc.) required to predict, at the temporal and spatial level, how and when the competent institutions will have the necessary financial resources to undertake the works and investments related to the storage, protection and distribution of these resources, as well as for their treatment at the stage when they become residual.

One good practice worth highlighting, established in Cuba and validated by the work undertaken over the past 50 years, is the systematic observation (twice a year) of inland water quality, through a network that has a number of stations totaling between 2 400 and 3 500. Seventy-five per cent of these stations classify as basic (generating descriptive, long-term information on the most important waterbodies in the country), while the other 25% correspond to control and monitoring stations, mostly associated with surface waters, including residual discharge.

The inventory of polluting sources of inland waters, which serves as a tool for the surveillance and control of their quality and the exercise of the responsibility that concerns the state in terms of the sustainable management of this resource, has identified 2 260 main polluting sources of inland waters.

This information, based on real data, serves as input for the adoption of the policies to be implemented in the short, medium and long terms, so that the institutions responsible for these actions can complete them with the corresponding responsibility. In fact, predictability is an effective ally of responsibility.

1.6. Receptivity

Receptivity in water resource management relies heavily on the effectiveness of the mechanisms institutions have for receiving information from the lowest levels at which they provide water of the appropriate quality.

An effective information system is built on the foundations of social mobilization and freedom of expression for its social appropriation.

On the basis of the previous elements, we think that the problem of water quality, like many others on the agendas of the governments of several countries in the region, emerges when each of these points is evaluated and it becomes clear that although ideas on water governance assume the desirable image of water management, the way they operate in practice is far from ideal. The way water governance occurs is based on power relations that subordinate the decision-making power of some to the detriment of political agendas that do not necessarily correspond to the ideals of inclusion. In this respect, the functioning of society can be said to pose obstacles to the achievement of good water governance.

2. Alienation as an inhibiting mechanism of good governance

According to Linton, (2010) the hegemonic construction of water refers to a social order that decides on its meanings, the uses of water, institutions, laws and the authorities responsible for managing it, as well as the techniques and distribution of the benefits derived from its allocation. In his text, he asks: how were we taught to produce the idea of water as an abstraction, a compound of hydrogen and oxygen synthesized in the chemical formula H20? A central point highlighted by the author points is that one of the main characteristics of modern water is its simplicity and its simplification.

Linton lists three main characteristics of the modern idea of water: its universality, the fact of being any (inland) water and of being anywhere. The first characteristic assumes that water under any circumstance can be reduced to H2O; the second refers to its deterritorialization,[3] in other words, its spatial delocalization; and lastly, it warns us about its dematerialization, in other words, the fact that the conquest of water through its abstraction and technical control has destroyed the relationship specific social groups had -or have-, with water in particular territories.

In short, from this perspective, what the modern construction of water ignores is its social nature, and as a result, it deprives society of the ability to think of itself as a producer of water and of its quality.

Accordingly, the starting point for the discussion is repeated, emphasizing that the nature of water is based on the ways society produces water through its practices, knowledge, ideas, meanings, values and the potentials it confers on it. Separating society from these ideas entails creating alienation from the social nature of water and, therefore, the political subordination of the majority of the population. In this respect, the power factor becomes crucial to understanding the governance of water and the future of the institutions that exercise its management.

These are the arguments that allow us to reflect and encourage discussions that will answer the question related to the water - society link. These arguments lead to the second question we formulated, explained below.

Box 2

The notion of the hydrosocial cycle is constructed in opposition to the conventional use of the *water cycle*, which "continues eternally with or without human activity", and points to a static and reified notion of this cycle as Maidment (1993) points out (Linton, 2010:231). In the opposite direction, the water cycle "proposes a science whose field is defined between the hydrological and the social and is therefore presented as a means of producing critical knowledge about the social nature of water," says Maidment (Larsimont and Grosso, 2014:8).

3. Also valid for islands, although the territorial dimension is reduced to municipalities and provinces or their equivalent.

How we achieve water quality with this diversity

At this point in the reflection, the aspect of power becomes central and therefore the conception of the hydrosocial cycle of critical geography expressed in the development of political ecology becomes extremely important. A central premise of political ecology, as noted by Swyngedouw (2004), is that the circulation of water is both a social and physical process. Accordingly, the idea of circulation invites us to understand how flows of water, capital and power are materially linked (Larsimont and Grosso, 2014:7)

Thus, in addition to examining how water flows within the physical environment (atmosphere, surface, subsoil, biomass), the "hydrosocial" cycle also considers how water is manipulated, used and concentrated by social stakeholders, how the struggles for water access and control, and exclusion and access mechanisms are expressed in institutions, through factors such as hydraulic works, legislation, institutions, practices and symbolic meanings (Larsimont and Grosso, 2014:8). When we speak of water flows, we refer to the complete hydrosocial cycle, not only the relationships activated for its access but also the relationships involved in the uses, quality and ways in which its final disposal occurs.

It is important to note that the natural resources existing in ecosystems are the sustenance of life and that water guarantees the services of ecosystems, while man is the main user of the goods (and services) they provide. These interrelationships determine the inseparability between water, sustainable socioeconomic development and life systems.

Figure 1. Sustainable Development Goals 2030

The essence of the Sustainable Development Goals until 2030 approved by the United Nations (December, 2015), is evidence of the transversality and social nature of water. None of these objectives can be met unless, "water availability and sustainable management and sanitation for all are guaranteed".

Accordingly, it is necessary to become aware that from a scientific perspective, the water cycle that schematizes the occurrence of water in nature must be perceived as a hydrosocial cycle, given the significant impact society has on the behavior of each of the components of that cycle. In this respect, becoming aware of the social construction of water quality is a determining factor for creating better institutional models that enable good water governance.

From the above, we can therefore derive what we initially recognized, namely that access to water in quantity and quality for all sectors of society can only be achieved by destroying the epistemic obstacles imposed by the various disciplinary perspectives and instead adopting an integrated, multidimensional approach, built on the reappropriation of the knowledge and powers of the citizens with whom water governance is organized.

A global look forward: United Nations Sustainable Development Goals (SDG) until 2030

Water-related problems facing society require global answers: problems are global and the integration of their multiple aspects is the solution.

Actions at the local level have exceeded the limits of ecosystems,[4] and that level has created global consequences. Accordingly, the change in society's actions and attitudes towards these problems must be conceptualized and addressed at all levels, beginning with the local level, but always with a view towards the global level.

Figure 1 attempts to outline how the 17 SDGs relate to SDG 6 concerning water. It show the social perspective of water and its transversality with local and global scales.

According to Sandoval Minero (2017), this means that the effort to achieve SDGs must be much greater in terms of financial terms, institutional reforms, organization and governance. In this respect, the achievement of the water target entails the reduction of poverty, the improvement in food and health of the population, regular school attendance by children, the reduction of domestic burdens that mainly affect women, labor productivity, the reduction of social inequality, the sustainability of cities, as well as the care of marine and inland aquatic ecosystems (Sandoval Minero, 2017:129). Lastly, integrated water management influences water quality access.

4. Human water management has not only jeopardized the ability to create a sustainable water cycle, but also endangers water for the different forms of life that also depend on it (Pacheco-Vega, 2017).

References

Alcocer, D.J., E. Kato, E. Robles y G. Vilaclara (1988). Estudio preliminar del efecto del dragado sobre el estado trófico del Lago Viejo de Chapultepec. *Contaminación Ambiental* 4 43–56.

Armienta, M.A.; L.K. Ongley; R. Rodríguez; G. Villaseñor; H. Mangoy (2002). The role of arsenic-bearing rocks in groundwater pollution at Zimapan Valley, Mexico. *Environmental Geology* 42:433–438.

Budds, J (2012). La demanda, evaluación y asignación del agua en el contexto de escasez: un análisis del ciclo hidrosocial del valle del río La Ligua, Chile. *Revista Geografía Norte Grande,* No. 52: 167-184.

Comisión Nacional del Agua (CONAGUA) (2011). Estadísticas del agua en México. México, CONAGUA

Comisión Nacional del Agua (CONAGUA) (2013). *Situación del subsector agua potable, alcantarillado y saneamiento.* México: CONAGUA

Carrillo, A. and Drever, J. (1998). Environmental assessment of the potential for arsenic leaching into groundwater from mine wastes in Baja California Sur, México. *Geofísica Internacional,* 37, 35-39.

Carrillo-Rivera, J.J., Cardona, A., Huizar-Alvarez, R., Graniel-Castro, E. (2008). Response of the interaction between groundwater and other components of the environment in Mexico. *Environmental Geology,* 55, 303-319.

Escolero, O.; S. Kralisch, S.E. Martínez, M. Perevochtchikova (2016). Diagnóstico y análisis de los factores que influyen en la vulnerabilidad de las fuentes de abastecimiento de agua potable a la Ciudad de México. *Boletín de la Sociedad Geológica Mexicana*, Vol. 68 N° 3 pp. 409–427.

García, R. (2006). *Sistemas complejos.* Barcelona: Gedisa

Global Water Partnership (2003). Tec Background Text No.7, Peter Rogers and Alan W. Hall

Hukka, J.J. & T. Katko (2009). Complementary Paradigms of Water and Sanitation Services: Lessons from the Finnish Expirience. *Water and Sanitation Services. Public Policy and Management.* Earthcan, UK.

Jiménez, B. (2009) Management of Water in Mexico City, in Mays, L. (ed.) *Integrated Urban Water Management in Arid and Semi-arid Regions around the World.* Paris: UNESCO.

Larsimont, R. y Grosso, V. (2014). Aproximación a los nuevos conceptos híbridos para abordar las problemáticas híbridas. *Cardinalis*, Revista del Departamento de Geografía, Año 2, No. 2, Facultad de Filosofía y Humanidades, Universidad de Córdoba, Argentina

Linton, J. (2010). *What is Water? A history of a modern abstraction.* University of Vancouver. Canada: British Columbia Press.

Meerganz Von Medeazza, G. (2006) Flujos de agua, flujos de poder. La aportación de Erik Swyngedouw al debate sobre los recursos hídricos en Latinoamérica y en el Estado Español. *Doc. Anal. Geogr.* 47: 127-139.

Muradian R., B. Nath, A. Jafar and L. Doménech (2009). The South Asian Experience: Financial Arrangements for Facilitating Local Participation in Water and Sanitation Services (WSS) Interventions in Poor Urban Areas- Lessons from Bangladesh and Nepal. *Water and Sanitation Services. Public Policy and Management.* Earthcan, UK.

Peña, A. (2011). Introducción al libro *What's Water* en *Boletín* 74. México: El Colegio de Hidalgo.

Pietilä P., M. J. Gunnarsdóttir, P Hjorth and S. Balslev (2009). Decentralized Services: The Nordic Experience. *Water and Sanitation Services. Public Policy and Management.* Earthcan, UK.

Swyngedouw, E. (2004). *Social power and the urbanization of water: flows of power.* Oxford: Oxford University Press.

Torregrosa, M.L. (Coordinadora) (2013). *AGUA. Agenda ciudadana de ciencia, tecnología e innovación.* México: CONACYT, AMC, UNAM.

Torregrosa, M.L & B. Jiménez (2009). Faxcing the Universal Access of Water and Sanitation in Mexico. *Water and Sanitation Services. Public Policy and Management.* Earthcan, UK.

Water and Health

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Introduction

The link between water and human health is immutable. Water not only is essential for life, but more immediately, for good health and well-being. Given that over 60% of the human body is water, readily having it in sufficient quantities and quality is fundamental both for our health and wellbeing.

When the United Nations launched the first International Drinking-Water Supply and Sanitation Decade (1981 – 1990) in 1977, its purpose was to bring attention and support for clean water and sanitation worldwide. The philosophy that all peoples, regardless of their socio-economic status, have a basic right to drinking-water both in quantities and quality equal to their basic needs was recognized and adopted. In the sentinel conference held to elucidate primary health care factors held in Almaty (formerly Alma-Ata), Kazakhstan, 1978, the need for an adequate supply of safe water and basic sanitation was specified.

In 2000, the United Nations codified political commitments aimed at tackling major development issues faced by the developing world within a fixed period of time into 8 Millennium Development Goals (MDGs). While many of these MDGs can either be directly or indirectly linked to water supply and sanitation issues, Goal 7 on environmental sustainability, and in particular Target 10, declared the goal that by 2015 to halve the proportion of people without sustainable access to safe drinking water and basic sanitation. In 2015, the UN launched the Sustainable Development Goals (SDGs), also known as Global Goals, which again declared as one of its goals (Goal #6) that all humans by 2030 have access to safe and affordable drinking water

The continued, sustained focus on providing safe drinking water to all was reiterated by the UN Secretary-General António Guterres at the launch of the International Decade for Action 2018-2028, in New York, on World Water Day, March 22, 2018. Prime goals of this latest water-based plan are to make a global call to action for water, sanitation and hygiene¬¬–or WASH¬–and to put a greater focus on water-related sustainable development goals and integrated management of water resources over the next ten years.

The UN's SDG Water Goal has both a direct and indirect impact on human health as it can be related to child mortality, maternal health, hunger, and several notable diseases such as malaria, dengue fever and others. The former United Nations Secretary-General Kofi A. Annan declared that "we shall not finally defeat AIDS, tuberculosis, malaria, or any of the other infectious diseases that plague the developing world until we have also won the battle for safe drinking-water, sanitation and basic health care."

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Around the world, millions are deprived on adequate drinking water supplies and/or are forced to consume potentially unsafe water which ultimately adversely impacts on their health and wellbeing. The World Health Organization (WHO) estimates that 1.1 billion people lack access to sufficient water supplies and 2.6 billion lack adequate sanitation. Further, as a consequence of having to consume water of poor quality and inadequate quantity, WHO reports that annually millions of deaths¬––especially among children––are associated with water-related diseases and infections (e.g. water-borne and vector-borne). Additionally, inadequate and poor water quality supplies also affect crops production and can lead to food contamination when untreated wastewater in used for irrigation, ultimately impacting on the nutritional status of populations.

The problems of poor drinking water quality are not limited to only developing countries but are also experienced in several developed countries. For example, although many developed countries have made substantial improvements in their drinking water treatment systems, emergent pathogens have caused major water-borne outbreaks among the populations they serve. In April 1993, the United States reported the largest document waterborne outbreak which happened in Milwaukee city, Wisconsin (Dore 2015). In a more recent review of the water supply system in the U.S., an investigation of 680,000 water quality and monitoring violations recorded by the Environmental Protection Agency revealed that as many as 63 million persons in the U.S. are exposed to potentially unsafe water.

Water contaminants and health

The water that humans consume needs to be clean and free of both chemical and microbial contaminants. The adverse health effects that can arise by drinking contaminated water range from acute health effects such as acute gastrointestinal diseases to long-term outcomes such as cancer and physical and neurological developmental delays in children.

Chemical contaminants

Chemical contaminants can be found in water supplies as a result of their introduction through natural processes and/or anthropological sources. There are more than 100,000 registered chemicals that are used in manufacturing and commercial products (Schwarzman and Wilson, 2009), many of which ultimately find their ways to natural bodies of water. As a result, several regulatory agencies have established limits as to how much of these contaminants can be in potable water (**Table 1**).

Chemical contaminants can be categorized as carcinogenic, genotoxic, and mutagenic based on their effect on human health. Carcinogenic contaminants cause cells to become cancerous and induce the growth of cancerous cells. Genotoxic contaminants cause changes to the structure of the genetic material of cells. Mutagenic contaminants induce permanent and heritable changes to the genetic material, and carcinogenic and genotoxic chemicals are usually mutagenic as well. At low concentration levels, it might take an extended period of time ranging from several years to several decades after exposure to these toxic contaminants before the first signs of these chronic health effects appear. Acute health effects, which can be seen within a few days, can also occur if the chemical contaminant concentration levels are very high.

Naturally occurring contaminants are typically released from geological formations and are typically found in higher concentrations in groundwater compared to surface waters. Natural chemical contaminants are mainly inorganic in origin and include arsenic, fluoride, iron and manganese, nitrates and nitrites, and radionuclides. Arsenic has been shown to cause skin, lung, bladder, and liver cancers, hyperkeratosis and peripheral vascular disease in humans, and is a major cause of concern in the Indian sub-continent, South America and Far East (Fawell and Nieuwenhuijsen, 2003). High concentrations of fluoride can lead to skeletal deformity and dental fluorosis and is also a cause of significant morbidity in the Indian sub-continent, Africa, and Far East (Fawell and Nieuwenhuijsen, 2003). Manganese and iron, abundant in many soils, at lower concentrations cause discoloration, taste and turbidity issues. Several epidemiological studies have linked manganese to adverse neurological effects after long exposures to high concentrations, however, this is currently debated as there are also studies which showed no significant correlation between manganese in drinking water and neurological effects (WHO, 2017a). Nitrites cause methemoglobinemia mainly in infants, commonly referred to as blue baby syndrome, where the nitrite converts hemoglobin to methemoglobin and limits oxygen transport. Nitrate and nitrite have been linked to esophagus, stomach, bladder and colon cancers (IARC, 2010). Radionuclides are naturally occurring radioactive isotopes in the environment, and their presence varies from location to location. Radon is a decay product of radium, and among the radionuclides, it is the most important one and is suspected of causing lung cancer (EPA, 2010). Radon is an odorless, colorless gas that can enter the indoor living spaces from water taps and showering. Ninety percent of the exposure to radon in drinking water has been reported to be through inhalation and not ingestion (UNSCEAR, 2000).

Naturally occurring organic chemicals may also threaten water quality, although there are relatively few of these contaminants compared to the naturally occurring inorganic chemical contaminants. The main naturally occurring organic contaminant in surface waters is microcystin, which is a toxin produced by cyanobacteria and can pose a major threat to the quality and safety of drinking and recreational waters during algal blooms. Algal blooms are primarily driven by nitrogen and phosphorus pollution, and their frequency, intensity, and duration have increased in recent years due to the increased discharges of wastewaters into surface water bodies, as well as due to the effects of climate change. In 2014, 400,000 people were without usable water in Toledo, Ohio, after an algal bloom in Lake Erie, generated high levels of toxins in water (Benedict *et al.*, 2017). The threat from naturally occurring organic contaminants to water resources is much worse in developing countries where there is limited to no wastewater treatment.

Anthropological sources of water contaminants include sewage and industrial wastewater discharges, agricultural activities, mining operations, accidental spills and illegal dumps, as well as chemicals from water treatment and distribution systems. Domestic and industrial wastewaters are the main sources of emerging contaminants, such as endocrine disrupting compounds, pharmaceuticals, and personal care products, which exist in parts per trillion (ppt) to parts per billion (ppb) levels in surface waters. Even at these minute concentration levels, emerging contaminants have been shown to have adverse impacts on aquatic life and human health (Sumpter and Johnson, 2005).

Other sources of emerging contaminants include agricultural activities through the use of herbicides and pesticides, which are carried by surface runoff to water bodies. Mining activities and industrial waste are the main sources of heavy metals (e.g., Cr, Ni, Cu, Pb, Hg) and their toxic health effects on humans have been well-documented. Unlike organic compounds, heavy metals do not go through biological or chemical degradation, and their toxicity, bioavailability, and transport in the environment are determined by the oxidation/reduction, precipitation and adsorption reactions. There are well-established limits for the concentrations of heavy metals in drinking water (**Table 1**).

High concentrations of lead in drinking water due to leaching of lead from plumbing and water distributions systems remains a major public health issue around the world. In the recent water lead contamination case in Flint, Michigan, USA, in April 2014, consumers experienced very high lead concentrations in their drinking water with at least a quarter of the houses sampled exceeding the federal limit of 15 ppb and some water samples measuring as high as 13,200 ppb (Lazarus, 2016). This lead to a doubling of the infants and children with elevated blood lead levels (Hanna-Attisha *et al.*, 2015).

Chemical disinfectants used during water treatment processes can also lead to the formation of chlorinated, iodinated, and nitrogenized disinfection byproducts (DBPs). Trihalomethanes (THM), which are chlorinated DBPs, have been linked with bladder cancer at concentrations lower than what has been established in regulations (Villanueva *et al.*, 2004).

Current regulations are currently structured to focus on individual chemicals and specific health-based targets. This approach, however, is not very realistic for emerging contaminants given that these tend to be present at very low concentrations in water and persons are exposed to not one but a mixture of these chemicals for very long periods of time. There are major knowledge gaps in assessing the health impacts of chronic exposure to multiple chemicals and understanding what interactions occur (WHO, 2017b). At present, there is no agreed-upon risk assessment and management methodology for chemical mixtures. The European Commission (EU, 2012) has recommended prioritizing the risk assessment of chemical mixtures based on several parameters including their chemical characteristics, prevalence, adverse health effects at the typical exposure levels, persistence and bioaccumulation potential, and threshold concentrations. The WHO Guidelines for the Drinking Water Quality (WHO, 2017a) currently recommends an additive approach for nitrate/nitrite and THMs and stipulates the need to consider the mixtures of pesticides that have similar structures and modes of action, such as atrazine and simazine.

Considering the very large number of chemical contaminants, the complexity of their chemistries and interactions, the difficulties in measuring and studying their effects on humans and environment, the need for high-tech but high-cost treatment systems for their removal, the most effective approach in managing chemical contaminants is to protect drinking water sources, minimize or eliminate all sources of pollution and switch to less harmful chemical substitutes when possible.

Biological contaminants

Water and food are the two main routes of exposure for various gastrointestinal microorganisms whose reservoirs are humans, animals and/or the environment. All segments of the human population are susceptible to water-borne pathogens, however, the very young, elderly and immunosuppressed suffer disproportionately the most severe consequences.

Microbial water contaminants can be broken down into the following major groups: Viruses, Bacteria, Protozoa, Metazoan (helminths), and Algae (**Table 2**). Virus can infect all living organisms including bacteria, plants, animals, and humans. The most important viruses from a water contamination perspective are as follows: Rotaviruses, Astrovirus, Norovirus, Hepatitis A, Hepatitis E, Coxsackie, Enterovirus, Polioviruses, Adenoviruses, and Echoviruses. These viruses are primarily transmitted by contaminated water via the fecal-oral route.

While most human viral infections are asymptomatic or produce mild symptoms, moderate to severe clinical cases can occur during outbreaks. The United Sates reported 64 water-borne viral outbreaks during the period 1971-2006 (Craun *et al*., 2010), with Europe reporting 136 similar outbreaks during the period 2000-2007 (ENHIS, 2009). Although it is expected that the occurrence of water-borne viral outbreak should be more frequent in middle and low-income countries, the absence of resources and the techniques to detect viral contaminants in water in these countries explains the apparent dearth of such reports.

For centuries, *Vibrio cholera* has caused lethal epidemics with thousands of deaths all around the world. Although great advances have been made in the area of improving water sanitation, low and limited resources in many countries, many times exacerbated by ongoing conflicts means that many are still being killed by this pathogen (Izurieta, 2006). Three of the six Escherichia coli strains (0127, 0148, and 0157) are of major importance as waterborne pathogenic bacteria. Other bacteria such as *Salmonella* spp., *Shigella* spp., and *Campylobacter* spp. have also been the causal pathogen in many water-borne outbreaks.

Of increasing concern is the emergence of new pathogenic bacteria which can be transmitted through water. *Helicobacter pylori,* the necessary element in the pathogenesis of gastric cancer, has been found in drinking water, as well as other pathogens like *Mycobacterium Avium Complex* (MAC) and *Aeromonas hydrophyla*. Standard laboratory methods need to be updated in order to introduce alternative bio-molecular and fluorescence methods to detect viable but non-cultivable bacteria in water (Cabral, 2010).

The HIV/AIDS epidemic has brought to the fore the pathogenicity of parasites like *Cryptosporidium* spp. among the immunosuppressed, the young and the elderly. Toxigenic cyanobacteria have also been associated with eutrophication and massive human and animal intoxications (Tundisi, 1998). And of increasing concern, even the long sought-after goal of eradicating the Guinea worm (*Dracunculus medianesis*) by substantial improvements in improving the safety of drinking water may be slipping away due to the emergence of canine reservoirs (Cairncross, 2002).

Most recently, the emergence of Antibiotic Resistant Microorganism (ARM) due to the heavy use of antibiotics in food-producing animals has led the WHO to recommend that farmers and the food industry stop using antibiotics routinely to promote

Table 1. Regulatory limits for chemicals in drinking water

Chemical	WHO	U.S. EPA	EU	Chemical group
Acrylamide	0.5	[a]	0.1	Organic
Alachlor	20	2	—	Organic
Aldicarb	10	—	—	Organic
Aldrin + dieldrin	0.03	—	—	Organic
Antimony	20	6	5.0	Inorganic
Arsenic	10	10	10	Inorganic
Asbestos (million fibers >10 μm per liter)	—	7	—	Inorganic
Atrazine	100[b]	3	—	Organic
Barium	700	2,000	—	Inorganic
Benzene	10	5	1.0	Organic
Benzo[*a*]pyrene	0.7	0.2	0.010	Organic
Beryllium	—	4	—	Inorganic
Boron	2,400	—	1,000	Inorganic
Bromate	10	10	10	DBP
Bromodichloromethane	60	—	—	DBP
Bromoform	100	—	—	DBP
Cadmium	3	5	5.0	Inorganic
Carbofuran	7	40	—	Organic
Carbon tetrachloride	4	5	—	Organic
Chloramines (as Cl_2)	—	4,000	—	Disinfectant
Chlorate	700	—	—	DBP
Chlordane	0.2	2	—	Organic
Chlorine	5,000	4,000	—	Disinfectant
Chlorine dioxide	—	800	—	Disinfectant
Chlorite	700	1,000	—	DBP
Chlorobenzene	—	100	—	Organic
Chloroform	300	—	—	DBP
Chlorotoluron	30	—	—	Organic
Chlorpyrifos	30	—	—	Organic
Chromium (total)	50	100	50	Inorganic
Copper	2,000	13,000	2,000	Inorganic
Cyanazine	0.6	—	—	Organic
Cyanide	—	200	50	Inorganic
2,4-D (dichlorophenoxyacetic acid)	30	70	—	Organic
Dalapon	—	200	—	Organic
2,4-DB (dichlorofenoxybutyric acid)	90	—	—	Organic
DDT (dichlorodiphenyltrichloroethane) and metabolites	1	—	—	Organic
Dibromochloromethane	100	—	—	DBP
1,2-Dibromo-3-chloropropane (DBCP)	1	0.2	—	Organic
1,2-Dibromoethane	0.4	—	—	Organic
Dichloroacetate	50	—	—	DBP
Dichloroacetonitrile	20	—	—	DBP
1,2-Dichlorobenzene (*o*-dichlorobenzene)	1,000	600	—	Organic
1,4-Dichlorobenzene (*p*-dichlorobenzene)	300	75	—	Organic
1,2-Dichloroethane	30	5	3.0	Organic
1,2-Dichloroethene	50	—	—	Organic
1,1-Dichloroethylene	—	7	—	Organic
cis-1,2-Dichloroethylene	—	70	—	Organic
trans-1,2-Dichloroethylene	—	100	—	Organic
Dichloromethane	20	5	—	Organic
1,2-Dichloropropane	40	5	—	Organic
1,3-Dichloropropene	20	—	—	Organic
Dichlorprop	100	—	—	Organic
Di(2-ethylhexyl) adipate	—	400	—	Organic
Di(2-ethylhexyl) phtalate	8	6	—	Organic
Dimethoate	6	—	—	Organic
Dinoseb	—	7	—	Organic
1,4-Dioxane	50	—	—	Organic
Dioxin (2,3,7,8-TCDD)	—	0.00003	—	Organic
Diquat	—	20	—	Organic
Edetic acid	600	—	—	Organic
Endothall	—	100	—	Organic
Endrin	0.6	2	—	Organic
Epichlorohydrin	0.4	[a]	0.10	Organic
Ethylbenzene	300	700	—	Organic
Ethylene dibromide	—	0.05	—	Organic
Fenoprop/Silvex/2,4,5-TP/2-(2,4,5-trichlorophenoxy)propionic acid	9	50	—	Organic
Fluoride	1,500	4,000	1,500	Inorganic
Glyphosate	—	700	—	Organic
Haloacetic acids (HAAs)[c]	—	60	—	DBP
Heptachlor	—	0.4	—	Organic
Heptachlor epoxide	—	0.2	—	Organic
Hexachlorobenzene	—	1	—	Organic
Hexachlorobutadiene	0.6	—	—	Organic
Hexachlorocyclopentadiene	—	50	—	Organic
Hydroxyatrazine	200	—	—	Organic
Isoproturon	9	—	—	Organic
Lead	10	15	10	Inorganic
Lindane	2	0.2	—	Organic
Mecoprop	10	—	—	Organic
Mercury	6	2	1.0	Inorganic
4-(2-Methyl-4-chlorophenoxy) acetic acid (MCPA)	2	—	—	Organic
Methoxyclor	20	40	—	Organic
Metolachlor	10	—	—	Organic
Microcystin-LR	1	—	—	Algal toxin
Molinate	6	—	—	Organic
Monochloramine	3,000	—	—	Disinfectant
Monochloroacetate	20	—	—	DBP
Nickel	70	—	20	Inorganic
Nitrate	50,000	45,000	50,000	Inorganic
Nitrilotriacetic acid	200	—	—	Organic
Nitrite	3,000	4,500	500	Inorganic
N-Nitrosodimethylamine (NDMA)	0.1	—	—	DBP
Oxamyl (Vydate®)	—	200	—	Organic
Pendimethalin	20	—	—	Organic
Pentachlorophenol	9	1	—	Organic
Pesticides	—	—	0.10	Organic
Pesticides (total)	—	—	0.50	Organic
Picloram	—	500	—	Organic
Polychlorinated biphenyls (PCBs)	—	0.5	—	Organic
Polycyclic aromatic hydrocarbons	—	—	0.10	Organic
Selenium	40	50	10	Inorganic
Simazine	2	4	—	Organic
Sodium dichloroisocyanurate/cyanuric acid	50,000/40,000	—	—	Disinfectant
Styrene	20	100	—	Organic
Tertbutylazine	7	—	—	Organic
Tetrachloroethene (tetrachloroethylene)	40	5	—	Organic
Tetrachloroethylene + trichloroethylene	—	—	10	Organic
Thallium	—	2	—	Inorganic
Toluene	700	1,000	—	Organic
Toxaphene	—	3	—	Organic
Trichloroacetate	200	—	—	DBP
1,2,4-Trichlorobenzene	—	70	—	Organic
1,1,1-Trichloroethane	—	200	—	Organic
1,1,2-Trichloroethane	—	5	—	Organic
Trichloroethene/trichloroethylene	20	5	—	Organic
2,4,6-Trichlorophenol	200	—	—	Organic
2,4,5-T (2,4,5-trichlorophenoxyacetic acid)	9	—	—	Organic
Trifluralin	20	—	—	Organic
Trihalomethanes (total)	—	80	100	DBP
Vinyl chloride	0.3	2	0.50	Organic
Xylenes	500	10,000	—	Organic

DBP, disinfection by-product.
[a]Each water system must certify annually that when it uses acrylamide and/or epichlorohydrin to treat water, the combination of dose and monomer level does not exceed the levels specified, as follows: acrylamide = 0.05% dosed at 1 mg/L (or equivalent); epichlorohydrin = 0.01% dosed at 20 mg/L (or equivalent). [b]Includes its chloro-*s*-triazine metabolites. [c]Includes the sum of monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid.

Source: De Villanueva *et al.*, 2014.

growth and prevent disease in healthy animals (WHO, 2017c). Preliminary studies carried out in Ecuador have revealed a 71.2% prevalence of colistin resistant *E coli* and 65.9% prevalence of extended-spectrum beta-lactamases (ESBL) producing resistant *E coli* in feces of chickens and pigs, and that these high prevalences were associated with the use of antibiotics in pig and chicken feeding formulas. Given that there are currently no restrictions of the disposal of animal bio solids into water bodies, these feces are being discharged in stream, rivers and lakes. Therefore, it is plausible that highly ARMs are already present in raw waters of Ecuador (Izurieta and Yamamoto, 2018) which can led to poor health outcomes when consumed by humans.

Influence of Economic Conditions on water quality and health

Terrestrial waters can be considered as being part of productive processes, generating costs that are included in the financial balance (income, charges) of these processes. This is why water management (protection included) is considered in the economic context.

The current economic dimensions of water management had their origin at the end of past century. Basically, economists have traditionally viewed water as just one component in several production processes. However, other economists have noted that water is fundamentally a different type of resource. Aguilera-Klink (1995) points out that "water is more than a production factor. It is overall a factor of social, economic and environmental cohesion." Aguilera- Klink (2001) later stated that "water can be seen from different perspectives: as a production element, as financial issue and as eco-social resource."

The economy has a direct impact on several water-related aspects, such as its quality, and therefor on its uses. When water quality is low, water-related diseases and illness appears.

Most developed countries have financial resources and requisite technologies to mitigate the impacts of industrial development. These countries also have developed the necessary legal instruments and regulations which establish permissible limits for disposal of waste water and polluting substances which have been generated from different process. By and large, however, adequate investments and technology transfer for water management in developing countries has not occurred. The high demographic growth experienced in most developing countries has served to further exacerbate this problem. In many developing countries, river and lakes which serve as the primary sources for drinking water are heavily polluted due to the wanton and indiscriminate disposal of domestic and industrial wastes. These practices persist in part due to the lack of legal regulations and/or political unwillingness to enforce laws and regulations that are already on the books.

In countries with limited financial resources the pollution of key drinking water sources is usually associated with the drainage of gray water flowing along ditches built close to the houses, the unavailability of daily collection of solid wastes and the effects of wastes lixiviates. These problems are caused by the lack of sewerage systems, waste treatment stations and water purification plants which meet internationally recognized water quality standards.

It is well known and widely disseminated that in many tropical countries rainwater accumulates in soil depressions, vessels without covers or discarded tires, thus becoming larvae repositories for mosquitos such as the *Aedes aegypti,* the transmitter of the dengue disease.

Investments made to protect a population's drinking water can lead to many social benefits including a saving of scarce public sector´s financial resources due to the reduction of water-related diseases. According to the World Bank, losses in Gross Domestic Product in the African continent as a consequence of the malaria (2003) exceeded 12,000 million dollars (Larbi Bouguerra, 2007).

It is thus recommended that developing countries evaluate possible solutions and ways to supply water with the required quality, despite the fact that the problems mentioned above are not solved and financial limitations do not allow to give them solution in a short time. The political will of governments is important. It is necessary to quantify the costs, to establish priorities to give access to this natural resource on the basis of social inclusion, prioritizing the most vulnerable communities who have to least material and financial resources. In this way societies will be more likely attain human

Table 2 Most important water-borne human pathogens

Agent	Disease		Reservoir
Viral	Rotaviruses	Gastroenteritis	Humans, Animals
	Astrovirus	Gastroenteritis and Acute Respiratory Infection	Humans
	Norovirus	Gastroenteritis	Humans
	Hepatitis A	Hepatitis	Humans
	Hepatitis E	Hepatitis	Humans, Animals
	Coxsackie viruses	Gastroenteritis, Upper Acute Respiratory Infection, hand, foot, and mouth disease, meningitis, cardiac infection, and peripheral neuropathy	Humans
	Enterovirus	Gastroenteritis and Upper Acute Respiratory Infection, hand, foot, and mouth disease, cardiac infection, meningitis and peripheral neuropathy	Humans
	Polioviruses	Poliomyelitis	Humans
	Adenoviruses	Gastroenteritis and Acute Respiratory Infection	Humans
	Echoviruses	Gastroenteritis, Acute Respiratory Infection, meningitis, and hepatitis	Humans
Bacterial	*Campylobacter* spp.	Gastroenteritis	Humans, Animals
	Escherichia coli	Gastroenteritis	Humans, Animals
	Helicobacter pylori	Gastritis, Gastric cancer	Humans
	Legionella spp.	Pneumonia, gastroenteritis	Aquatic
	Leptospira spp.	Mild fever with rash or Hemorrhagic fever	Aquatic, Soil, Animals
	Salmonella spp.	Gastroenteritis	Humans, Animals
	Shigella spp.	Gastroenteritis	
	Vibrio cholera	Gastroenteritis with watery diarrhea	Aquatic (estuaries)
	Yersinia enterocolítica	Gastroenteritis	
Protozoan	*Criptosporidium* spp.	Chronic diarrhea	Humans, Animals
	Giardia duodenalis	Abdominal pain	Humans, Animals
	Entamoeba histolytica	Dysentery, Hepatic abscess	Humans
	Balantidium coli		Humans, Animals
Metazoan	*Schistosoma* spp	Intestinal, Hepatic and Urinary infections	Humans, Aquatic
	Dracunculus medinensis	Painful papule in the skin, gastroenteritis	Humans, Animals, Aquatic
Algae	*Cianobacterias*	Intoxication	Aquatic

habitats that are inclusive, secure, resilient and sustainable, in harmony with the United Nations SDG #11 by the year 2030.

Water scarcity and health

Water scarcity is the lack of sufficient, readily available water resources to meet the demands of those living within a specific region. A lack of safe drinking water to meet daily needs can have serious health consequences. Worldwide, over 2.8 billion persons around on every continent at least one month out of every year does not have adequate safe drinking water to consume. The problem of inadequate safe drinking water supplies is predicted to get worse over the foreseeable future due to population growth, increased demands especially from the agricultural sector, and climate change.

Insufficient water supplies to meet daily needs has both immediate and distal impacts on human health and wellbeing. It is estimated that humans require a minimum daily water intake that ranges from 1.8 to 5 liters per capita per day (Gleick 1996). These estimates, however, increase in warmer climates, higher levels of physical activity and for sensitive sub-population such as pregnant and lactating women. Thus, the WHO recommends a minimum of 7.5 liters per capita per day to meet the requirements of most people under most conditions.

Sufficient water is essential for proper human hygiene. If persons are required to walk farther than 1 kilometer or spend more than 30 minutes for water collection, they then may not collect sufficient water for proper hygiene (Gleick 1996). As a result, some have observed that many "waterborne" diseases may be more accurately labeled as "water-washed" diseases due to inadequate quantities of water being available for necessary human activities such as washing hands, food preparation, laundry, and washing cooking utensils (Bradley 1977).

Each year, the WHO estimates that about 2.2 million persons die from diarrhea of which 90% are children. Further, many more suffer debilitating and chronic health problems. Diarrheal and other diseases caused or worsened by water scarcity have also been linked to other adverse health conditions such as malnutrition, decreased food intake, impaired nutrient absorption, and compromised immune systems (Rice *et al*. 2000; Stephenson 1999; UN 2003).

Particularly in developing countries, as a result of water scarcity, many are forced to drink poor quality water from untreated sources such are local streams or rivers, which are contaminated either chemically, microbial or both. Additionally, inadequate water supplies mean that sewage does not easily flow, which then creates its own sequelae of health-related problems and can exacerbate the spread of vector-borne diseases such as malaria.

Water scarcity impacts human health in other ways. For example, fetching water from distant sites, a task that is usually borne solely by women and children, places additionally calorific burdens on already malnourished women and children. Additionally, this necessary task exacts significant time and effort from these vulnerable segments of the population. This, in turn, severely limits the opportunities and time women and children have to engage in other socially productive activities such as small business enterprises, localized garden farming, and schooling.

By far, the agricultural sector is currently largest user of freshwater resources. The additional demands this sector will place on water resources is predicted to further increase with population growth, the continued use of inefficient animal husbandry and crop irrigation techniques, and anthropogenically driven climate changes.

The International Water Management Institute (IWMI) projects that nearly 1 billion people may not have access to water by the year 2025. Further, they predict that unless the issue of water scarcity is appropriately addresses today, many countries will soon face a series of impossible decisions when choices have to made on how to reduce the amount of water used in agriculture that is demanding more of it and transferring it to other competing users in the industrial and domestic sectors. There is therefore an urgent need for meaningful investments to be made today in water supply systems so as to ensure adequate supplies of high quality water is delivered to all, and this need must be clearly articulated and acknowledged in all public health policies.

Conclusions

In addition to providing adequate supplies of water as of 2017 to all 7.5 billion inhabitants of this planet, increasing attention will need to be directed at ensuring that the quality of this water is high enough to guarantee human health and wellbeing. This means significant and consistent resources will need to be allocated to not only building new water treatment and distribution systems, but also towards their maintenance and upkeep as they wear and age over time. In the U.S, their Environmental Protection Agency estimates that local water systems will need to invest USD 384 billion in the coming decades to ensure that the water is of sufficient quality to be consumed.

It is well established that improving a community's water supply, hygiene and sanitation leads to measurable improvements in health. For example, the WHO has found that the incidence of diarrhea can be reduced by 26% simply by providing persons with clean water.

It is estimated that out of the 35,000 Km^3 to 50,000 Km^3 fresh water globally available, due to increasing anthropogenic polluting activities, only about one-third can be used for human needs. Given that clean water is essential to good health, protecting this diminishing and threatened resource will require concerted efforts by governments and other policy makers who manage and oversee the use of this precious resource.

References

Aguilera-Klink, F. (1995). El agua como activo económico, social y ambiental. *El Campo* 132, 15–27.

Aguilera-Klink, F. (2001). Economía del agua: algunas cuestiones ignoradas mucho antes del Nuevo Milenio. En: Robot, L., Baldeón, J. y Villares, R. (2001). *Año 1000, Año 2000. Dos milenios en la historia de España.* Madrid: Nuevo Milenio.

Benedict KM, Reses H, Vigar M, *et al*. (2017). Surveillance for Waterborne Disease Outbreaks Associated with Drinking Water - The United States, 2013–2014. *Morb Mortal Wkly Rep (MMWR) 2017*; 66:1216–1221. DOI: http://dx.doi.org/10.15585/mmwr.mm6644a3

Bradley, D. (1977). Health aspects of water supplies in tropical countries. In: (Feachem, R.G., McGarry, M. & Mara, D.D. eds.) *Wastes and Health in Hot Climates.* Chichester, UK: John Wiley and Sons. pp. 3–17.

Cabral, JPS. (2010). Water Microbiology. Bacterial Pathogens and Water. *International Journal of Environmental Research and Public Health.* 2010;7(10):3657-3703. doi:10.3390/ijerph7103657.

Cairncross S, Muller R, Zagaria N. (2002). Dracunculiasis (Guinea Worm Disease) and the Eradication Initiative. *Clinical Microbiology Reviews.* 2002;15(2):223-246. doi:10.1128/CMR.15.2.223-246.2002.

Craun GF, Brunkard JM, Yoder JS, Roberts VA, Roy SL *et al*. (2010). Causes of Outbreaks Associated with Drinking Water in the United States from 1971 to 2006. *Clinical Microbiology Reviews.* American Society of Microbiology. July 2010, p. 507–528. DOI: 10.1128/CMR.00077-09.Vol. 23, No. 3. 0893-8512/10/$12.00doi:10.1128/CMR.00077-09 http://aquaticpath.phhp.ufl.edu/waterbiology/handouts2011/outbreaks-craun2010.pdf

Dore MH. (2015). Global Drinking Water Management and Conservation, *Springer Water,* Springer International Publishing Switzerland, DOI 10.1007/978-3-319-11032-5_2

European Environment and Health Information System (ENHIS) (2009). *Outbreaks of waterborne diseases.* Fact sheet no. 1.1, December 2009 z Code: RPG1_WatSan_E1. http://www.euro.who.int/__data/assets/pdf_file/0009/96885/1.1.-Outbreaks-of-waterborne-diseases-EDITED_layout_V03.pdf

European Union (EU) (2012). *Toxicity and assessment of chemical mixtures.* Brussels: EU.http://ec.europa.eu/health/scientific_committees/environmental_risks/docs/scher_o_155.pdf

Gleick, P. H. (1996). Basic water requirements for human activities: Meeting basic needs. *Water International* 21(2), 83–92.

Hanna-Attisha, Mona; LaChance, Jenny; Sadler, Richard Casey; Champney Schnepp, Allison (2015). Elevated Blood Lead Levels in Children Associated with the Flint Drinking Water Crisis: A Spatial Analysis of Risk and Public Health Response. *American Journal of Public Health.* 106 (2): 283–290.

Izurieta R. (2006). *A Death Foretold in the Times of Cholera* (Presentation). Institute for the Study of Latin America and the Caribbean, University of South Florida.

Izurieta R & Yamamoto Y. (2018). Preliminary results about the prevalence of colistin resistant and ESBL producing resistant *E coli* in swine and poultry farming in Ecuador. Non-published document, March.

Larbi Bouguerra, Mohamed (2007). Las batallas por el agua. Por un bien común de la humanidad. En: *El agua y la salud,* cap. 9, pp. 170 y 172. Madrid: Editorial Popular.

Lazarus, O. *In Flint, Michigan, a crisis over lead levels in tap water.* Public Radio International. https://www.pri.org/stories/2016-01-07/flint-michigan-crisis-over-lead-levels-tap-water

Mac Kenzie WR, Hoxie NJ, Proctor ME, Gradus MS, Blair KA, Peterson DE, Kazmierczak JJ, Addiss DG, Fox KR, Rose JB, *et al*. (1994). A massive outbreak in Milwaukee of cryptosporidium infection transmitted through the public water supply. *N Engl J Med.* 1994 Jul 21;331(3):161-7.

Rice AL, Sacro L, Hyder A, Black RE (2000). Malnutrition as an underlying cause of childhood deaths associated with infection diseases in developing countries. *Bulletin of the World Health Organization* 2000: 8: 1207-1221

Schwarzman M.R. & Wilson, M.P. (2009). New science for chemicals policy. *Science*, 326:1065-66.

Stephenson CB. Burden of infection on growth failure. *Journal of Nutrition* 1999: 129(2S Suppl) 534S-538S.

Sumpter J. P. & Johnson, A. C. (2005). Lessons from Endocrine Disruption and Their Application to Other Issues Concerning Trace Organics in the Aquatic Environment. *Environmental Science & Technology,* 39 (12), 4321-4332.

Tundisi J.G., O. Rocha, T. Matsumura-Tundisi, B. Braga (1998). Reservoir management in South America. *Int. J. Water Resour. Dev.,* 14 (1998), pp. 141-155, 10.1080/07900629849367

United Nations (UN) (2003). *Water and Sanitation in the World's Cities: Local Action for Global Goals.* Human Settlements Programme. London: Earthscan.

Villanueva, C.M., Cantor, K.P., Cordier, S., Jaakkola, J.J., King, W.D. Lynch, C.F. *et al*. (2004). Disinfection by products and bladder cancer: a pooled analysis. *Epidemiology*, 15:367-367.

Villanueva, C. M., Kogevinas, M., Cordier, S., Templeton, M. R., Vermuelen, R. *et al*. (2014). Assessing exposure and health consequences of chemicals in drinking water: Current state of knowledge and research needs. *Environmental Health Perspectives,* 122 (3), 213-221.

World Health Organization (WHO) (2017a). *Chemical mixtures in source water and drinking water.* Licence: CC BY-NC-SA 3.0 IGO. ISBN 978-92-4-151237-4. www.who.int/water_sanitation_health/publications/chemical-mixtures-in-water/en/

World Health Organization (WHO) (2017b). *WHO guidelines on use of medically important antimicrobials in food-producing animals.* Geneva: WHO; 2017 http://apps.who.int/iris/bitstream/handle/10665/258970/9789241550130-eng.pdf;jsessionid=BCED73094DF5752A2E3DB6BB672B7F19?sequence=1

Biological Monitoring of Water Quality in the Americas

Ernesto González (Venezuela) and Gabriel Roldán (Colombia)

The determination of water quality is often based on the evaluation of its physical (temperature, color, turbidity, transparency, total dissolved solids, suspended solids, color), chemical (conductivity, pH, alkalinity, acidity, hardness, dissolved oxygen, oxygen demand, nitrogen and phosphorus concentrations, chlorides, heavy metals, biocides, among others) and microbiological characteristics (presence of pathogenic bacteria, viruses, helminths and protozoa, among other considerations) (WHO, 2017). Although these parameters are accurate, they provide partial, specific information. Accordingly, in recent years, the concept of water quality has changed from a physical and chemical approach to one integrating all the components of the ecosystem (Roldán & Ramírez, 2008). In fact, the European Parliament Framework Guideline COM-97 has proposed establishing the ecological status of the system studied through the use of biological, hydromorphological and physico-chemical indicators as a measure of the quality of aquatic ecosystems.

The physical and chemical parameters useful for the evaluation of water quality are determined by the presence of both organic and inorganic compounds, which may be in suspended or dissolved form. Some of these compounds are toxic to the ecosystem, while others serve as nutrients for organisms (Eletta & Adekola, 2005).

Aquatic ecosystems maintain an enormous diversity of organisms, as a result of which impacts such as pollution induce changes in the structure of communities, the biological function of aquatic systems and the body itself, affecting their life cycle, growth and its reproductive condition (Vázquez Silva *et al*., 2006). For this reason, some organisms can provide information on physical and chemical changes in water, since over time they reveal changes in the composition of the community (Laws, 1981). Thus, an aquatic ecosystem is a functional system in which there is a cyclical exchange of matter and energy between living organisms and the abiotic environment. Biology and chemistry are therefore closely related and play complementary roles in the evaluation of natural and polluted waters.

Levels of impact can vary from one aquatic ecosystem to another, and it has been found that there are groups of species whose presence in the ecosystem depends on the degree and type of impact and contaminants (Tabash, 1988). In each region, some organisms have a very broad range of tolerance to the environmental conditions that occur in the habitat, depending largely on the degree of contamination at the site. It is also possible to identify species that are the first to disappear due to the increase in alterations caused by human activities (Vázquez Silva *et al*., 2006), either because of the inadequate water quality, habitat degradation or a combination of these two factors, as a result of which accurate knowledge must be obtained of the intolerant species found in each region.

For an organism to be considered a good indicator of water quality, it must be found in an ecosystem with specific characteristics and its population must have a higher or slightly similar percentage to the rest of the organisms with which it shares the same habitat (Roldán & Ramírez, 2008). It has therefore been possible to identify groups of organisms that can be

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used as biological indicators of environmental impacts that affect the water quality of different ecosystems, such as bacteria, periphyton, phytoplankton, macrophytes, benthic macroinvertebrates and fish (Vázquez Silva *et al.*, 2006). Although the biological information produced by these bioindicator organisms does not replace physicochemical analysis, it can lower costs, which is why these studies are important for monitoring water quality (Chapman, 1996).

In the countries on the American continent, there are numerous experiences related to the use of organisms to determine water quality, mainly in surface sources. This chapter seeks to provide a modest overview of the experiences in the American continent in cases related to the proliferation of certain groups of phytoplankton in lakes and reservoirs according to their degree of eutrophication and the use of macroinvertebrates as bioindicators of river water quality.

Eutrophication and phytoplankton

Excessive enrichment with surface water nutrients, mainly in phosphorus (P) and nitrogen (N), produces changes in the structure and functioning of aquatic ecosystems and the deterioration of water quality (Quirós, 2004). Among the structural changes produced by eutrophication is the dominance of the main community of primary pelagic producers of lakes and reservoirs, phytoplankton, by cyanobacteria.

Bellinger & Sigee (2010) state that the detection and analysis of algae indicators provides a rapid assessment of trophic status and possible contamination by human activities of freshwater bodies. They therefore present what the indicator species of the trophic state would be in mid-summer in temperate lakes (**Table 1**).

The predominance of cyanobacteria in many mesotrophic and eutrophic lakes and reservoirs can be explained by their ability to fix molecular nitrogen (in the form of dissolved gas). At that time, nitrogen is usually the nutrient limiting primary productivity and cyanobacteria would have competitive advantages in this situation (Pizzolón, 1996). The dominance of cyanobacteria in these lakes and reservoirs with high concentrations of nutrients can also be explained by their high capacity to absorb dissolved carbon dioxide, even at very low concentrations. High pH values (basic) also encourage the development of cyanobacteria, due to their capacity to transform bicarbonate and carbonate ions into carbon dioxide. In fact, cyanobacteria are the only microalgae that develop im-

Table 1. Phytoplankton species indicative of trophic status in temperate lakes in mid-summer

Type of lake	Algae Indicators
Oligotrophic	**Diatoms:** *Cyclotella comensis, Rhizosolenia* spp.
	Green algae: *Staurodesmus* spp.
Mesotrophic	**Diatoms:** *Tabellaria flocculosa*
	Chrysophites: *Dynobrion divergens, Mallomonas caudata*
	Green algae: *Sphaerocystis schroeteri, Dyctiosphaerium elegans, Cosmarium* spp., *Staurastrum* spp.
	Dinoflagellates: *Ceratium hirundinella*
	Cyanobacteria: *Gomphosphaeria* spp.
Eutrophic	**Diatoms:** *Aulacoseira* spp., *Stephanodiscus rotula*
	Green algae: *Eudorina* spp., *Pandorina morum, Volvox* spp.
	Cyanobacteria: *Anabaena* spp., *Aphanizomenon flos-aquae, Microcystis aeruginosa*
Hipereutrophic	**Diatoms:** *Stephanodiscus hantzschii*
	Green algae: *Scenedesmus* spp., *Ankistrodesmus* spp., *Pediastrum* spp.
	Cyanobacteria: *Aphanocapsa* spp., *Aphanothece* spp., *Synechococcus* spp.

Source: Adapted from Bellinger & Sigee, 2010

Table 2. Algae distribution by trophic state in lakes in the western region of Canada

Type of lake	Algae Indicators
Oligotrophic	**Diatoms:** *Asterionella formosa, Melosira islandica, Tabellaria fenestrata, Tabellaria flocculosa, Fragilaria capucina, Stephanodiscus niagarae, Staurastrum* spp., *Melosira granulata*
	Chrysophites: *Dynobrion divergens*
Mesotrophic	**Diatoms:** *Fragilaria crotonensis*
	Green algae: *Pediastrum boryanum, Pediastrum duplex*
	Dinoflagellates: *Ceratium hirundinella*
	Cyanobacteria: *Coelosphaerium naegelianum, Anabaena* spp., *Aphanizomenon flos-aquae, Microcystis aeruginosa*
Eutrophic	**Cyanobacteria:** *Microcystis flos-aquae*

Source: Adapted from Rawson, 1956.

portant biomasses in naturally alkaline and saline environments. Another type of factor involved in its predominance is the low consumption rate by zooplankton, either because they are unappetizing, or because they mechanically interfere with the process of their consumption, or because zooplankton stop feeding when there are toxic strains of cyanobacteria in the environment.

According to Bellinger & Sigee (2010), in the mid-20th century, between 1945 and 1972, researchers such as Thunmark, Nygaard and Stockner developed trophic status indexes by using large taxonomic groups that were considered typical of oligotrophic (particularly desmids, a group of green algae) or eutrophic conditions (chlorococcal, cyanobacterial, euglenoid). Although these indices provide useful information, they tend to lack environmental resolution, since many kinds of algae prove to be heterogeneous, containing typical lake species, both oligotrophic and eutrophic. The improvement of sampling methods and the increase in taxonomic resolution enabled the development of indices based on indicator species separated from taxonomic groups.

In the Americas, there have been experiences in the use of phytoplankton groups and species for the determination of the trophic status and quality of surface waters. In Canada, Rawson (1956) published a list of dominant trophic status indicators for lakes in the western region, shown in **Table 2**. This list is based on 25 years of observations.

Other examples of studies of eutrophication and dominance of phytoplankton groups in the Americas are shown in **Table 3**.

Macroinvertebrates as water quality bioindicators

Aquatic macroinvertebrates are organisms that live at the bottom of rivers and lakes, attached to aquatic vegetation, trunks and submerged rocks (Roldán, 1988). Their populations are mainly composed of flatworms, insects, mollusks and crustaceans. They are called macroinvertebrates, since they can be seen with the naked eye and range in size from 0,5 mm to approximately 5,0 mm. Since the composition of macroinvertebrate communities reflects the quality of aquatic ecosystems, evaluation methods based on these organisms have been widely used for several decades as an integral part of water quality monitoring. European Union and North American countries have been the leaders in this field (Gaufin & Tarzwell, 1952; Hynes, 1959; Resh *et al*., 1995). Studies based on this methodology have permitted an awareness of the ecological status of their rivers and lakes, which have served as the basis for developing plans for their unexpected recovery in the past 20 years.

Based on the knowledge of the aquatic fauna of each country, this evaluation can be undertaken with various levels of accuracy. Thus, for example, Germany, which has had a longer tradition in the knowledge of its aquatic flora and fauna, has adopted the Saprobic method, which requires the identification of organisms up to the species level for its application. Other countries, such as Belgium, France, Great Britain, Italy, Portugal, Denmark, the Netherlands and Ireland, have adopted evaluation systems based on the level of orders, families and in

Table 3. Examples of eutrophization and dominance of phytoplankton groups in the Americas

Country	Eutrophication and phytoplankton	References
Mexico	Replacement of green algae and diatoms by cyanobacteria, particularly *Anabaena* spp., *Microcystis aeruginosa*, *Oscillatoria* spp. and *Lyngbya* spp. in various eutrophicated lakes.	Alcocer & Lugo (1995), Díaz-Pardo *et al.* (1998), Quiroz Castelán *et al.* (2004), Bravo-Inclán *et al.* (2008), Oliva Martínez *et al.* (2008), López-López *et al.* (2010), entre otros.
Guatemala	Prevalence of cyanobacteria in Lake Amatitlán due to eutrophic conditions.	Basterrechea (1987)
	Blooms of the *Lyngbya* species complex on Lake Atitlán, as a result of the change in land use and increase in nutrient concentration.	Rejmánková *et al.* (2010)
Costa Rica	The mesotrophic Arenal Reservoir contains a varied phytoplankton community dominated by green algae, some diatoms and the *Microcystis* spp. *cyanobacterium*.	Jones *et al.* (1993), Umaña *et al.* (1999)
Colombia	Reservoirs with more signs of eutrophication (El Peñol, Prado and Tominé) have a predominance of cyanobacteria, especially of the genera *Anabaena* spp. and *Oscillatoria* spp.	Roldán (2002)
Bolivia	Positive responses (increase) in the cyanobacterial families *Oscillatoriaceae* and *Nostocaceae* to enrichment with nutrients and the pH increase in Lake Titicaca.	Fontúrbel & Castaño-Piña (2011)
Brazil	*Microcystis* spp. and Anabaena spp. cyanobacteria blooms in reservoirs in the State of São Paulo, with severe eutrophication due to industrial and agricultural waste.	Tundisi (1988)
	Predominance of toxic cyanobacteria, particularly the *Planktothrix agardhii* (drought period) and *Microcystis aeruginosa* (rainy period) species in the Armando Ribeiro Gonçalves reservoir (Rio Grande do Norte).	Chellappa *et al.* (2001)
Argentina	Phosphorus is the main determinant of phytoplankton biomass in more than 100 Argentine reservoirs, and the increase in the frequency of cyanobacterial blooms in eutrophic lakes.	Quirós (1991, 2000), Quirós *et al.* (2006)
Chile	The rise in nitrogen and phosphorus concentrations has led to an increase in phytoplankton biomass and the dominance of cyanobacteria, generally with *Anabaena* spp., *Microcystis* spp. and *Oscillatoria* spp. blooms.	Mühlhauser & Vila (1987), Parra (1989), Parra *et al.* (2003), Campos *et al.* (2005, 2007), Almanza-Marroquín *et al.* (2016)
Uruguay	The process of eutrophication in large reservoirs (Salto Grande, Bonete, Baygorria and Palmar) has led to an intense growth of phytoplankton, with a predominance of diatoms and cyanobacteria.	Chalar & Conde (2000), De León & Chalar (2003), Chalar *et al.* (2002), Chalar (2006, 2009)
	Predominance of cyanobacteria throughout the year and a marked increase in the frequency and duration of microalgae blooms, particularly of *Microcystis aeruginosa* in the Laguna del Sauce.	RAP-AL (2010)
Venezuela	Reservoirs can be divided into three groups. Group 1: reservoirs with low concentrations of P (<20µg/L) and dominated by green algae. Groups 2 and 3: reservoirs with moderate to high concentrations of P (>20µg/L). In group 2 there is a low nitrate/ammonium ratio, with high residence times of its waters and a predominance of cyanobacteria, whereas in group 3, there is a higher nitrate/ammonium ratio, short residence times of its waters and phytoplankton is dominated by taxa other than cyanobacteria.	González & Quirós (2011)

some cases genera. Its effectiveness has been proven in a high percentage for "Rapid Ecosystem assessment," in addition to the fact that it provides a considerable reduction in costs and time (De Pauw & Hawkes, 1993; Roldán, 2003).

Current state of knowledge of aquatic macroinvertebrates in the Americas

The use of aquatic organisms as bioindicators of the quality of aquatic ecosystems began in the Americas in the mid-20th century. Patrick (1949, 1950) developed biological methods to evaluate the ecological conditions of currents in North America, while Gaufin & Tarzwell (1952) proposed macroinvertebrates as pollution indicators and Hynes (1959, 1963) proposed macroinvertebrates as water quality indicators. In Maryland (United States), Resh *et al*. (1995) developed rapid water quality assessment methods, using macroinvertebrates as bioindicators, assessing habitat conditions and predicting the expected fauna at a given site.

Table 4 shows examples of the use of bioindication in Latin America, based on pioneering work in Colombia.

Use of aquatic macroinvertebrates as water quality indicators

Aquatic macroinvertebrates are regarded as the best water quality indicators because they are abundant, widely distributed and easy to collect. They are mostly sedentary and therefore reflect the conditions of their habitat. They are relatively easy to identify, reflect the effects of short-term environmental variations, provide information to integrate cumulative effects, have long life cycles (weeks and/or months), can be recognized at a glance and be cultivated in the laboratory, respond quickly to environmental stressors and vary very little genetically (Roldán, 1999, 2003). Moreover, macroinvertebrate communities display different responses to pollution. Accordingly, Metcalf (1989) distinguishes three main approaches to assess the response of macroinvertebrate communities to pollution. These include: the saprobic, diversity and biotic method.

The saprobic approach. The term saprobic, used to refer to the capacity of certain organisms to live in certain levels of pollution, was coined in Germany by Kolkwitz & Marsson (1908, 1909). They defined three levels of saprobity: a) polysaprobic zone, with predominantly reductive processes, b) mesosaphobic zone, partially reductive with predominantly oxidative processes and c) oligosaphobic zone, with exclusively oxidative processes.

The diversity approach. This includes three main components of natural communities: richness, uniformity and abundance, to describe the community's response to environmental quality. A natural community is characterized by having a great diversity of species and a low number of individuals per species, or a low number of species and many individuals per species. This situation is observed in nature in places such as the depths of large lakes and the sea, very high mountains and extreme temperatures. Water pollution produces a similar situation, causing certain very sensitive communities to disappear and other more resistant communities to increase in number.

The biotic approach. This approach includes the essential aspects of saprobity, combining a quantitative measure of species diversity with qualitative information on the ecological sensitivity of taxa of individuals in a simple numerical expression. Beck (1955) proposed the biotic index in the United States based on the ratio between pollution intolerant and tolerant species; values range between 0 and 10.

The BMWP method

The Biological Monitoring Working Party (BMWP) was established in England in 1970 as a quick, simple method to assess water quality using macroinvertebrates as bioindicators. The reasons for this were mainly economic, and linked to the time taken to undertake the assessment. The method only requires reaching the family level and the data is qualitative (presence or absence). The score ranges from 1 to 10 according to the tolerance of the different groups to organic contamination. The most

Table 4. Examples of work on aquatic macroinvertebrates and bioindication in Latin America

Country	Works on aquatic macroinvertebrates and bioindication	References
Colombia	Start of bioindication in Latin America. The first works were based on codes developed by researchers from the USA and Europe.	Roldán *et al.* (1973); Pérez & Roldán (1978)
	Publication of the *Guide for the Study of Aquatic Macroinvertebrates of the Department of Antioquia*, which served as the basis for the beginning of knowledge on macroinvertebrate communities in Latin America.	Roldán (1988)
Central America	Publication of the book *Diversity, conservation and use of freshwater macroinvertebrates of Mexico, Central America, Colombia, Cuba and Puerto Rico.*	Alonso *et al.* (2014)
El Salvador	Publication of a complete series of works on macroinvertebrates.	Sermeño Chicas *et al.* (2010)
Costa Rica	Publication of the first macroinvertebrates code	Springer *et al.* (2010)
Nicaragua	Publication of guide to macroinvertebrates as biological water quality indicators in the Gil González River and the main tributaries.	Salvatierra (2012)
Guatemala	Publication of status of aquatic macroinvertebrates	Reyes (2013)
Honduras	Publication of code for the identification of freshwater macroinvertebrates	García & Jiménez (2006)
Dominican Republic	Presentation of report on the final sampling of macroinvertebrates from the Ebano Verde region.	Pérez (2015)
Ecuador	Proposal of protocol for the ecological quality of the Andean rivers (CERA) and its use in two basins in Ecuador and Peru.	Acosta *et al.* (2009)
Peru	Publication of studies on macroinvertebrates in Cajamarca and the Amazon.	Paredes *et al.* (2004)
Paraguay	Characterization of ecosystem services of wetlands, taking aquatic macroinvertebrates into account.	Espinosa *et al.* (2012)
Panama	Publication of a guide entitled *Diagnosis of pollution in surface streams of Panama using freshwater macroinvertebrates.*	Cornejo *et al.* (2017)
Puerto Rico	Use of methodology to evaluate water quality using the BMWP-Cub.	Gutiérrez-Fonseca *et al.* (2013)
Argentina	Publication of book on benthic macroinvertebrates of South America.	Domínguez & Fernández (2009)
	Publication of macroinvertebrate guidelines as water quality indicators.	Rocha (2004)
Venezuela	Several experiences in the use of macroinvertebrates to determine water quality and draw up indexes of the biotic integrity of rivers in various regions of the country.	Rincón (1995), Rivera & Marrero (1995), Segnini (2003), Segnini *et al.* (2009), Echevarría & Marrero (2012), Barrios *et al.* (2015), entre otros
Bolivia	Publication of technical guide for the evaluation of waterbody conditions using aquatic macroinvertebrates.	Valencia (2014)
Brazil	Publication of a book on the ecology of aquatic insects.	Nessimian y Carvalho (1998)
Chile	Study of the aquatic macroinvertebrates of the Limari basin.	Carvacho (2012)
Uruguay	Publication of study on aquatic macro-vertebrates in riparian vegetation.	Morelli & Verdi (2014)

sensitive families such as Perlidae and Oligoneuriidae receive a score of 10. On the other hand, the most pollution-tolerant ones, for example, Tubificidae, receive a score of 1.0 (Armitage *et al*., 1983). The sum of the scores of all families provides the total BMWP score.

Bioindication in Colombia dates back to the 1970s with publications in Medellín (Roldán *et al*., 1973) constituting the first experiences in Latin America. Subsequently, Matthias & Moreno (1983) undertook a physicochemical and biological study of the same river, using macroinvertebrates as water quality indicators. Bohórquez & Acuña (1984) undertook the first studies for the Bogotá savannah. Zúñiga *et al*. (1993) adapted this method for some of the basins in Valle del Cauca. Reinoso (1999) and Reinoso *et al*. (2008) conducted a study of the Combeima River in the Department of Tolima. Zamora (2000) adapted the BMWP index to assess the quality of epicontinental waters in Colombia. Roldán (2001) used this methodology for the Piedras Blancas basin in the Department of Antioquia. Riss *et al*. (2002) establish biondication values for the Bogotá Savannah. Roldán (2003) adapted the BMWP system to evaluate water quality in Colombia through the use of aquatic macroinvertebrates. On the basis of the knowledge that currently exists in Colombia about the different groups of macroinvertebrates up to the family level, he proposes to use the BMWP/Col method, as a first approach to evaluating mountain aquatic ecosystems. Table 5 presents the families and their assessment according to their degree of adaptation to the various water qualities. Each region, in both Colombia and in Latin America, has made its own score assessments on the basis of their experiences (Zamora & Sarria, 2001, Sánchez-Herrera, 2005, Zúñiga, 2009, Springer *et al*., 2010).

The information available in Latin America on the taxonomy, ecology and bioindication of water quality is not the same in all groups of macroinvertebrates. More information is available on Ephemeroptera, Plecoptera and Trichoptera than the other taxa. It is also important to expand the study of annelids, mollusks and diptera, especially of the Chironomidae family. It is necessary to advance the association of immature states and their corresponding winged forms, as well as between males and females, in order to achieve a rigorous taxonomic determination. It is important to define a unified methodology for the study of lentic ecosystems and large rivers.

Table 5. Scores of aquatic macroinvertebrate families for the BMWP/Col index

Families	Scores
Anomalopsychidae, Atriplectididae, Blepharoceridae, Calamoceratidae, Ptilodactylidae, Chordodidae, Gomphidae, Hidridae, Lampyridae, Lymnessiidae, Odontoceridae, Oligoneuriidae, Perlidae, Polythoridae, Psephenidae.	10
Ampullariidae, Dytiscidae, Ephemeridae, Euthyplociidae, Gyrinidae, Hydrobiosidae, Leptophlebiidae, Philopotamidae, Polycentropodidae, Xiphocentronidae.	9
Gerridae, Hebridae, Helicopsychidae, Hydrobiidae, Leptoceridae, Lestidae, Palaemonidae, Pleidae, Pseudothelpusidae, Saldidae, Simuliidae, Veliidae.	8
Baetidae, Caenidae, Calopterygidae, Coenagrionidae, Corixidae, Dixidae, Dryopidae, Glossosomatidae, Hyalellidae, Hydroptilidae, Hydropsychidae, Leptohyphidae, Naucoridae, Notonectidae, Planariidae, Psychodidae, Scirtidae.	7
Aeshnidae, Ancylidae, Corydalidae, Elmidae, Libellulidae, Limnichidae, Lutrochidae, Megapodagrionidae, Sialidae, Staphylinidae.	6
Belostomatidae, Gelastocoridae, Hydropsychidae, Mesoveliidae, Nepidae, Planorbiidae, Pyralidae, Tabanidae, Thiaridae.	5
Chrysomelidae, Stratiomyidae, Haliplidae, Empididae, Dolicopodidae, Sphaeridae, Lymnaeidae, Hydraenidae, Hydrometridae, Noteridae.	4
Ceratopogonidae, Glossiphoniidae, Cyclobdellidae, Hydrophilidae, Physidae, Tipulidae.	3
Culicidae, Chironomidae, Muscidae, Sciomyzidae.	2
Tubificidae	1

Source: Roldán, 2003.

Immature forms of the entomofauna have a good potential as bioindicators, as well as being a diverse, abundant community with a broad altitudinal distribution in water ecosystems. For example, in Colombia, the genus *Anacroneuria* (Plecoptera: Perlidae), was one of the groups with the greatest sensitivity to habitat degradation and the enrichment of the residual organic load (Roldán, 2003, Zúñiga, 2010). The most sensitive genera of Ephemeroptera include *Lachlania* (Ologineuriidae), *Haplohyphes* (Leptohyphidae), *Mayobaetis*, *Andesiops* (Baetidae) *Atopophlebia* and *Thraulodes* (Leptobhlebiidae), while *Camelobaetidius*, *Baetodes* (Baetidae), *Leptohyphes* and *Tricorythodes* (Leptohyphidae) have a large environmental spectrum (Zamora, 1996, Zúñiga *et al*., 1997, Roldán, 2003, Zúñiga & Cardona, 2009). The most sensitive genera of the order *Trichoptera* are *Triplectides* (Leptoceridae), *Rhyacopsyche* (Hydroptiliidae), *Chimara* (Philopotamidae), *Marilia* (Odontoceridae) and *Phylloicus* (Calamoceratidae). The genera *Leptonema* (Hydropsychidae) and *Atanatolica* (Leptoceridae) have a broad scope, with adaptations to ecosystems with incipient degradation (Zúñiga *et al*., 1993, Zamora, 1996, Ballesteros *et al*., 1997, Roldán, 2003, Guevara *et al*. , 2007a, b, Zúñiga & Cardona 2009, Forero *et al*., 2013, Forero & Reinoso, 2013, Vásquez *et al*., 2013, 2014).

Standardization of work protocols

In Latin America, it is necessary to work on the standardization of sampling protocols, with an emphasis on large rivers and lentic water bodies, such as wetlands or large lakes. This homogenization of field work protocols, counting organisms, laboratory analysis and the use of indices is essential to achieving consistent, comparable results and data bases (Roldán *et al*., 2016). In this respect, in Colombia, Rueda-Delgado (2002) published the Manual of Methods in Limnology, in which he compiled the general information on the various study methods for the most important biota in aquatic environments. The Institute of Hydrology, Meteorology and Environmental Studies of Colombia (IDEAM) is currently developing a methodology for evaluating water quality for Colombia through the use of aquatic macroinvertebrates as bioindicators.

One of the problems in the use of bioindication to measure water quality is the indiscriminate use of biotic indices, in both lysic and lentic water ecosystems. These ecosystems have different hydrological and ecological characteristics and a biota adapted to the particular conditions of each of these environments. The BMWP index is extremely popular and, although there are some adaptations of this biological parameter at the regional level, to ensure the validity of its application, it is important to take into account the type of water bodies where it is used (Zúñiga *et al*., 1993; Zamora, 2000, Roldán, 2003).

Final considerations

Determining water quality can easily integrate traditional biochemical indicators, the information corresponding to the biotic components of ecosystems, which provides a more holistic vision of the response to the impacts on them.

As has been seen, in the case of eutrophication, as in numerous studies on the temperate zones, in the Americas it has also been recorded that the increase in nutrient concentrations, mainly of phosphorus, leads to greater biomass of phytoplankton and a predominance of cyanobacteria. Likewise, in most cases, the dominant cyanobacterial species correspond to the genera Microcystis spp., Anabaena spp. and Planktothrix spp., with the risk that many of their species have toxic strains, which turn them into potential health risks, particularly if the waterbodies are used to supply water for human consumption.

In the case of the use of aquatic macroinvertebrates for bioindication, information on the taxonomy and ecology of some of the entomological groups with the greatest diversity, abundance and biomass remains limited. This situation applies to the Diptera, Odonata and Hemiptera orders, taxa which could provide valuable information from the point of view of bioindication, especially for lentic environments, where their abundance and diversity is usually greater than that which occurs in the ecosystems of running water. On the other hand, molluscs and annelids, whose abundance and biomass are very high in contaminated environments and enriched with organic matter, lack more detailed taxonomic information, leading to generalizations and misinterpretations about their potential as water quality bioindicators.

References

Acosta, R.; Ríos, B.; Rieradevall, M. y Prat, N. (2009). Propuesta de un protocolo de la calidad ecológica de los ríos andinos (CERA) y su aplicación a dos cuencas del Ecuador y Perú. *Limnetica*, 28 (1): 35-64.

Alcocer, D.J. & Lugo, A. (1995). The urban lakes of Mexico City (Lago Viejo de Chapultepec). *Lakeline*, 15(2): 14–31.

Almanza-Marroquín, V.; Figueroa, R.; Parra, O.; Fernández, X.; Baeza, C.; Yáñez, J. y Urrutia, R. (2016). Bases limnológicas para la gestión de los lagos urbanos de Concepción, Chile. *Lat. Am. J. Aquat. Res.*, 44(2): 313-326.

Alonso-Eguíalis, P.; Mora, J.M. Campbel. B y Springer, M. (Eds.) (2014). *Diversidad, conservación y uso de los macroinvertebrados dulceacuícolas de México, Centroamérica, Colombia, Cuba y Puerto Rico*. México: IMTA.

Armitage, P.D.; Moss, D. & Furse, M.T. (1983). The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpollute running-water sites. *Water Res*., 17: 33-347.

Barrios, M.C.; Rodríguez-Olarte, D.; García Silva, E. (2015). Índice de integridad de los ecosistemas fluviales con base a las comunidades de insectos acuáticos en el río Misoa de la cuenca del lago de Maracaibo, Venezuela. *Entomotrópica*, 30: 69-83.

Basterrechea, M. (1987). Enfoque global del lago de Amatitlán y su cuenca. En: *Estudios recientes sobre la contaminación del Lago de Amatitlán.* Ciudad de Guatemala: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), 9-31

Ballesteros, Y.V.; Zúñiga, M. del C. & Rojas, A.M. (1997). Distribution and structure of the order Trichoptera in various drainages of the Cauca River basin, Colombia, and their relationships to water quality. En: R.W. Holzenthal, & O. Flint (eds.). *Proceedings of the 8th International Symposium on Trichoptera, 1995.* Columbus, Ohio, USA: Ohio Biological Survey, 19-23.

Beck, W. M. (1955). Suggested method for reporting biota data. *Sewage Ind. Wastes,* 27: 1193-1197.

Bellinger, E.G. & Sigee, D.C. (2010). *Freshwater algae. Identification and use as bioindicators.* Chichester: Wiley-Blackwell. 271 pp.

Bohórquez, A. y Acuña, A. (1984). *Inventario de las morfofamilias de las clases Gasterópoda y Clitelata como bioindicadores limnológicos de la laguna de La Herrera.* Memorias XIX Congreso Nacional y III Grancolombiano de Ciencias Biológicas. Bucaramanga: Universidad Industrial de Santander, 70 pp.

Bravo-Inclán, L.A.; Saldaña-Fabela, M.P. & Sánchez-Chávez, J.J. (2008). Long-term eutrophication diagnosis of a high altitude body of water, Zimapan Reservoir, Mexico. *Water Science & Technology,* 57(11): 1843-1849.

Campos, V.; Lisperguer, S.; Weckesser, J.; Vera, A. y Muñoz, D. (2005). Cianobacterias y riesgos potenciales de toxicidad en aguas continentales de Chile. *Boletín Micológico,* 20: 73-81.

Campos, V.; Muñoz, D.; Straube, M.; Lisperguer, S. y Weckesser, J. (2007). Péptidos tóxicos y no tóxicos de cianobacterias en cuerpos de agua dulce de La V Región, Chile. *Boletín Micológico,* 22: 95-100.

Carvacho, C. (2012). *Estudio de las comunidades de maroinvertebrados bentónicos y desarrollo de un índice multimétrico para evaluar el estado ecológico de los ríos de la cuenca del Limari, Chile.* Tesis de maestría. Universidad de Barcelona. Barcelona 70 pp.

Chalar, G. (2006). Dinámica de la eutrofización a diferentes escalas temporales: Embalse Salto Grande (Argentina-Uruguay). En: J.G. Tundisi, T. Matsumura-Tundisi & Corina Sidagis Galli (eds.). *Eutrofização na América do Sul: Causas, conseqüências e tecnologias de gerenciamento e controle.* Instituto Internacional de Ecologia, Instituto Internacional de Ecologia e Gerenciamento Ambiental, Academia Brasileira de Ciências, Conselho Nacional de Desenvolvimento Científico e Tecnológico, InterAcademy Panel on International Issues, InterAmerican Network of Academies of Sciences. São Carlos: 87-101.

Chalar, G. (2009). The use of phytoplankton patterns of diversity for algal bloom management. *Limnologica*, 39: 200-208.

Chalar, G. y Conde, D. (2000). Antecedentes y estado actual del conocimiento científico de los embalses del Uruguay. En: A. Fernández-Cirelli (ed.). *El Agua en Iberoamérica: Acuíferos, lagos y embalses.* Ciencia y Tecnología para el Desarrollo (CYTED). Subprograma XVII. Aprovechamiento de Recursos Hídricos. Buenos Aires: 145-147.

Chalar, G.; De León, L.; Brugnoli, E.; Clemente, J. y Paradiso, M. (2002). Antecedentes y nuevos aportes al conocimiento de la estructura y dinámica del embalse Salto Grande. En: A. Fernández-Cirelli y G. Chalar-Marquisá (Eds.). *El agua en Iberoamérica. De la Limnología a la Gestión en Sudamérica.* Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo, CYTED XVII. Aprovechamiento y Gestión de Recursos Hídricos; Centro de Estudios Transdisciplinarios del Agua; Facultad de Ciencias Veterinarias de la Universidad de Buenos Aires. Buenos Aires: 123-141.

Chapman, D. (1996). *Water quality assessments: A guide to the use of biota, sediments and water in environmental monitoring.* London: Chapman Hill. 626 pp.

Chellappa, N.T.; Camara, F.R.A. & Rocha, O. (2009). Phytoplankton community: indicator of water quality in the Armando Ribeiro Gonçalves Reservoir and Pataxó Channel, Rio Grande do Norte, Brazil. *Brazilian Journal of Biology,* 69(2): 241-251.

Cornejo, A.; López-López, E.; Ruiz-Picos, R.A.; Sedeño Díaz, J.E.; Armitage, B.; Arefina, T.; Nieto, C.; Tuñón, A.; Molinar, M.; Ábrego, T.; Pérez, E.; Tuñón Rivas, A.R.; Magué, J.; Rodríguez, A.L.; Pineda, J.E.; Cubilla Higuera, J.J. y Ávila Quintero, I.M. (2017). *Diagnóstico de la Condición Ambiental de los Afluentes Superficiales de Panamá.* Instituto Conmemorativo Gorgas de Estudios de la Salud. Panamá: Ministerio de Ambiente. 326 pp.

De León, L. y Chalar, G. (2003). Abundancia y diversidad del fitoplancton en el Embalse de Salto Grande (Argentina-Uruguay). Ciclo estacional y distribución espacial. *Limnetica*, 22(1-2): 103-113.

De Pauw, N & Hawkes, H.A. (1993). Biological monitoring of water quality. En: *River quality monitoring and control.* W.J. Walley & S. Judd (Eds.). UK: Aston University. 249 pp.

Díaz-Pardo, E., Vázquez, G. & López-López, E. (1998). The phytoplankton community as a bioindicator of health conditions of Atezca Lake, México. *Aquatic Ecosystem Health and Management,* 1: 257-266.

Domínguez, E. y Fernández, H. (Eds.) (2009). *Macroinvertebrados bentónicos sudamericanos: Sistemática y biología.* San Miguel de Tucumán, Argentina: Fundación Miguel Lillo. 656 pp.

Echevarría, G. y Marrero, C. (2012). Determinación del estado ecológico del río Guanare, estado Portuguesa, Venezuela, utilizando macroinvertebrados bentónicos como indicadores. *Acta Biol. Venez.*, 32(1): 29-55.

Eletta, O.A.A. & Adekola, F.A. (2005). Studies of the physical and chemical properties of Asa River water, Kwara State, Nigeria. *Science Focus,* 10(1): 72-76.

Espinoza, A.; Villalba-Forcadell, C.V. e Ibarra, J.E. (2012). Caracterización de servicios ecosistémicos de humedales: regulación de la calidad de agua en el humedal del rio salado, Paraguay. *Boletín de la Red Iberoamericana y del Caribe de Restauración Ecológica,* 6(1): 3-4.

Fontúrbel, F.E. & Castaño-Villa, G.J. (2011). Relationships between nutrient enrichment and the phytoplankton community at an Andean oligotrophic lake: a multivariate assessment. *Ecología Aplicada,* 10(2): 75-81.

Forero, C.A.M.; Gutiérrez, C. y Reinoso, F.G. (2013). Evaluación de la calidad del agua del río Opia (Tolima-Colombia) a través de la fauna de macroinvertebrados acuáticos y parámetros fisicoquímicos. *Rev. Caldasia,* 35(2): 371-387.

Forero, C.A.M y Reinoso, F.G. (2013). Estudio de la familia Baetidae (Ephemeroptera: Insecta) en una cuenca con influencia de la urbanización y agricultura: río Alvarado- Tolima. *Rev. Asoc. Col. Cienc.* (Col.), 25: 12-21.

García, L.A y Jiménez, F. (2006). Efectos del bosque ribereño y de las actividades antrópicas en las características físico-químicas y en poblaciones de macroinvertebrados acuáticos en la subcuenca del río Tascalapa, Honduras. *Recursos Naturales y Ambiente,* 48: 35-46.

Gaufin, A.R. & Tarzwell, C.M. (1952). Aquatic invertebrates as indicators of stream Pollution. *Amer. Publ. Health Rep.*, 67(1): 57-64.

González, E.J. & Quirós, R. (2011). Eutrophication of reservoirs in Venezuela: Relationships between nitrogen, phosphorus and phytoplankton biomass. *Oecologia Australis,* 15(3): 458-475.

Guevara-Cardona, G.; Reinoso-Flórez, G. & Villa-Navarro, N.F. (2007a). Caddisfly larvae (Insecta: Trichcotera) of the Coello River Basin in Tolima (Colombia): Spatial and temporal patterns and bioecological aspects. En: J. Bueno-Soria, R. Barba-Álvarez & B. Armitage (eds.). *Proceeding of the XIIth International Symposium on Trichoptera.* The Caddis Press: 113-120.

Guevara-Cardona, G.; López-Delgado, E.O.; Reinoso-Flórez, G. & Villa-Navarro, N.F. (2007b). Structure and distribution of the Trichoptera fauna in a Colombian Andean river basin (Prado, Tolima) and their relationship to water quality. En: J. Bueno-Soria, R. Barba-Álvarez & B. Armitage (eds.). *Proceeding of the XIIth International Symposium on Trichoptera.* The Caddis Press: 129-134.

Gutiérrez-Fonseca, P.E.; Rosas, K.G. & Ramírez, A. (2013). Aquatic insects of Puerto Rico: a list of families. *Dugesiana*, 20(2): 215–219.

Hynes, H.B.N. (1959). The use of invertebrates as indicators of river pollution. *Proc. Linnean. Soc. London,* 170(2): 165-170.

Hynes, H.B.N. (1963). *The biology of polluted water.* UK: Liverpool University Press, 202 pp.

Jones, J.R.; Lohman, K. & Umaña, G. (1993). Water chemistry and trophic state of eight in Costa Rica. *Verh. Internat. Verein. Limnol.,* 25(2): 899-905.

Kolkwitz, R. & Marsson, W.A. (1909). Ökologie der tierischen Saprobien. Beitäge zür Lehre von der biologische Gewäserbeuteilung. *Internationale Reveu der gesamten Hydrobiologie,* 2: 126-152.

Kolkwitz, R. & Marsson, W.A. (1908). Ecology of plant saprobia. *Verh. Ges. Oekol.*, 26: 505-516.

Laws, A.E. (1981). *Aquatic Pollution.* USA: Wiley Interscience Publication. 482 pp.

López-López, E.; Sedeño-Díaz, J.E.; Ortiz-Ordóñez, E.; Rosas Colmenárez, M. & Abeja Pineda, O. 2010. Health condition assessment in Lake Xochimilco (Mexico). *Rom. J. Biol.-Zool.,* 55(1): 69-80.

Matthias, U. y Moreno, H. (1983). Estudio de algunos parámetros físicoquímicos y biológicos del río Medellín y sus principales afluentes. *Actualidades Biológicas* 12(46): 106-117.

Metcalf, J.L. (1989). Biological water quality assessment of running waters based on macroinvertebrate communities: history and present status in Europe. *Environ. Pollut.*, 60: 101-139.

Morelli, E. y Verdi, A. (2014). Diversidad de los macroinvertebrados acuáticos en cursos de agua con vegetación ribereña de Uruguay. *Revista Mexicana de Biodiversidad,* 85(4): 1160-1170.

Mühlhauser, H.A. y Vila, I. (1987). Eutrofización, impacto en un ecosistema acuático montañoso. *Arch. Biol. Med. Exp.*, 20: 117-124.

Nessimian, J.L & Carvalho, A.H. (Eds.) (1998). *Ecologia de insectos aquâticos do Brasil.* Programa de Posgrado de Ecologia. Rio de Janeiro: Universidad Federal de Rio de Janeiro. 309 pp.

Oliva Martínez, M.G.; Rodríguez Rocha, A.; Lugo Vázquez, A. y Sánchez Rodríguez, M.R. (2008). Composición y dinámica del fitoplancton en un lago urbano hipertrófico. *Hidrobiologica*, 18 (S1): 1-13.

Paredes, C.; Iannacone, J. y Alvariño, L. (2004). Macroinvertebrados bentónicos como indicadores biológicos de la calidad de agua en dos ríos de Cajamarca y Amazonas, Perú. *Rev. Per. Ent.*, 44: 107-118.

Parra, O. (1989). La eutroficación de la Laguna Grande de San Pedro, Concepción, Chile: un caso de estudio. *Amb. y Des.*, 5(1): 117-136.

Parra, O.; Valdovinos, C.; Urrutia, R.; Cisternas, M.; Habit, E. y Mardones, M. (2003). Caracterización y tendencias tróficas de cinco lagos costeros de Chile Central. *Limnetica*, 22(1-2): 51-83.

Patrick,R.(1949). A proposed biological measure of stream conditions based on a survey of Conestoga Basin, Lancaster County, Pennsylvania. *Proc. Acad. Nat. Sci.* Philadelphia, 101: 277-341.

Patrick, R. (1950). Biological measure of stream conditions. *Sewage Ind. Wastes,* 22: 926-939.

Pérez, D. (2015). Entomofauna de Ébano Verde, Cordillera Central, República Dominicana. *Novitates Caribea,* 8: 61-81.

Pérez, G. y Roldán, G. (1978). Niveles de contaminación por detergentes y su influencia en las comunidades bénticas del Río Rionegro (Antioquia). *Actualidades Biológicas,* 7(24): 27-36.

Pizzolón, L. (1996). Importancia de las cianobacterias como factor de toxicidad en las aguas continentales. *Interciencia*, 21(6): 239-245.

Quirós, R. (1991). Empirical relationships between nutrients, phyto and zooplankton and relative fish biomass in lakes and reservoirs of Argentina. *Verh. Internat. Verein. Limnol.*, 24: 1198-1206.

Quirós, R. (2000). La eutrofización de las aguas continentales en Argentina. En: A. Fernández-Cirelli (ed.). *El Agua en Iberoamérica: Acuíferos, lagos y embalses.* Ciencia y Tecnología para el Desarrollo (CYTED). Subprograma XVII. Aprovechamiento de Recursos Hídricos. Buenos Aires: 43-47.

Quirós, R. (2004). *Cianobacterias en lagos y embalses de Argentina: década de los 80. Serie de documentos de trabajo del área de Sistemas de Producción Acuática.* Documento N° 2. Departamento de Producción. Facultad de Agronomía. Universidad de Buenos Aires. Buenos Aires. 23 pp.

Quirós, R.; Boveri, M.B.; Petracchi, C.A.; Rennella, A.M.; Rosso, J.J.; Sosnovsky, A. y von Bernard, H.T. (2006). Los efectos de la agriculturización del humedal pampeano sobre la eutrofización de sus lagunas. En: J.G. Tundisi, T. Matsumura-Tundisi & Corina Sidagis Galli (eds.). *Eutrofização na América do Sul: Causas, conseqüências e tecnologias de gerenciamento e controle.* Instituto Internacional de Ecologia, Instituto Internacional de Ecologia e Gerenciamento Ambiental, Academia Brasileira de Ciências, Conselho Nacional de Desenvolvimento Científico e Tecnológico, InterAcademy Panel on International Issues, InterAmerican Network of Academies of Sciences. São Carlos: 1-16.

Quiroz Castelán, H.; Mora Zúñiga, L.M.; Molina Astudillo, I. y García Rodríguez, J. (2004). Variación de los organismos fitoplanctónicos y la calidad del agua en el Lago de Chapala, Jalisco, México. *Acta Universitaria,* 14(1): 47-58.

RAP-AL Uruguay (2010). *Contaminación y eutrofización del agua. Impactos del modelo de agricultura industrial.* Red de Acción en Plaguicidas y sus Alternativas para América Latina (RAP-AL). Montevideo: RAP-AL. 36 pp.

Rawson, D.S. (1956). Algal indicators of trophic lakes types. *Limnology and Oceanography,* 1(1): 18-25.

Reinoso, G. (1999). Estudio de la fauna béntica del río Combeima, Colombia. *Revista de la Asociación Colombiana de Ciencias Biológicas,* 11: 35-44.

Reinoso, G.; Guevara, G.; Vejarano, M.; García, J. y Villa, F. (2008). Evaluación del río Prado a partir de los macroinvertebrados y de la calidad del agua. *Revista de la Asociación Colombiana de Ciencias Biológicas,* 20(1): 102-116.

Rejmánková, E.; Komárek, J.; Dix, M.; Komárková, J. & Girón, N. 2011. Cyanobacterial blooms in Lake Atitlán, Guatemala. *Limnologica*, 41: 296-302.

Resh, V.H.; Richard, H.N. &. Barbour, M.T. (1995). Design and implementation of rapid assessment approaches for water resource monitoring using macroinvertebrates. *Aust. J. Ecology,* 20: 108-121.

Reyes, F. (2013). Macroinvertebrados acuáticos de los cuerpos lénticos de la Región Maya. Guatemala. *Revista Científica de la Facultad de Ciencias Químicas y Farmacia,* 23(1): 7-16.

Rincón, J. (1995). Evaluación preliminar de la calidad de las aguas del río Mucujún (estado Mérida) utilizando los macroinvertebrados bénticos. *Investigaciones Científicas,* 1(1): 33-46.

Riss, W.; Ospina, R. & Gutiérrez, J.D. (2002). Establecimiento de valores de bioindicación para macroinvertebertados acuáticos de la Sabana de Bogotá. *Caldasia*, 24(1): 135-156.

Rivera, M. y Marrero, C. (1995). Determinación de la calidad de las aguas en las cuencas hidrográficas mediante la utilización del Índice de Integridad Biótica (IIB). *Biollania* 11: 127-148.

Rocha, Z. (2004). Los macroinvertebrados acuáticos como indicadores de la calidad de aguas. *Cultura Científica*, 2: 34-40.

Roldán, G. (1988). *Guía para el estudio de los macroinvertebrados acuáticos del Departamento de Antioquia.* Fondo FEN-Colombia-Conciencias-Universidad de Antioquia. Santafé de Bogotá: Editorial Presencia Ltda.

Roldán, G. (1999). Los macroinvertebrados y su valor como indicadores de la calidad del agua. *Revista de la Academia Colombiana de Ciencias Exactas Físicas y Naturales,* 23(88): 375-387.

Roldán, G. (2001). *Estudio limnológico de los recursos hídricos del parque de Piedras Blancas.* Academia Colombiana de Ciencias Exactas Físicas y Naturales. Colección Jorge Álvarez Lleras N° 9.

Roldán, G. (2002). Limnología y eutrofización de embalses en Colombia. En: A. Fernández-Cirelli y G. Chalar-Marquisá (Eds.). *El agua en Iberoamérica. De la Limnología a la Gestión en Sudamérica.* Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo, CYTED XVII. Aprovechamiento y Gestión de Recursos Hídricos; Centro de Estudios Transdisciplinarios del Agua; Facultad de Ciencias Veterinarias de la Universidad de Buenos Aires. Buenos Aires: 107-122.

Roldán, G. (2003). *La bioindicación de la calidad del agua en Colombia.* Medellín: Editorial Universidad de Antioquia. 170 pp.

Roldán, G.; Builes, J.J.; Trujillo, C.M. y Suárez, A. (1973). Efectos de la contaminación industrial y doméstica sobre la fauna béntica del río Medellín. *Actualidades Biológicas,* 2(5): 54-64.

Roldán, G. y Ramírez, J.J. (2008). *Fundamentos de Limnología Neotropical.* 2ª edición. Medellín: Editorial Universidad de Antioquia. 440 pp.

Roldán, G.; Zúñiga, M. del C.; Zamora, H.; Álvarez, L.F.; Reinoso, G. y Longo, M. (2014). Capítulo de Colombia. En: P. Alonso-Eguíalis, J.M. Mora, B. Campbell y M. Springer (Eds.). *Diversidad, conservación y uso de los macroinvertebrados dulceacuícolas de México, Centroamérica, Colombia, Cuba y Puerto Rico.* México: IMTA.

Rueda-Delgado, G. (Ed.) (2002). *Manual de Métodos en Limnología.* Asociación Colombiana de Limnología. Santafé de Bogotá: Pen Clips Publicidad y Diseño Ltda.

Salvatierra, T. (2012). Los macroinvertebrados acuáticos como indicadores biológicos de la calidad del agua en el rio Gil González y tributarios más importantes en Nicaragua. Centro para la Investigación en Recursos Acuáticos de Nicaragua (CIRA/UNAN) ENITEL. *Revista Universidad y Ciencia,* 6(9): 38-46.

Sánchez-Herrera, M.J. (2005). El índice biológico BMWP (Biological Monitoring Working Party score), modificado y adaptado al cauce principal del río Pamplonita, Norte de Santanter. *Bistua: Revista de la Facultad de Ciencias Básicas,* 3(2): 54-67.

Segnini, S. (2003). El uso de los macroinvertebrados bentónicos como indicadores de la condición ecológica de los cuerpos de agua corriente. *Ecotrópicos* 16(2): 45-63.

Segnini, S.; Correa, I. y Chacón, M. (2009). Evaluación de la calidad del agua en ríos de los Andes Venezolanos usando el índice biótico BMWP. En: *Enfoques y temáticas en entomología.* Arrivillllaga, A., M. El Souki y B. Herrera (eds.). XXI Congreso Venezolano de Entomología. Maracaibo: Sociedad Venezolana de Entomología, 40 pp.

Sermeño Chicas, J.M.; Serrano Cervantes, L.; Springer, M.; Paniagua Cienfuegos, M.R.; Pérez, D.; Rivas Flores, A.W.; Menjivar Rosa, R.A.; Bonilla de Torres, D.L.; Carranza Estrada, F.A.; Flores Tensos, J.M.; González, C.; Gutiérrez Fonseca, P.E.; Hernández Martínez, M.A.; Monterrosa Urías, A.J. y Arias de Linares, A.Y. (2010). Determinación de la calidad ambiental de las aguas de los ríos de El Salvador, utilizando invertebrados acuáticos: índice biológico a nivel de familias de invertebrados acuáticos en El Salvador (IBF-SV-2010). En: *Formulación de una guía metodológica estandarizada para determinar la calidad ambiental de las aguas de los ríos de El Salvador utilizando insectos acuáticos.* Proyecto Universidad de El Salvador (UES)-Organización de los Estados Americanos (OEA). San Salvador: SINAI Editores e Impresores, S.A. de C.V. 43 pp.

Springer, M.; Ramírez, A. y Hanson, P. (2010). Macroinvertebrados de agua dulce de Costa Rica I. *Revista de Biología Tropical,* 58 (Supl. 4): 97-136.

Tabash, F.A. (1988). Utilización de indicadores biológicos para el diagnóstico del estado de contaminación de las aguas lóticas. *Uniciencia*, 5(1-2): 87-89.

Tundisi, J.G. (1988). Management of reservoirs in Brazil. En: *Guidelines of Lake Management.* Vol. 1. Principles of Lake Management. S.E. Jorgensen & R.A. Vollenweider (eds.). International Lake Environment Committee (ILEC) & United Nations Environment Programme (UNEP). Shiga: 155-169.

Umaña, G.; Haberyan, K.A. & Horn, S.P. (1999). Limnology in Costa Rica. En: R.G. Wetzel & B. Gopal (eds.). *Limnology in Developing Countries 2.* International Association of Theoretical and Applied Limnology (SIL). International Scientific Publications. New Delhi: 33-62.

Valencia, E. (2014). *Evaluación de las condiciones biológicas de los cuerpos de agua utilizando los macroinvertebrados bentónicos.* La Paz, Bolivia: Ministerio del Medio Ambiente y Aguas.

Vásquez-Ramos, J.M.; Guevara-Cardona, G. y Reinoso-Flórez, G. (2013). Impactos de la urbanización y agricultura en cuencas con bosque seco tropical: Influencia sobre la composición y estructura de larvas de tricópteros. *Revista de la Asociación Colombiana de Ciencias Biológicas,* 25: 61-70.

Vásquez-Ramos, J.M.; Guevara, G. y Reinoso-Flórez, G. (2014). Factores ambientales asociados con la preferencia de hábitat de larvas de tricópteros en cuencas con bosque seco tropical (Tolima, Colombia). *Revista de Biología Tropical,* 62: 21-40.

Vázquez Silva, G.; Castro Mejía, G.; González Mora, I.; Pérez Rodríguez, R. y Castro Barrera, T. (2006). Bioindicadores como herramientas para determinar la calidad del agua. *ContactoS 60*: 41-48.

World Health Organization (WHO) (2017). *Guidelines for drinking-water quality: Fourth edition incorporating the first addendum.* Ginebra: WHO. 541 pp.

Zamora, H. (1996). Aspectos bioecológicos de las comunidades de macroinvertebrados dulceacuícolas en el Departamento del Cauca. *Unicauca Ciencia,* 1: 1-11.

Zamora, H. (2000). Adaptación del índice BMWP para la evaluación biológica de la calidad de las aguas epicontinentales en Colombia. *Unicauca Ciencia,* 4: 47-59.

Zamora, H. (2002). Análisis biogeográfico de los macroinvertebrados acuáticos epicontinentales (MAE) en el Departamento del Cauca, Colombia. *Revista de la Asociación Colombiana de Ciencias Biológicas,* 14(1): 37-64.

Zamora, H. y Sarria, H. (2001). Calidad biológica de dos ecosistemas lóticos afectados por aguas residuales de rallanderías de yuca mediante la utilización de sus macroinvertebrados acuáticos como bioindicadores, comparando además la aplicación de los índices de Shannon-Weaver y BMWP. *Unicauca Ciencia,* 6: 21-42.

Zúñiga, M. del C. (2009). Bioindicadores de calidad de agua y caudal ambiental: Caso del Río Meléndez (Valle del Cauca, Colombia). En: J. Cantera, Y. Carvajal y L. Castro (Compiladores). *Caudal ambiental: Conceptos Experiencias y Desafíos.* Programa Editorial de la Universidad del Valle, Cali, Colombia: 303-310.

Zúñiga, M. del C. (2010). Diversidad, distribución y ecología del orden Plecoptera (Insecta) en Colombia, con énfasis en *Anacroneuria* (Perlidae). Universidad de la Amazonía. *Momentos de Ciencia,* 7(2): 101-112.

Zúñiga, M. del C. & Cardona, W. (2009). Water quality and environmental flow bioindicators. En: *Environmental Flow: Concepts, Experiences and Challenges.* Cali, Colombia: Del Valle University. pp. 167-198.

Zúñiga, M. del C.; Rojas, A.M. y Caicedo, G. (1993). Indicadores ambientales de calidad de agua en la cuenca del Río Cauca. *Revista de la Asociación de Ingenieros Sanitarios de Antioquia-AINSA,* 13(2): 17-28.

Zúñiga, M. del C.; Rojas, A.M. & Mosquera, S. (1997). Biological aspect of Ephemeroptera in rivers of southwestern Colombia (South América). En: P. Landolt & M. Sartori (eds.). *Ephemeroptera and Plecoptera biology, ecology and systematics.* MTL, Mauron Tinguely y Lachat S.A., Switzerland: 261-268.

Use of New Methodologies in Monitoring and Zoning Water Bodies in Argentina

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In order to illustrate the use of new technologies, it was decided to take a real case that recently took place in Argentina. During the month of April 2017, the city of Villa Carlos Paz, in the Province of Córdoba, was forced to declare an Environmental Emergency due to the advanced state of eutrophication of the San Roque Reservoir, which caused outcrops or cyanobacterial blooms of the genus *Microcistys* spp. (**Figure 1**). This problem, although not new for this waterbody, has achieved an alarming periodicity, which implies a high potential degree of danger for collective health.

Given the recurrent nature of the phenomenon and the impossibility of a short-term solution (in the next few years), it is essential for the municipal government to at least monitor and zone the water mirror and its main tributaries on a regular basis in order to zone the various recreational activities developed in it, in order to prevent health problems for both residents and tourists. In addition to being important for the tourist development of Villa Carlos Paz, one should recall that this reservoir is the main source of drinking water of the second largest population in Argentina (the city of Córdoba with over 1,300,000 inhabitants).

Achieving the objective of developing a system that will make it possible to monitor the state of proliferation of algae and create alerts for severe events that occur as a result, an interdisciplinary approach has been proposed, which will allow the creation of an Experimental Monitoring and Remediation Laboratory that will make it possible to:

- Have information on the status of the reservoir and its tributaries by monitoring the quality and quantity of water from Lake San Roque and its tributaries, as well as adapting methodologies to identify the surface cover of algae, using satellite images and Unmanned Aerial Vehicles (UAV).
- Periodically zone the tributaries and the reservoir based on state indicators as a tool for making quick decisions regarding their use for recreation or navigation. Issuance of early warnings in extreme cases.
- Perform in-situ experimentation to evaluate the mitigation and remediation methods suggested in the local system and determine the costs/benefits of the various mitigation alternatives and control bloom events, which are dangerous for society.

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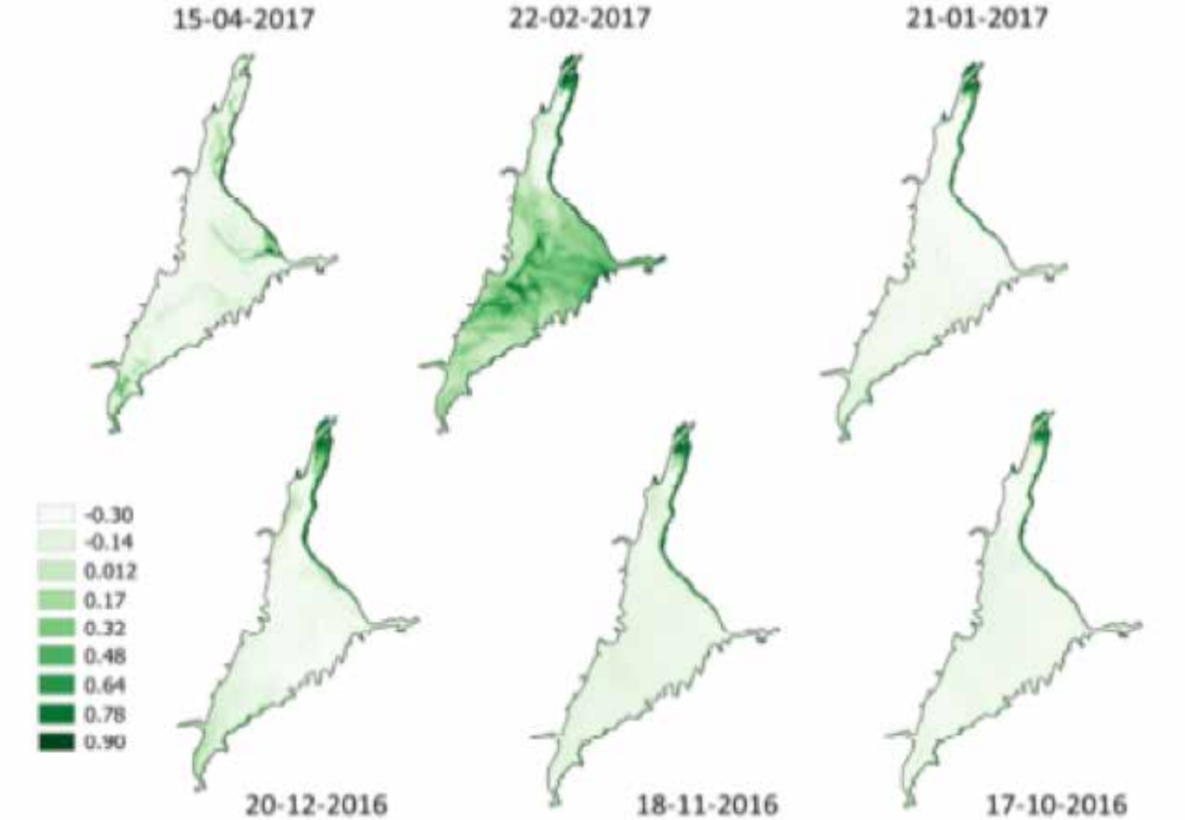
a. Detection of algal blooms using remote sensors

It is possible to monitor algal blooms with biomass measurement, examining the species present. One of the indicators normally used is the concentration of chlorophyll-a. Peak values of the latter for an oligotrophic lake are approximately 1 to 10 µg 1^{-1}, whereas in a eutrophic lake, it can reach 300 µg 1^{-1}. It has been shown by the specialized literature that the temporal and spatial frequencies of conventional water sampling programs are not sufficient to report changes in the biomass of phytoplankton, especially during bloom conditions, when the spatial and temporal variability in the density of phytoplankton is particularly high. This is where remote sensing is a fundamental tool for complementing traditional monitoring and understanding the processes that take place in waterbodies. This involves measuring a property of an object of interest from a distance, such as a sensor on board a satellite or a UAV.

Germán *et al*. (2017) have implemented the monitoring of algal blooms in the San Roque Reservoir through remote sensors, using images obtained through the Moderate Resolution Imaging Spectroradiomenter (MODIS) sensor on board the TERRA satellite, specifically the reflectance product at the top of the atmosphere and images of the Operational Land Imager (OLI) sensor on board the Landsat 8 satellite. The authors can observe various bloom events during the spring-summer 2016-2017 season, and measure their intensity (**Figure 2**).

Figure 1. Entry of the San Antonio River into the body of the San Roque Reservoir, Villa Carlos Paz

Figure 2. Calculation of NDVI for different dates in the San Roque Reservoir



Source: Germán *et al.*, 2017.

b. Estimation of surface velocities with the LSPIV technique and using UAV video

The presence of tracers in a waterbody, whether fluvial or lentic, such as a reservoir or lagoon, makes it possible to use the Particle Image Velocimetry (PIV) procedure. However, because of considerations of scale, this technique, commonly used in laboratories combined with Unmanned Aerial Vehicles (UAV), makes it possible to use a similar methodology on surfaces with an approximate area of 5000 m^2, which resulted in the Large-Scale PIV technique or LSPIV-Large Scale Particle Image Velocimetry.

An example of the use of a combination of these techniques with traditional methodologies is the monitoring of the air diffusers installed in the San Roque Reservoir. Other participants included both the Municipality of Villa Carlos Paz, the Province of Córdoba through the Secretariat of Water Resources, the River Patrol and other agencies, as well as national organizations represented by the National University of Córdoba and its Water Technology Center (CETA) and the National Water Institute and its Center for the Semi-Arid Region (INA-CIRSA).

The objective was to evaluate the efficiency of the diffuser system installed in reducing the eutrophication of the lake, which causes the proliferation of algae in the water mirror. The system comprises seven lines of pipes with small perforations, through which air is injected. They are placed in the deepest zone, one meter away from the bottom. One of the lines is placed in the direction of the gorge while the rest are directed towards the central area of the dike.

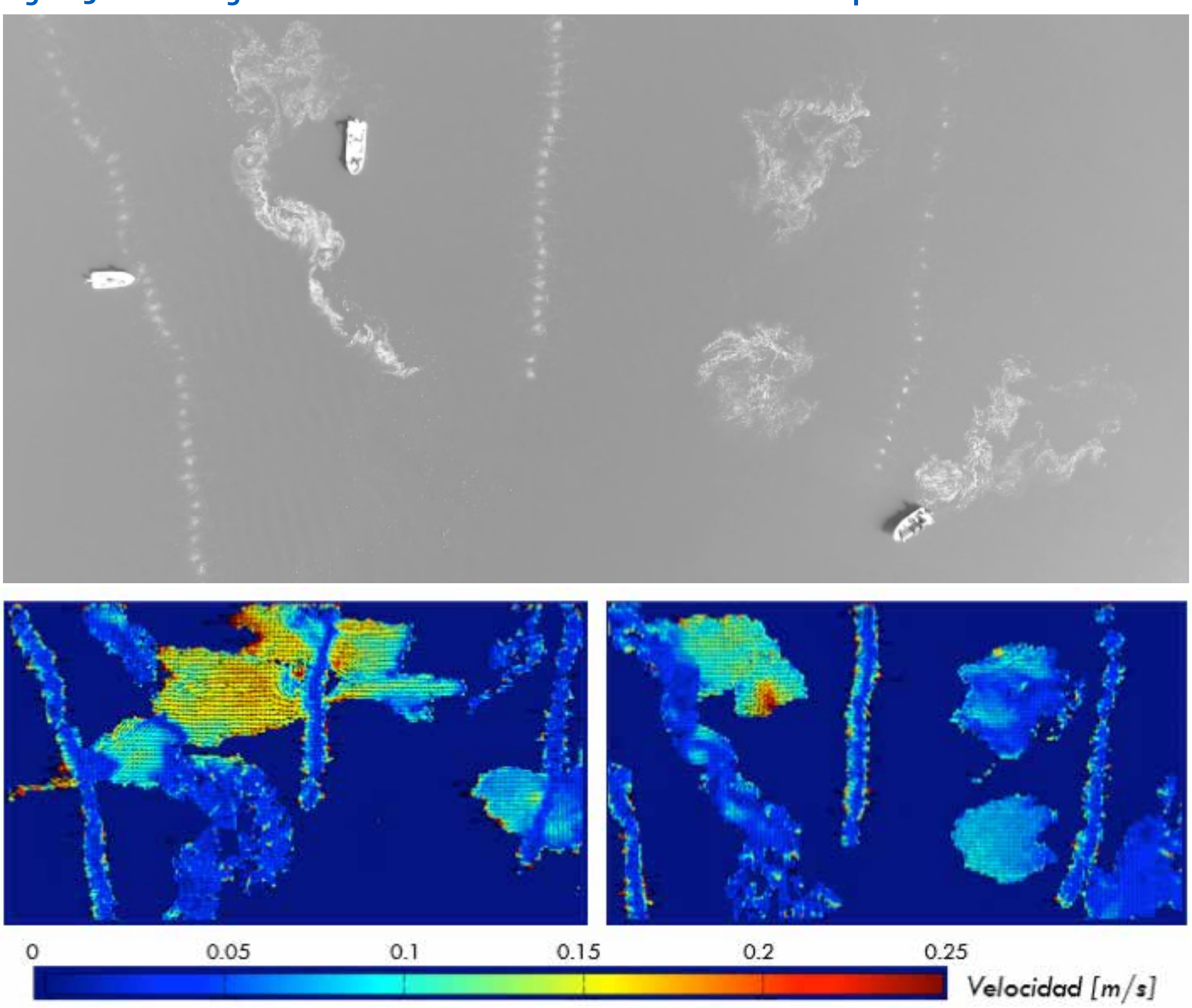
In theory, it is hoped to increase the circulation of water at the bottom of the lake by homogenizing the temperature, which is achieved by breaking the thermal stratification, which is considerably more evident during the spring and summer months.

The mechanism, the only one of its kind used in the country, was installed in 2008. This was the first time that monitoring the effectiveness of the system was proposed. For this reason, technicians and municipal and provincial civil servants were joined by CETA personnel and those from the areas of Limnology and Water Quality, Geomorphology, together with INA-CIRSA support personnel, who used multi-parametric probes to measure the dissolved oxygen, as well as UAV to track the biodegradable tracers thrown onto the water body to determine the flow lines.

References

Germán, A.; Ferral, A.; Romero Arijon, D.; and Bernasconi, I. (2017). Detección y caracterización de floraciones algales en el embalse San Roque a partir de Sensores Remotos. XXVI Congreso Nacional del Agua. September 20 to 23. *Anales de resúmenes de XVI CONAGUA.* Volume I. 1st Edition. Editorial Universitas. ISBN 978-987-4029-23-2

Figure 3. Monitoring the effectiveness of aeration diffusers in the San Roque Reservoir - LSPIV



Argentina

Argentina, which faces a greater challenge regarding water quality than water shortage, must make a great effort to achieve 100% safe water coverage in the shortest possible time and significantly increase urban sanitation, including treatment prior to discharge into the receiving bodies. It is also necessary to increase controls to minimize the generation of industrial pollutants, reduce the use of harmful herbicides and promote agricultural reuse with treated residual liquids.

Potrerillos reservoir in Mendoza, Argentina © iStock

On the subject of water quality in the Americas: Argentina

Luis E. Higa, Emilio J Lentini, José María Regueira, Melina Tobías and Raúl A. Lopardo

1. Introduction

1.1 General framework

In Argentina, the supply of surface water resources is estimated to have an average flow of approximately 26,000 m^3/s (INCyTH, 1994, Pochat, 2005). Since the population reported in the 2010 National Population, Household and Housing Census (INDEC, 2012) was 40,117,096, this would yield an annual amount of renewable water resources per person of approximately 20,500 m^3/inhabitant/year, much higher than the 1,700 m^3/inhabitant/year adopted as water stress or the Falkenmark Index" (White, 2012).

However, this average availability does not accurately reflect the actual supply of surface water in the country, since its geographic distribution is markedly unequal. Thus, 85% of these water resources are located in the Plata Basin, whose surface area is only one third of the mainland area (INCyTH, 1994, Rodríguez *et al*., 2008), while semi-arid and arid areas occupy the remaining two thirds, with the arid zone representing half the total area (SDSyPA, 2002).

Moreover, in order to assess the actual availability, the very different population density in the various river basins must be taken into account (INDEC, 2012). In this respect, key Argentine provinces (such as Tucumán and Córdoba) have lower annual water availability per inhabitant than the water stress limit. Accordingly, groundwater resources are crucial to reducing this deficit, in the arid and semi-arid regions of the country,

In Argentina, the main consumption of water corresponds to irrigation, accounting for nearly 70% of the total water extracted. The remainder is distributed among the other three main uses: human, livestock and industrial consumption. **Table 1** shows the estimated values of the consumption of the water extracted in the country between 1993 and 1997 (Calcagno *et al*., 2000).

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Table 1. Water Extractions by use and source between 1993 and 1997

Water uses	Surface water		Ground water		Total	
	10^6 m³/year	% of total water used	10^6 m³/year	% of total water used	10^6 m³/year	% of use compared to total extracted
Irrigation	18,000	75	6,000	25	24,000	71
Livestock	1,000	34	2,000	66	3,000	9
Municipal	3,500	78	1,000	22	4,500	13
Industrial	1,500	60	1,000	40	2,500	7
Total	**24,000**	---	**10,000**	---	**34,000**	**100**

Source: Calcagno *et al*., 2000.

The implementation of the National Water Plan (PNA), prepared in 2016 by the current Secretariat of Water Infrastructure and Policy (formerly the Undersecretariat of Water Resources),[1] is based on four central areas, namely: i) guaranteeing water for production, ii) ensuring drinking water and sewerage, iii) adapting to climate extremes, and iv) creating matter and energy from biomass will surely modify these proportions (SIPH, 2017).

1.2 Drinking water and sewerage

Basic sanitation (safe water and excreta collection and treatment) is crucial to the health of the population. Around the world, the number of people who lack access to safely managed drinking water totals 2.1 billion, while those without adequate sanitation services amount to 4.5 billion (WHO/UNICEF, 2017). Shortcomings in basic sanitation claim the lives of over five million people annually. Moreover, it is estimated that approximately 2.3 billion people suffer from water-borne diseases. Sixty per cent of deaths of children under 5 due to parasitic and infectious diseases caused by the water they consume.

Water for human consumption is not only essential as drinking water, but also for personal hygiene and food preparation. In addition, in the case of dwellings that have a sanitation system with a connection to mains sewerage or septic tank discharge or cesspits, water is used for keeping toilets clean, and the transportation and removal of excreta. According to the WHO (WHO, 2015), diarrheal diseases are the third leading cause of death among the under 5s. It is estimated that over 340,000 of them die annually due to diarrheal diseases resulting from poor sanitation, amounting to nearly 1,000 children a day. It also attributes the fact that 161 million children suffer from stunting or chronic malnutrition to the lack of water, sanitation and hygiene.

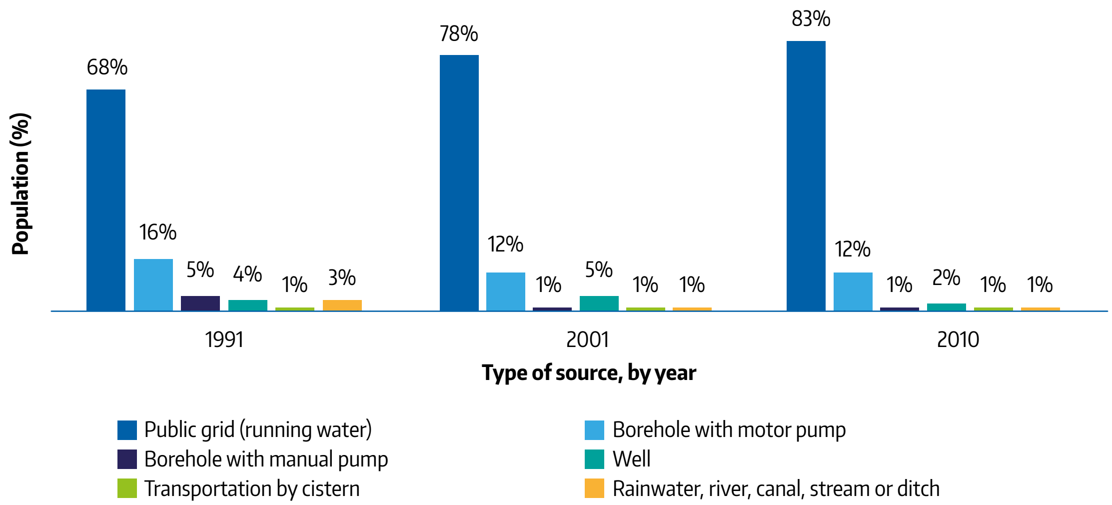
According to the same report, in 2015, 842,000 annual deaths could have been prevented by improving water, sanitation and hygiene. It also notes that deficiencies in water, sewerage and hygiene contribute significantly to diseases such as schistosomiasis, trachoma and helminthiases, affecting more than 1.5 billion people a year. It should be noted that these alarming figures are updated WHO estimates for 2015, in other words, at the end of the period agreed by the countries that signed the Millennium Development Goals.[2]

The crucial importance of water and sewerage in human development has been recognized by the UN through Resolution 58/217, which declares the period from 2005-2015 the International Decade for Action: "Water for life". Moreover, on July 28, 2010, at the United Nations Plenary Session, Resolution 64/292, recognized water and sewerage as a human right.

1. Through the Decree of the National Executive Power No. 174 of March 2, 2018, the agency of the Undersecretariat of Water Resources of the Nation was raised to the rank of Secretariat, and renamed as the Secretariat of Infrastructure and Water Policy.

2. The MDGs were set at the Millennium Summit in 2010, organized by the United Nations Assembly, where -among other things- the vital importance of both services was recognized and by 2015, countries pledged to halve the proportion of people who lacked access to drinking water and basic sanitation or who were unable to afford it.

Figure 1. Drinking water coverage by type of source (2010)



Source: INDEC (2010).

In Argentina, the latest census data available (2010) show national water coverage by public network that reaches 82% of the population, and sewerage coverage that reaches 40%.

Comparing these data with those from previous censuses reveals a continuous increase in both services, with significantly higher values for drinking water than for sewerage (Bereciartúa, 2017).

The estimates made by the SIPH for 2015 show that 39.8 million people of the national total reside in urban areas, 87% of which have access to water through the public network and 58% to sewers. Although reliable statistics regarding the level of wastewater treatment are as yet unavailable, some sources estimate that it is between 15% and 20% of the collected water (PNAPyS, 2017:10). These data at the national level show the current challenge facing the country in terms of water and sanitation expansion, a situation which, as shown in **Figure 2**, is exacerbated by disaggregating coverage in urban and rural areas.

Likewise, the data presented show that the coverage disparity not only occurs in relation to the area (urban/rural), but also in relation to the type of service, with potable water coverage being considerably larger than that of sewers. On the other hand, accessibility to services is not distributed homogeneously among society as a whole, with the most vulnerable social sectors having the lowest coverage levels. This can be seen when comparing the access to services of the population with Unsatisfied Basic Needs (UBN), compared to that of the rest of the population. Whereas in sectors with UBN, water from the network reaches 73% of the population, in the other social sectors it amounts to 85%. The same trend is observed in the case of sewerage service, where coverage values range from 31% to 56% (PNAPyS, 2017:22) (**Figure 3**).

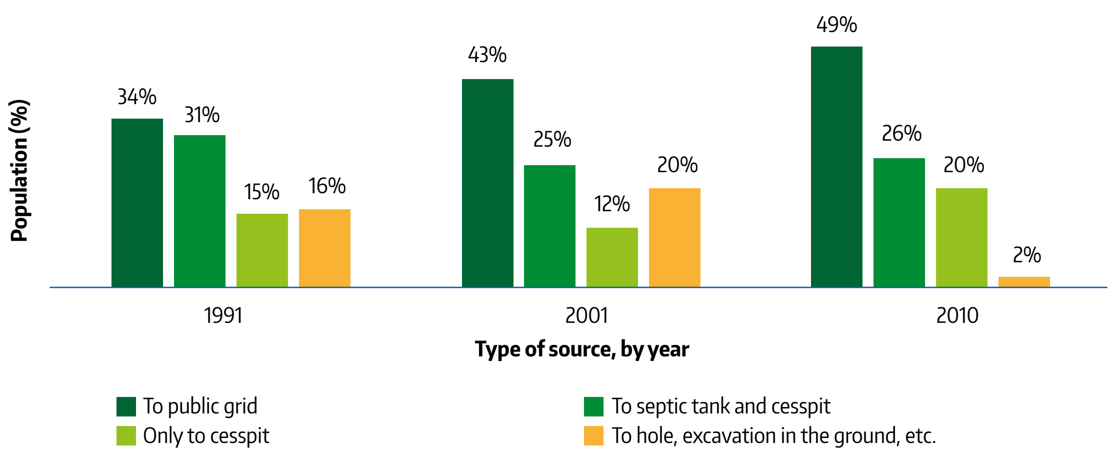
In order to offset the shortage of services facing the country, in 2016, the National Government designed a National Plan for Drinking Water and Sewerage (PNAPyS) (in line with the National Water Plan), whose goals for 2023 include achieving 100% coverage of water supplied by public network and 75% coverage in sewers for the urban population of the country. In order to meet the objectives of the plan, in 2016 the National Directorate of Drinking Water and Sewerage was created within the Secretariat of Infrastructure and Water Policy, responsible for monitoring the goals and systematizing relevant information on the sector (**Figure 4**).

Actions that the Directorate has undertaken during this period include the survey of the Indicators and Performance Indexes for Water and Sewerage Providers, whose aim is to gather relevant information from the providers linked to the identification of the provider, data on the population and accounts or connections, facilities and supplies, production, consumption, management indicators (personnel, meters, unaccounted for water, etc., wastewater treatment, service quality, customer service and economic data (billing, costs, financial statements). So far it has been possible to compile the corresponding information on nine of the leading companies in the country, which account for 54% of the total population, covered at the national level.

1.3 Water for irrigation

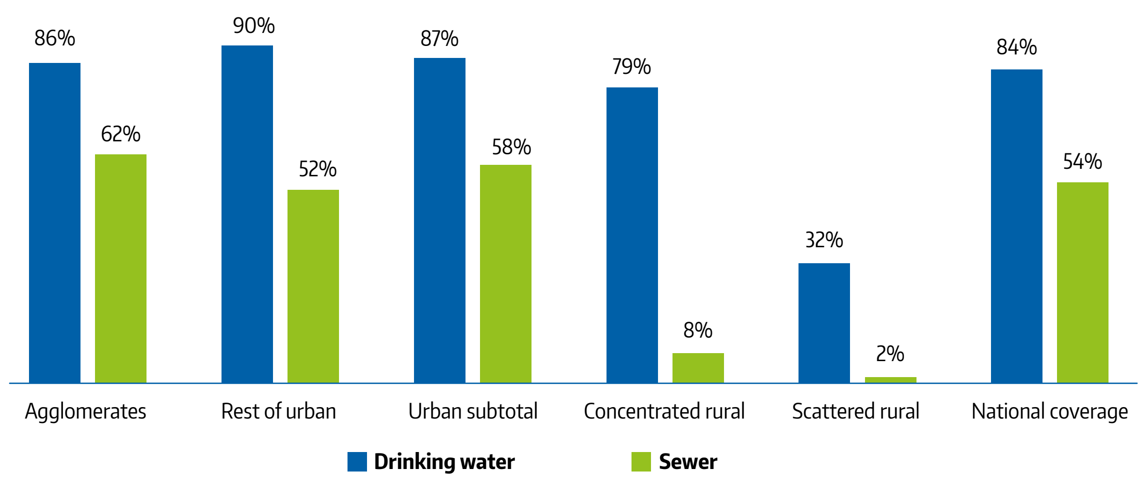
As regards water for irrigation, according to the National Agricultural Census 2002 (INDEC, 2002), the total area used for this purpose in the country was 33,491,480 ha (approximately 19% of total arable land), only 1,355,601 ha of which were actually irrigated (approximately 4%), Mendoza being the province with the largest irrigated area, with a total of 267,889 ha, equivalent to 19.8% of the total irrigated area in the country.

Figure 2. Drinking water coverage by type of source (2010)



Source: INDEC (2010).

Figure 3. Inhabitants with and without potable water and sewerage service in urban and rural areas (2015)



Source : PNAPyS, 2017.

At present, (FAO-PROSAP, 2015), it is estimated that the irrigated area in the country amounts to 2.1 million hectares, 68% of which is located in arid and semi-arid regions. The remaining 32% corresponds to the humid regions, where complementary irrigation is undertaken.

As shown in the aforementioned **Table 1**, approximately 71% of the water extracted is used for irrigation. In 2014 (Aquastat, 2014), the percentage of cultivated area was approximately 14.5%, of which 5.8% (in 2011) was under irrigation. The percentages of water sources used for irrigation are: surface water (57.6%), groundwater (17%) and mixed water (25.4%).

Since agriculture is the most important activity in the country from an economic point of view, involving extremely large areas of land, significant volumes of water are required for irrigation. As this requires increasingly intensive use of agrochemicals (pesticides and fertilizers) to maximize yields, agricultural activity is one of the activities that produces the greatest impact on water resources.

One should also mention the decision of the National State through the Secretariat of Agriculture, Livestock and Fisheries (Ministry of Agribusiness) to design the National Irrigation Plan of Argentina (PNR), to promote the fully sustainable development of irrigated agriculture throughout the country. The goal is to double the current irrigated area to reach 4,000,000 hectares by 2030 and increase the efficiency of water use for irrigation through collective supply projects and private systems, using groundwater. The plan thereby seeks to modify the percentages of the type of water sources used, since 65% of the water for irrigation is currently obtained from surface sources, and only 35% from ground sources (National Water Policy and Federal Directorate-SIPH, 2018a). In other words, greater pressure on available water resources is expected in the future.

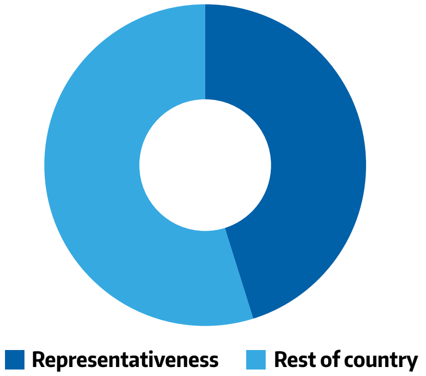
One way to mitigate this situation - which should be evaluated - is to reuse treated household wastewater for agricultural and forestry irrigation (forestry) purposes. However, the positive impacts (use of nutrients and organic matter by crops, which would reduce the use of chemical fertilizers) also entail potentially negative effects, such as the increase in salinity and toxicity in irrigation water, the increase in harmful ions in the soil matrix, and the need for pathogen control in crops.

In this respect, the Guiding Principles of the Water Policy of the Argentine Republic (COHIFE, 2003), in its Water and Environment section (Principle 11) under the title of Water Conservation and Reuse, state the following: “Conservation practices and the reuse of water provide opportunities for resource saving that yield significant social, productive and environmental benefits, which must be shared among the multiple users of this resource. Water recycling through the modification of industrial processes, the reduction of high consumption of drinking water, the reuse of wastewater from urban and industrial centers in other activities, and streamlining water consumption by the sector under irrigation, constitute concurrent lines of action in pursuit of the rational, sustainable use of this resource”.

At present, the main experiences of treated wastewater reuse occur in the province of Mendoza (Calcagno *et al*., 2000), the only province with a specific regulation -Resolution No. 400/2003- for the direct reuse of treated wastewater (General Irrigation Department, 2003). The main treatment plants in that province are those of Campo Espejo and El Paramillo, which process nearly 80% of the domestic wastewater treated in the province. Both use stabilization pond systems.

Approximately 140,000 m^3/day (1.7 m^3/s) are treated at the Campo Espejo treatment plant, which are used to irrigate approximately 2,000 hectares

Figure 4. Representativeness of the data obtained by the Indicators Guide. May 2018



Source: DNAPyS (2018).

through direct reuse (Fasciolo *et al*., 1998) and indirectly irrigate more than 10,000 hectares through the Jocoli canal (Barbeito Anzorena, 2001).

The El Paramillo treatment plant treats approximately 91,000 m^3/day (1 m^3/s), used to water roughly 1,800 ha in the summer (Álvarez *et al*., 2008). According to this information (Fasciolo *et al*., 1998, Barbeito Anzorena, 2001, Álvarez *et al*., 2008), taking the total irrigated area in the province of Mendoza (INDEC, 2007), less than 2% of that area uses irrigation through the direct reuse of treated wastewater.

It should be noted that Resolution No. 400/2003 of the General Irrigation Department of the province of Mendoza, chapter 12 of which establishes the Regulation of Special Restricted Crops Area (ACRE), determines the irrigation methods allowed within ACRE (by plots of land prepared for sowing without slopes, furrows without drainage at the bottom, subsurface irrigation, localized irrigation) and expressly prohibits irrigation by sprinkling, pivots or other similar methods that project effluent into the atmosphere. This Resolution also provides for complementary measures for the protection of workers (use of personal protection elements) and consumers through health education campaigns, restricting reuse to certain types of crops and only allowing them to be harvested four weeks after the last irrigation.

Although much more limited, there are also other experiences of reuse of treated wastewater in other provinces, such as Chubut, Córdoba, Neuquén and Río Negro.

Argentina has very little experience of reusing treated sewage sludge. The most important of these is the production of compost in the treatment plant in the tourist city of Bariloche, in the province of Río Negro. The regulations that apply are Resolution No. 410/2018 of the Ministry of Environment and Sustainable Development of the Nation (currently Secretariat of Environment and Sustainable Development - SAyDS), which repeals Resolution No. 97/2001 of the SAyDS and Resolution No. 264 / 2011 and Appendix I of the National Service of Health and Agri-Food Quality (SENASA) of the Ministry of Agriculture, Livestock and Fisheries of the Nation (currently Ministry of Production and Labor), through its "Regulation for the registration of fertilizers, amendments, substrates, conditioners, protectors and raw materials in Argentina".

1. 4 Main causes of water quality problems

Argentina has several problems related to the quality of surface and groundwater. In the case of surface water, the main problems are associated with the discharge of domestic and industrial wastewater without proper treatment. The main pollutants found are: biodegradable organic matter, macronutrients, bacteria and other microorganisms, and toxic organic and inorganic substances. In groundwater, quality problems are mainly associated with pollutants of natural origin -mainly arsenic and fluoride- or anthropogenic contaminants -nitrates, faecal contaminants, pesticides and various toxic industrial sources (such as organochlorine solvents, hydrocarbons and phenolic compounds).

The main cases of anthropogenic pollution in the country are as follows:

- Pollution in major basins close to highly populated urban centers, such as: Matanza Riachuelo and Reconquista in Buenos Aires, Salí-Dulce in the province of Tucumán, which also impacts on Santiago del Estero (Río Hondo Dam) and San Antonio in the province of Córdoba (San Roque Dam).
- Contamination of aquifers with nitrates due to the infiltration of nitrogenous compounds because of inadequate excreta disposal, owing to the low coverage of the sewage network, intensive livestock farming (feedlots) and the inadequate use of chemical fertilizers in agricultural activities.
- Contamination of groundwater with fuels, caused by losses in storage tanks, as has happened in several points of the city of Buenos Aires and near the Ministro Pistarini - Ezeiza International Airport.
- Surface water contamination has also been reported in the northeast and other parts of the country due to deforestation processes to increase arable land, which increases the speed of runoff and the dragging of surface material from the soil, causing its erosion and the greater contribution of solids to the waters.

These problems are compounded by the lack of unified official information sources to monitor water quality nationwide. This is due to the lack of a single database that brings together measured concentrations of the necessary parameters (TON, reactive P, pH, conductivity and DO) in homogenously distributed sites of Argentina. In this line, since 2018, the Secretariat of Infrastructure and Water Policy has complemented the activities of the Hydrological Network by incorporating the measurement of water quality parameters: oxidizable total nitrogen, nitrite nitrogen, ammonium nitrogen, reactive phosphorus, pH, conductivity and dissolved oxygen (National Water Policy and Federal Coordination-SIPH, 2018b).

1. 5 Objectives and scope of the chapter

The objectives of this chapter are to show the overall legal structure in Argentina for environmental issues in general and water resources in particular, monitoring tools and databases related to water resources, and the main pollutants and their effects on water and soil quality.

2. Water quality authorities and governance

2.1 Legal framework

Argentina Republic has a representative, republican and federal government, with the central government being divided into three branches: executive, legislative and judicial. In accordance with the principles, declarations and guarantees of the National Constitution, each province is governed by its own Constitution. The national territory comprises the Federal Capital, established in the Autonomous City of Buenos Aires and 23 provinces (INDEC, 2012).

The Constitution states that "the provinces retain all the power not delegated by this Constitution to the Federal Government, which they have expressly reserved by special pacts at the time of their incorporation". Article 124 of the constitutional reform of 1994 stipulated that "the original domain of the natural resources existing in its territory corresponds to the provinces", so that they have the power to regulate the relations arising between their use, defense and conservation. Due to the above, when water resources are shared by several provinces, it is necessary to seek agreements between the parties. This role is fulfilled by the Basin Committees and the Interprovincial Basin Organizations (https://www.mininterior.gov.ar/obras-publicas/rh-cuencas.php).

On the other hand, Article 41 of the National Constitution established various guarantees for the inhabitants, relating to the environment and natural resources; explaining that, "It is the responsibility of the Nation to issue the standards that contain the minimum budgets of protection, and of the provinces, to issue those required to complement them, without their altering local jurisdictions".

It should be noted that, to date, there is no national water law. Although several bills for national or federal water law have been submitted, they have not found the necessary support for their sanction and enacted. Thus, in December 2002, Law No. 25688, known as the "Regime of Environmental Management of Waters" was enacted, which establishes the creation, for interjurisdictional basins, of water basin committees. However, its regulation is still pending and it has received criticism because it would take precedence over provincial powers not delegated to the Nation. In any case, the technical groups in the national government are currently working on the definition of the environmental water quality levels.

The main organisms linked to water resource management at the national level are:

- Secretariat of Infrastructure and Water Policy (SIPH) (Former Undersecretariat of Water Resources (SSRH), answerable to the Ministry of the Interior, Public Works and Housing
- National Entity of Sewerage Water Works (ENOHSA)
- Secretariat of Environment and Sustainable Development
- Federal Water Board (COHIFE)
- Federal Environment Board (COFEMA)
- Interprovincial Basin Organizations
- International Basin Organizations

Nationwide, the agency responsible for this sector is the Secretariat of Infrastructure and Water Policy (SIPH) within the Ministry of the Interior, Public Works and Housing. This entity is responsible for intervening in the preparation and implementation of the national water policy and the policy regarding public services for the supply of drinking water and sewerage. As mentioned early, the new DNAPyS operates within the SIPH. At the same time, the SIPH proposes the regulatory framework for water resource management, as well as the organization and strengthening of the drinking water and sewerage sector, and links and coordinates the action of other jurisdictions and agencies in the provision and expansion of these services.

The ENOHSA, created in 1995, as a continuation of an existing body, is responsible for organizing and managing the implementation and instrumentalization of infrastructure development programs derived from the national policies for the sector, as well as the financing allocated for the latter (whether national or international).

The Secretariat of Environment and Sustainable Development is responsible for the National Directorate of Biodiversity and Water and Aquatic Resources, whose main water-related tasks including the compilation of a list of wetlands nationwide, drawing up a glacier inventory (Law 26639), safeguarding protected coastal areas, managing water basins and water quality data collection.

For its part, the Federal Water Council (COHIFE) was formally constituted on March 27, 2003, through the signing of a protocol by the provinces and the nation (http://www.cohife.org.ar/Dfundacionales.html). Its creation constituted a substantial step towards integrated water resource management in the country. The first step has been the establishment of the "Guiding Principles of Water Policy" (COHIFE, 2003). Law 26438 has ratified the Articles of Incorporation of COHIFE, its Organic Charter and the minutes of extraordinary assemblies 1 and 2 of the aforementioned Council.

The Federal Environment Board (COFEMA) is the highest environmental authority in the country. Formally created in 1990 (although the body was only recognized by all the provinces in 1993), it comprises representatives of the Secretariat of Environment and Sustainable Development, the provincial governments and the Autonomous City of Buenos Aires. Its main task is to coordinate the development of environmental policy among all the provinces, and to establish and update the required levels of environmental quality in the various environmental resources throughout the country, including water resources.

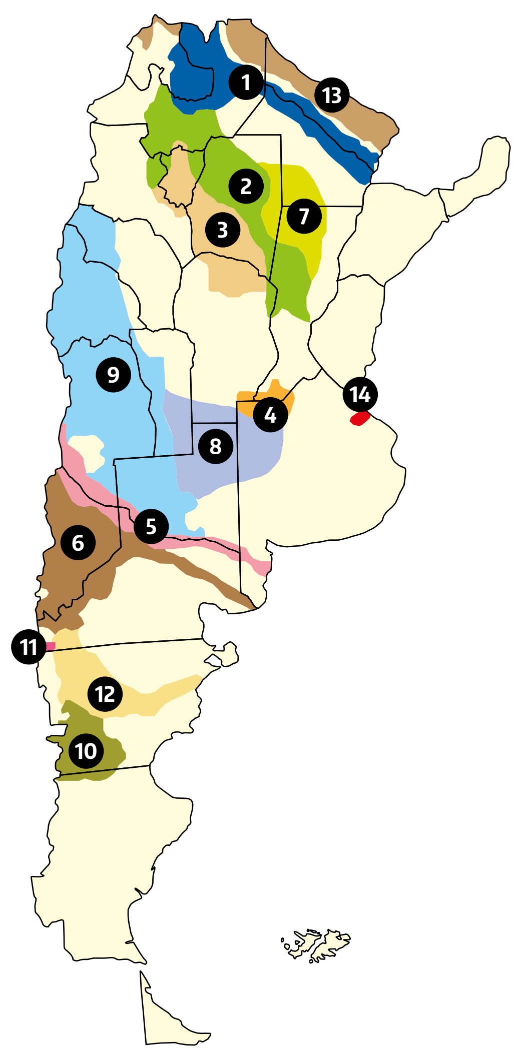
Lastly, in relation to interprovincial and international watersheds, there are various types of agencies responsible for their management: watershed committees, authorities or working groups. Nationwide, there are 16 main organizations.

With regard to regulations for wastewater reuse, including agricultural reuse, there is still no regulation in the country that establishes the minimum budgets applicable to all jurisdictions. Although there are several projects under study in the National Congress, they have yet to obtain the necessary consensus for their approval. (Source: http://www.hidricosargentina.gov.ar/politica_hidrica.php?seccion=2020)

2.2. Monitoring and database

In relation to the databases linked to water resources, within the scope of the SIPH, the National Water Information System (SNIH) (https://www.

Figure 5. Map of the main basin organizations in the country



Source: COHIFE.

mininterior.gov.ar/obras-publicas/rh-nac.php), has been created, whose objectives are to collect, process and store the data obtained by the National Hydrological Network (RHN). Currently, the RHN has 369 stations operated by third parties, most of which record hydrological and meteorological data (https://www.mininterior.gov.ar/obras-publicas/red-hidrologica.php).

Currently, the National Water Institute (INA) is working with the SIPH to evaluate the possibility of adding water quality parameter measurements to 110 of the existing stations, such as pH, temperature, specific conductivity, dissolved oxygen, turbidity, oxidizable nitrogen and orthophosphate phosphorus.

Moreover, Resolution 249-E/2017 of the MAyDS (former Ministry of Environment and Sustainable Development of the Nation, 2017. Actual Secretariat of Environment and Sustainable Development) recently created the Federal Environmental Control Network and the National Network of Environmental Laboratories, which have the support of the United Nations Development Program (UNDP).

3. Main problems impacting water quality in the country

3.1 Eutrophication

Eutrophication is one of the main problems affecting the water quality of Argentinian lakes and reservoirs. In cases of concern at the national level, the phenomenon is mainly due to the discharge into these water bodies of untreated or inadequately treated domestic wastewater. The increase in biological productivity in this type of water bodies creates problems in potabilization systems due to the need to use larger doses of coagulant-flocculants, reducing the flow in filtering systems. Moreover, the growth of cyanophytes increases the risk due to the high concentrations of microcystins and other toxins produced by these organisms, making it even more difficult to purify them.

Two important case examples are the San Roque dam reservoir in Villa Carlos Paz, in the province of Córdoba, and the Paso de las Piedras dam reservoir in Bahía Blanca, in the province of Buenos Aires.

Other examples include the effects on major water bodies in areas of great tourist importance. For example: Nahuel Huapi lake, in Bariloche (in the province of Río Negro), Lácar lake, in San Martín de Los Andes (in the province of Neuquén) and the Río Hondo reservoir, in the province of Santiago del Estero. With respect to the importance of the problem in the aforementioned reservoir of the San Roque dam, suffice it to say that it is the main source of drinking water for the city of Córdoba, the second most important city in Argentina, with more than 1,300,000 inhabitants.

3.1.1. Cyanobacteria

In recent years, Argentina has seen a series of toxigenic cyanobacterial blooms in various river systems, such as the rivers Uruguay, Paraná and Limay, and the reservoirs of Salto Grande, Río Tercero, Yaciretá, San Roque Dam, Los Molinos Dam, Paso de las Piedras Dam. Although Argentina lacks an information system on its impact on the health of the exposed populations, it is known that all cyanobacteria blooms should in principle be regarded as potentially toxic and, therefore, as a public health problem. which requires actions to minimize their negative effect on at-risk communities. Cyanobacteria or blue-green algae belong to the oldest organisms on the planet and share characteristics with other bacteria and eukaryotic algae, giving them unique qualities in terms of physiology, tolerance to extreme conditions and adaptive flexibility. Their natural development has been modified by human action, mainly due to the excessive contribution of nutrients from sewage discharges into freshwater bodies, the increasing use of fertilizers and river endication. This phenomenon has also been exacerbated by climate change, since the increase in the temperatures of the water bodies favors the development of the latter (cyanophytes) as a competitively successful group against the rest of the phytoplankton. The most frequent toxigenic cyanobacteria usually produce several toxins which cause neurological, hepatic, dermal and/or respiratory disorders in humans, both by ingestion, inhalation, and contact with water. There are several studies in Argentina where microcystins (San Roque Lake and Paso de las Piedras Dam) have been detected in all seasons, and even during the winter relatively high concentrations were observed (Ruibal Conti, AL, Guerrero JM, Regueira JM, 2005).

Nevertheless, controlling drinking water supply sources to detect the presence of harmful cyanobacteria and their metabolites is not yet common practice in Argentina, and counting cyanobacteria and measuring toxin concentration in drinking water quality standards has yet to be mandated.

The Ministry of Health of the Nation (2017a) has convened a group of specialists to organize knowledge on the subject and provide the health team with access to information.

3.2 Natural contaminants

In Argentina, the main pollutants of natural origin are: arsenic, fluoride and boron. The first two are mainly found in groundwater and boron in both surface and groundwater. Of these three pollutants, the greatest emphasis will be placed on arsenic due to its importance in the country.

3.2.1. Arsenic

On May 22, 2007, the Secretariat of Health Policies, Regulation and Relations (which is part of the Ministry of Health of the Nation) and the Ministry of Agriculture, Livestock, Fisheries and Food (which is part of the Ministry of Economy and Production of the Nation) decided to modify articles 982 and 983 of the Argentine Food Code (Resolution MSyAS No 494/94) on the physical, chemical and microbiological characteristics of drinking water and carbonated water, through Joint Resolution 68/2007 and 196/2007.The aforementioned Joint Resolution established a concentration of 0.01 mg / l as the new maximum value for arsenic, five times lower than the one valid until then, which was 0.05 mg / l, establishing a term of five years for water suppliers to adapt to the new limit. That deadline expired in May 2012.

That year, the Secretariat of Policies, Regulation and Institutes of the Ministry of Health and the Secretariat of Agriculture, Livestock and Fisheries issued Joint Resolution N° 34/2012 and 50/2012 (B.O. 02-16-12), extending the previous deadlines set until the results of the study are available: “Hydroarsenicism and Basic Sanitation in Argentina - Basic Studies for the establishment of sanitary criteria and priorities in Argentina,” the terms of which were drawn up within the ambit of the Undersecretariat of Water Resources of the Ministry of Federal Planning, Public Investment and Services.

The reason why the Argentine health authorities promoted this modification was that the World Health Organization (WHO), in its *Drinking Water Quality Guide* (third edition), recommends a guideline value for arsenic of 0.01 mg/L, among other reasons, because the International Agency for Research on Cancer (IARC), which is part of the WHO, classifies arsenic as a human carcinogen (Group 1).

In Argentina, as well as in other countries, chronic arsenic poisoning is mainly associated with the presence of this pollutant in relatively high concentrations in drinking water drawn from groundwater, its presence in these waters being mainly of natural origin.

The consumption of arsenic waters leads to various manifestations of Chronic Regional Endemic Hydroarsenicism (HACRE), which in Argentina occurs in an extensive region centered on the southeast of the province of Córdoba, extending to Buenos Aires, Santa Fe, Santiago del Estero, San Luis, Tucumán, La Pampa, Salta, Jujuy, Chaco and a few other provinces. In Argentina, the disease was first described in 1913 by Dr. Mario Goyenechea Over the years, the disease has received different names, until in 1944, “HACRE” and Argentinian Regional Chronic Endemic Hydroarsenicism “HACREA” were proposed, since in this country the disease has its own characteristics, which distinguish it from similar diseases in other endemic areas of the world, such as Mexico, Chile and Taiwan.

Although it is a well defined and well-described clinical pathology, it is still at the stage of epidemiological evaluation in Argentina. In the *Drinking Water Quality Guidelines*, the WHO declared that “... there may be an overestimation of the real risk ...” in determining the carcinogenic risk of arsenic and encourages local studies to be conducted. The WHO recognizes that in order for countries to establish their health priorities regarding drinking water quality, they should take the following priorities into account:

- Ensure an adequate supply of microbiologically safe water and maintain its acceptability to deter consumers from consuming potentially less healthy water.
- Control the main chemical pollutants recognized as causing adverse health effects.
- Manage other chemical contaminants.
- The cost of modifying existing potabilization plants required to be able to comply with such a stringent maximum value.

- The cost of the operation and maintenance of new facilities.
- The time required make the necessary investments.
- The quality control system to ensure such low arsenic concentrations requires human resources, analytical equipment and laboratory facilities unavailable in most small and medium-sized populations.

In the month of March 2017, the call for tenders was launched for the "Contracting of consultancy work on hydroarsenicism and basic sanitation in Argentina", Development Program of the Provinces of the Great North: Drinking Water and Sanitation Infrastructure - BID 2776/OC-AR loans, aimed at consulting firms to work on basic studies for the establishment of sanitary criteria and priorities related to hydroarsenicism, so that studies would begin in the coming months.

3.2.2 Boron

The main natural sources of boron are a small number of borate (boron oxide) minerals, whose main deposits of these minerals are found in the United States (USA), Turkey, Chile, Bolivia and Argentina, in addition to certain boron silicate minerals in China and Russia. According to the Argentine regulations, presented in the National Food Code, a maximum level of boron of 0.5 mg/l is considered admissible for drinking water.

Recent studies have increased knowledge of the presence of boron in the northern area of Argentina. In 2006 and 2007, specialists from the three countries comprising the Pilcomayo river basin decided to undertake intensive and extensive monitoring in the basin, on a monthly and six-monthly basis, respectively, agreeing on the analytical methodologies and the monitoring points in order to have reliable analytical data for its interpretation. Although the data generated by the monitoring carried out focus on heavy metals, high concentrations of boron dissolved in water, of geological origin with maximum and minimum values of between 974 and 235 µg/l respectively were observed (Coppo, Jakomin and Delrieux, 2017).

The maximum level of boron in water intended for human consumption, with conventional treatment at the supply source, for the sample of filtered water, is 260 µg/l. In Argentina, for certain surface bodies of water in the Province of Salta, high boron concentrations attributable to natural geology have been reported. This is the case of the Guachipas River (known as Las Conchas, in its southern section) and its main tributary system with a prediction of water quality parameters with neural networks of boron concentrations of over 10 mg/l.

3.2.3 Fluoride

Fluoride is normally present in natural conditions in groundwater. Fluoride is an essential element, from the point of view of human nutrition, since it is an essential trace element for the formation of bones and teeth. Nevertheless, it is a highly toxic element in which only the quantity of the doses consumed distinguishes beneficial from pernicious benefits. In Argentina, most of the water extracted from the subsoil comes from fine sediments of wind origin, resulting from the Andean orogeny, rich in volcanic glass and responsible for the high content of arsenic and fluorine, among other elements, in surface and groundwater. The concentration of fluoride in groundwater samples analyzed in the central zone of the province of Chaco ranges from 0.05 to 4.2 mg/l (Osicka *et al*., 2002). The National Food Code establishes a maximum amount for fluoride which occurs a result of the average temperature of the area, bearing in mind the daily consumption of drinking water (**Table 2**).

3.3. Agrochemicals

In Argentina, the main economic activities are agriculture and livestock raising. Argentina is the world's third largest soybean, fifth largest corn and eleventh largest wheat producer. Accordingly, it makes extremely intensive use of agrochemicals, particularly phytosanitary products.

The authority that approves and regulates this type of substances is the National Service of Health and Agri-Food Quality (SENASA), which is part of the Ministry of Agribusiness of the Nation, through Resolution SAGPyA 350/1999 and other complementary regulations. The literature (Mazzarella, 2016) shows the classification of phytosanitary products according to the controlling organism, the chemical group of the active principle and acute toxicity (dangerousness). The national laws regulating agrochemicals are:

Table 2. Maximum amount of fluorides based on the average temperature of the area

Average annual temperature	Maximum annual temp	Fluorine content limit	Fluorine content limit
ºC	ºC	Lower (mg/l)	Upper (mg/l)
10,0	12,0	0,9	1,7
12,1	14,6	0,8	1,5
14,7	17,6	0,8	1,3
17,7	21,4	0,7	1,2
21,5	26,2	0,7	1,0
26,3	32,6	0,6	0,8

- National Law N° 18073/1969 Prohibition of substances for the treatment of natural or artificial meadows and certain livestock species.
- National Law N° 18796/1970 Modification of pesticide regime.
- National Law N° 20418/1973 Tolerance and administrative limits of pesticide residues.

These laws mention pesticides that have been banned nationally and internationally, such as organochlorine pesticides. It should be noted that, due to the relative age of these regulations, there is an obvious need to update them in order to incorporate the pesticides currently used (INTA, 2015).

As mentioned earlier, since grain production is the main economic activity in the country, agrochemical products are widely used to increase productivity. In a survey carried out in 2013 by the two main chambers that market these products (CASAFE and CIAFA), a ranking of the 15 most used phytosanitary products was established. The three most commonly used ones were: glyphosate, 2,4 D and atrazine. Among them, glyphosate was by far the most widely used, accounting for 65% of the total volume.

According to national specialists (INTA, 2015), in Argentine soil, the leaching potential (the greater the potential, the greater the mobility) decreases as follows: imazapir> metribuzin> atrazine> glyphosate.

Regarding the frequency of detection of pesticides in the country's watersheds, the compound that has been most frequently detected is atrazine, due to its intensive use (it is the third most widely used pesticide), mobility (potential for leaching) and persistence.

Conversely, glyphosate and AMPA (amino methyl phosphonic acid), which is its main degradation product, are mainly associated with the particulate material dragged to surface waters by runoff and sediments.

Lastly, in the Argentine Food Code (CAA 2012), 11 of the 26 regulated organic compounds, correspond to phytosanitary products.

Despite the above, of the three most widely used pesticides in the country, only 2,4 D has a limit of 100 µg/L. This list also fails to mention the products obtained from degradation.

A key contribution to the study of pesticides in the country is "Children and Environmental Risk in Argentina" undertaken by the Ombudsman and UNDP UNICEF in 2010 (DPN, 2010).

The study seeks to estimate the risk of contamination from pesticides for each department or municipality in the country on the basis of the construction of the Pesticide Pollution Index. The methodology used takes into account the planted area of every crop in every department, the packages of agrochemicals used (herbicides, insecticides and fungicides), their application rates and toxicity, measured through oral LD50 in rats.

The methodology for calculating the Pesticide Contamination Index (PCI) is a simplified version of the Pesticide Contamination Risk indicator,[3] developed by the National Agricultural and Livestock Management Program of INTA (Viglizzo, 2002).

3. INTA developed this indicator together with another 11, with the aim of standardizing an agri-environmental system for monitoring plots of land. The original indicator also includes other factors related to the persistence and mobility of the compounds.

The data analysis shows that eleven departments in the country have high to very high PCI (accounting for 19% of total PCI). At the same time, 73 departments (14%) have an average PCI. It is important to note that the departments in these three categories account for nearly 60% of the accumulated PCI. The two departments with very high PCI values are Guaymallén and Maipú, both in the province of Mendoza. There, the large proportion of the area planted with vegetables (13 and 11% respectively) is crucial, since these are crops with an extremely toxic pesticide package. Additionally, albeit it to a lessers extent, the presence of pip fruit trees also contributes to PCI.

They are followed by Rawson (San Juan) and Florencio Varela (Buenos Aires) where vegetables also make the largest contribution to PCI, as in Pocito and Santa Lucia (San Juan) and La Plata and Escobar (Buenos Aires). The same happens in Córdoba Capital and Gral. Pueyrredón (Buenos Aires), although the presence of potatoes and soya in the value of the index is also significant. In the case of Rosario alone, the toxicity contributed by the cultivation of soybean exceeds that provided by vegetables, due to the high percentage of area planted with this oilseed.

If we observe the districts in the middle category (n=73), we find that soybean is the main crop in the humid pampa, as well as in several departments in the province of Chaco, where the contribution of toxicity by cotton is also significant.

Vegetables also play a key role in other parts of the Buenos Aires conurbation (Moreno, Berazategui, Merlo and Marcos Paz), in Gral. Alvarado - Buenos Aires Province and in departments from other provinces, such as Santa Fe Capital, El Carmen (Jujuy), Lavalle (Corrientes), Colón (Córdoba), Chimbas (San Juan), Yerba Buena (Tucumán), Leandro L. Alem and Cainguas (Misiones) and Junín, San Martín and Tupungato (Mendoza).

Some departments in La Pampa also make a significant contribution to the PCI of forage crops, as well as pip fruits in Gral. Roca (Río Negro) and Tunuyán (Mendoza), and citrus fruits in San Pedro (Buenos Aires) and Yerba Buena (Tucumán).

3.4 Salinization

Salinization and sodification of soils, together with the contamination of soil and water by agrochemicals, are the main environmental problems associated with irrigation, mainly observed in the arid and semiarid regions of the country that account for two thirds of its total surface.

In addition to the characteristics of soils, salinization can be caused by the composition of irrigation water, the rate of application, the method of irrigation used and the water table level.

In the arid and semi-arid regions under irrigation, the main soil deterioration is due to salinization, mainly because of the quality of the irrigation water and the groundwater level. In contrast, in the humid/semi-humid regions of the country, soil affectation is attributed to sodification (Sánchez *et al.*, 2016). It should be noted that high sodium content in irrigation water or soil (sodification) and also the relatively low calcium content with respect to sodium are usually the main causes of drainage deficiencies, as infiltration decreases. Both phenomena reduce crop yield.

Thirty years ago, INTA (INTA, 1986) reported that at the time, the total area irrigated in the country was 15,391,188 ha, 3.8% of which was affected by salinity and 3.6% suffered from poor drainage. This information was also presented by province in the same study.

A recent study by the same institution (Sánchez *et al.*, 2016) determined that the percentage of irrigated area in Argentina affected by these phenomena is 23.5%, 11.0% of which is located in the NOA region, 28, 3% in the Cuyo region, 36% in the Patagonia region and 27% in the Pampas and NEA regions.

Taking into account the implementation of the National Irrigation Plan, promoted by the Argentinian Government in 2015, whose objective is to achieve four million irrigated hectares by the year 2030 (NAP, 2016), the current irrigated area would be doubled, as a result of which soil deterioration will probably increase due to salinization and sodification.

3.5 Wastewater

The volume of wastewater produced by the municipal (urban and urban industry) and industrial sectors (outside cities) is unavailable because there are no centralized, updated databases recording this type of information. The SPIDES database (Permanent Sanitation Information Service), operated by the National Entity of Water Works of Sanitation (ENOHSA), has not been available since 2005.

A preliminary estimate of the volume of municipal wastewater discharged into the sewerage networks can be made by considering that, according to the National Population, Household and Housing Census of 2010, the population amounted to 40,117,096. A total of 48.8% of private homes had a sewer drain, there were 11,317,507 private homes, 12,171,675 households in which number of inhabitants per household was 3.3 inhabitants while 12.2% of households shared housing (INDEC, 2012).

By virtue of the above, adopting an average allocation for the country of 0.3 m^3/(inhab. day) and a reduction factor of 0.8 (80% of the water supplied and used is discharged into the sewage network), the volume of wastewater discharged into the network can be estimated at approximately 1,596 x 10^6 m^3/year (nearly one thousand six hundred million cubic meters per year).

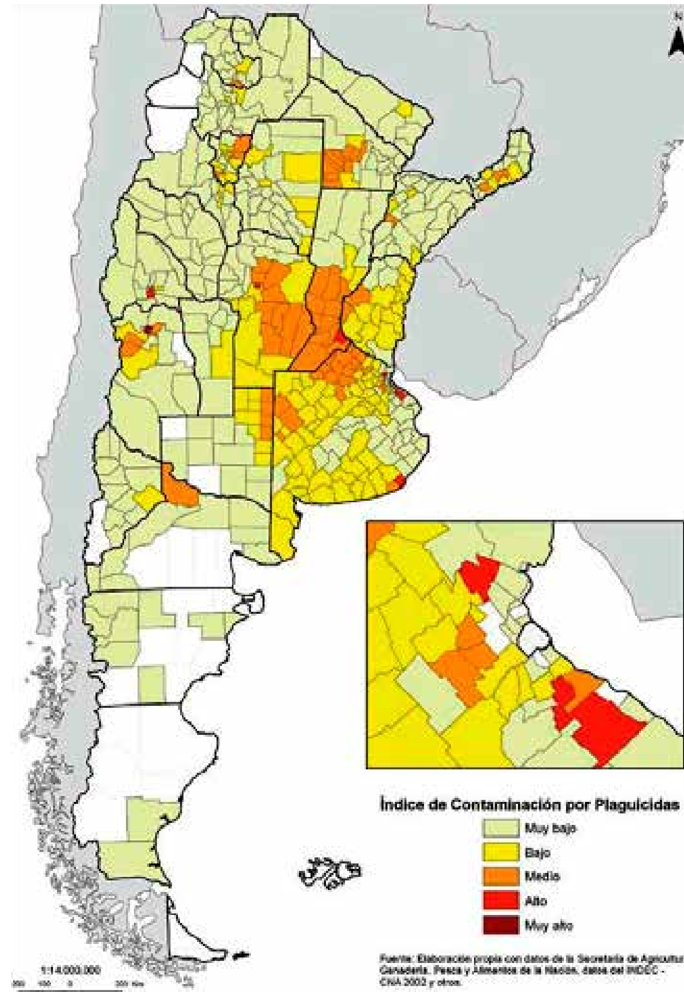
As mentioned earlier, information on the volume of treated domestic effluents, quantity and capacity of municipal wastewater treatment plants and treatment technologies used is unavailable, and there is no information on the status of existing facilities.

Information from 2000 indicates that only 10% of the total volume of domestic effluents collected by the sewerage systems was treated by a purification system (Calcagno *et al.*, 2000). According to the IANAS text (Dagnino Pastore *et al.*, 2012), on that date, the percentage of this type of wastewater treated at sewage treatment plants was in the order of 12%.

The National Directorate of Drinking Water and Sewerage (DNAPyS) of the SIPH is preparing a survey of sewage treatment plants for populations with over 10,000 inhabitants, with the aim of designing policies and investment plans in the wastewater treatment sector that will make it possible to promote efficiency in resource management at the local level and the adequate allocation of resources at the national level, ensuring the greatest impact and sustainability of investments and the protection of the environment and public health, thus fulfilling the goals established through the SDGs for this issue.

The project comprises two stages: the first, to be financed by the TC, will consist of preparing a database and subsequently undertaking a general sectoral diagnosis to define a National Plan for the Rehabilitation of Wastewater Treatment Plants.

Figure 6. Resulting Pesticide Contamination Index



Source: DPN (2010).

The second, financed by the loans in force through the ENOHSA and PBA executing units, consists of implementing the public works defined in the first stage.

The purification plant census that is currently being carried out by the National Directorate of Drinking Water and Sanitation includes facilities that serve populations of over 10,000 inhabitants. The information collected was provided by the provincial contact persons to the Secretariat of Infrastructure and Water Policy (SIPH). To date there are 358 records, as shown in **Table 3**.

The main treatment systems identified were: stabilization ponds (62%), activated sludge (16%) and filter beds (8%). **Figure 7** shows the corresponding disaggregation.

There is very little information on the operating status of all the plants registered. **Table 4** shows the information obtained to date.

The systematization of the information requested by the SIPH will make it possible to have greater accuracy regarding the type of accessibility to each service (drinking water and sewerage), and thereby meet the new requirements of the service ladders proposed by the SDGs.

Table 3. Registered treatment plants by province (as of May 2018)

Province	Plants
Buenos Aires	102
San Luis	50
Santa Fe	35
Mendoza	16
Salta	16
Entre Ríos	15
Chaco	13
Córdoba	13
Río Negro	13
Corrientes	11
Neuquén	10
Jujuy	9
Formosa	9
Misiones	8
Tucumán	7
Catamarca	6
Santa Cruz	6
Chubut	5
La Pampa	4
Santiago del Estero	4
La Rioja	3

Source: DNAPyS (2018).

Table 4. Status of Registered Sewerage Plants (as of May 2018)

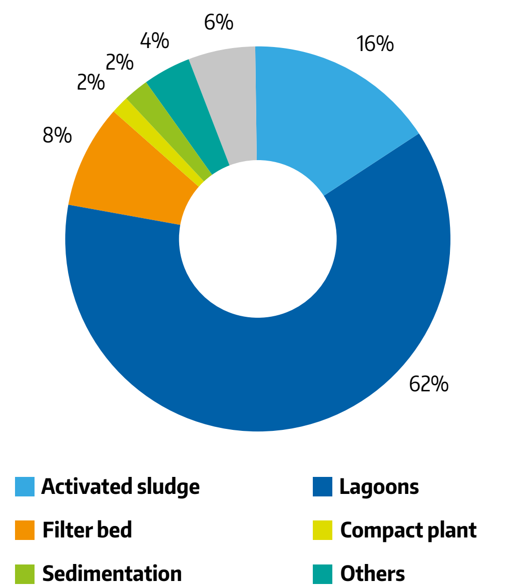
Status	Plantas
Good	39
Average	30
Poor	28
N/A	1
S/D	260
Total	358

Source: DNAPyS (2018).

3.6 Enteropathogens and opportunistic microorganisms in ambient water

Another important element to be highlighted, within the pollution from untreated wastewater, concerns the presence of enteropathogens (primary pathogens and opportunistic pathogens) -bacteria and viruses- and free-living opportunistic microorganisms, which pose a risk to health human through exposure to recreational waters and beach sands. The Ministry of Health has invited a group of specialists to organize knowledge on the subject and submit Guidelines for the Public Health Area (MSN, 2017b), providing information about the potential health risks, due to the exposure of people to enteropathogenic organisms (primary pathogens and opportunistic pathogens) -bacteria and viruses- and free-living opportunistic microorganisms present in freshwater and marine waters, through primary contact of the whole body and in recreational activities (as an extreme example: swimming, immersion, ingestion), as well as contact with beach sands in Argentina.

Figure 7. Type of treatment at plants surveyed. May 2018 (%)



Source: DNAPyS (2018).

3.7 Deforestation

Forests provide valuable services such as ensuring the regular flow of water in rainy areas, helping to offset the destructive effects of floods and drought that occur as a result of treefelling. When forest cover is lost, water flows more quickly into streams, leaving agricultural fields exposed to the possible erosion of productive soils. Thus, cropfields deteriorate and the population must invest in imported fertilizers or cut down more forest areas.

Deforestation is one of the main ecological problems humanity faces, since it causes the transformation of forested territories as a result of man's actions. One of the main causes of deforestation is the advance of the agricultural frontier. This transformation affects the natural dynamics of ecosystems at different scales, both local and global, directly and indirectly affecting water quality by incorporating sediments in riverbeds. In recent years, the advance of the agricultural frontier has replaced large areas of native forest, with the Parque Chaqueño, Selva Misionera and Selva Tucumano Boliviana regions being the most affected. In addition to agricultural crops, forest plantations have also increased their area mainly in the provinces of Entre Ríos, Corrientes and Misiones. In Argentina, the soyization process did not take place in the province of Misiones, where deforestation occurred later. Colonization occurred with the aim of populating the province and consolidating the borders of the country, initially through the exploitation of forest resources by selective felling and the cultivation of yerba mate. Moreover, the existence of large areas with high productivity for agricultural activities, such as the Pampas region, delayed the development of the latter in regions suitable for different uses, such as the case of Misiones with a clear forest vocation (Guerrero Borges, 2012).

Recent studies have been carried out jointly by the Regional Analysis and Remote Sensing Laboratory (LART) of the Faculty of Agronomy of the University of Buenos Aires (FAUBA), the National Institute of Agricultural Technology (INTA) and the Agro-forestry Network Chaco Argentina (Redaf), with the aim of providing up-to-date, accessible and spatially explicit information about the clearings that occurred in the Chaco ecoregion. The results of these studies show that deforestation rates in this region are among the highest in the world and are mainly promoted by the advance of the agricultural frontier. This process has triggered major territorial conflicts that increased the concern and interest in conserving the natural and cultural assets associated with these forests.

The Chaco Seco ecoregion has an area of 787,000 km^2 and includes areas of Northwest Argentina (62% of the total ecoregion), Western Paraguay (22%) and Southeast Bolivia (16%). The climate is semi-arid and seasonal, with high temperatures in summer and low temperatures in winter. Precipitation amounts to 400 annual mm in the central portion and 1000 mm in the East and West ends, and is concentrated in the summer period. The predominant natural vegetation is open forest.

This region possesses high natural biodiversity coexisting with various cultures. Approximately 7.5 million people live in the Chaco Seco, where aboriginal and creole communities reside, mainly engaging in a subsistence economy that includes family farming, extensive grazing, hunting and gathering.

4. Conclusions

This chapter has considered the main conclusions and actions regarded as a priority for preserving water resources (both in quantity and quality) and improving the quality of life of the population.

- The main sources of anthropogenic pollution, both surface and groundwater, are domestic and industrial waste liquids and those produced by agricultural-livestock activity.
- The most important pollutants produced by human activities are: organic matter, microorganisms, macronutrients, pesticides and heavy metals.
- The main pollutants of natural origin are arsenic, fluoride and boron. Arsenic and fluoride are present in groundwater, and boron in surface and groundwater.
- Considering their health importance, observed concentrations and territorial extension, arsenic is the most important pollutant of the three.

Taking into account these aspects, which are highlighted and described in this chapter, the following actions should be prioritized:

- Achieve 100% safe water coverage.
- Significantly increase sewerage network coverage, including treatment prior to discharge into receiving bodies. These treatment systems should include the treatment and disposal of the generated sludge and, when appropriate, the removal of nitrogen and/or phosphorus.
- With regard to arsenic, the study on “Hydroarsenicism and Basic Sanitation” should be implemented in such a way that the health authorities have the necessary information to be able to determine the maximum admissible concentration of total arsenic in the water distributed by the network in the country for a certain level of acceptable risk, and how this should progress to achieve the set limit.
- As for the pollutants generated in industrial activities, minimizing the generation of contaminants (for example, through the recovery and reuse of substances used as raw materials) and the minimization of water use in processes should be promoted.
- According to the specialized national agency (INTA, 2015), Argentina is one of the most inefficient countries in the use of herbicides per ton of grain produced (approximately one tonne of grains per kilogram of herbicide, compared to seven tons in the USA). Using a larger amount of herbicides, without increasing productivity, will negatively impact the environment in general and water resources in particular.
- In order to preserve surface and groundwater sources, it is necessary to leverage the nutrients and organic matter present and use it as a disposal method, and to evaluate and promote irrigation (agricultural reuse) with treated wastewater.

5. Bibliographical References

Álvarez A., Fasciolo G., Barbazza C., Lorenzo F. and Balanza M.E. (2008). Impactos en el agua subterránea de un sistema de efluentes para riego. El Sistema Paramillo (Lavalle, Mendoza, Argentina). *Revista de la Facultad de Ciencias Agrarias.* Vol. XL, N°2, Year 2. Argentina: Universidad Nacional de Cuyo.

Aquastat (2000). *Sistema de Información sobre el Uso del Agua en la Agricultura y el Medio Rural de la FAO.* Argentina: Organización de las Naciones Unidas para la Alimentación y la Agricultura.

Barbeito Anzorena, E. (2001). *Estudio general del caso Campo Espejo del aglomerado Gran Mendoza - República Argentina.* Convenio IDRC – OPS/HEP/CEPIS.

Bereciartua, P. (2017) *Los objetivos de desarrollo sostenible y el plan del agua en Argentina. Avances en materia de agua potable, saneamiento y tratamiento de efluentes.* Serie No 1 – AGUA POTABLE Y SANEAMIENTO. Argentina: Secretaría de Infraestructura y Política Hídrica.

CAA (2012). *Código Alimentario Argentino.* Capítulo XII. Argentina.

Calcagno A., Mendiburo N. and Gaviño Novillo M. (2000). *Informe sobre la gestión del agua en la República Argentina.* Argentina: CEPAL-Organización de las Naciones Unidas.

COHIFE (2003). *Principios Rectores de la Política Hídrica en la República Argentina.* Argentina: Consejo Hídrico Federal.

Coppo, R., Jakomin, M., and Delrieux, C. (2017). *Predicción de parámetros de calidad de agua mediante redes neuronales en la cuenca del Río Pilcomayo Argentina.* Argentina: PROIMCA-PRODECA.

Dagnino Pastore J.M. *et al.* (2012). El estado de situación de los recursos hídricos de Argentina: la cuestión del agua, en: Jiménez Cisneros, B. and Galizia Tundisi, J. (Coordinators), *Diagnóstico del agua en las Américas.* México: Interamerican Network of Academies of Sciences (IANAS) and Foro Consultivo Científico y Tecnológico, AC.

DPN (2010). *Niñez y Riesgo Ambiental en Argentina.* Maiztegui, C. Delucchi, M. (coordinadores). Buenos Aires: Defensoría del Pueblo de la Nación / PNUD / Unicef Argentina / Organización Panamericana de la Salud / Oficina Internacional del Trabajo. 1st edition.

Fasciolo G., Meca M.I. and Vélez O. (1998). Uso de efluentes domésticos para riego en zonas áridas. El Caso Mendoza. Argentina: AIDIS.

FAO-PROSAP (2015). *Desarrollo Institucional para la Inversión: Estudio del Potencial de Ampliación del Riego en Argentina.* (UTF/ARG/017/ARG). Argentina: FAO.

Guerrero Borges, V. (2012). *Deforestación y fragmentación de la selva misionera: estrategias y herramientas para el diseño del paisaje Caso de estudio Colonia Andresito.* Master's thesis in Territorial Sciences. Argentina: Universidad Nacional de La Plata.

INCyTH (1994). *Balance hídrico de la República Argentina: Memoria descriptiva.* Argentina: Secretaría de Recursos Naturales y Ambiente Humano / Instituto Nacional de Ciencia y Técnica Hídricas / UNESCO / Programa Hidrológico Internacional (PHI).

INDEC (2007). *Censo Nacional Agropecuario 2002. Total del país. Resultados definitivos.* Buenos Aires: Instituto Nacional de Estadística y Censos.

INDEC (2012). Censo Nacional de Población, Hogares y Viviendas 2010. Censo del Bicentenario. Resultados definitivos. Serie B N°2. Vol. 1. Buenos Aires: Instituto Nacional de Estadística y Censos.

INTA (1986). *Documento básico para programa de riego y drenaje.* Disposición D.N. Nº 314/85. Argentina. 94 pp.

INTA (2015). *Compiladores varios. Los plaguicidas agregados al suelo y su destino en el ambiente.* Argentina: Ediciones INTA.

Mazzarella D. (2016). *Residuos de productos fitosanitarios: Criterios regulatorios locales e internacionales.* Serie de Informes Especiales ILSI, Vol. IV. Argentina.

Ministerio de Ambiente y Desarrollo Sustentable (2018). Resolución 410/2018. Argentina: Ministerio de Ambiente y Desarrollo Sustentable de la Nación.

Ministerio de Ambiente y Desarrollo Sustentable (2017). Resolución 249-E/2017. Argentina: Ministerio de Ambiente y Desarrollo Sustentable de la Nación.

Ministerio de Salud de la Nación (2017a). *Cianobacterias como determinantes ambientales de la Salud.* Argentina.

Ministerio de Salud de la Nación (2017b). Directrices sanitarias para enteropatógenos y microorganismos oportunistas en agua ambiente. Argentina.

Municipio de Puerto Madryn (2006a). Ordenanza N° 6.301/2006. Reúso de efluentes cloacales tratados. Argentina.

Municipio de Puerto Madryn (2006b). *Reúso de efluentes cloacales tratados.* Anexo I. Argentina.

ODM (2010). *Objetivos de Desarrollo del Milenio. Rendición de Cuentas 2010. República Argentina.* Proyecto PNUD/ARG/04/046. Argentina: Consejo Nacional de Coordinación de Políticas Sociales / Presidencia de la Nación / Programa de Naciones Unidas para el Desarrollo (PNUD).

OMS-UNICEF (2017). "Progress on drinking water, sanitation and hygiene". On-line: https://goo.gl/36nDXz

OMS (2015). *Informe 2015 del PCM: datos esenciales.* Organización Mundial de la Salud.

ONU (2002a). Resolución aprobada por la Asamblea General 55/2. Organización de las Naciones Unidas.

ONU (2002b). *Objetivos de Desarrollo del Milenio.* Objetivo 7: Garantizar la sostenibilidad del medio ambiente. Meta 7.C: Reducir a la mitad, para 2015, la proporción de personas sin acceso sostenible al agua potable y a servicios básicos de saneamiento. Organización de las Naciones Unidas.

ONU (2003). Resolución 58/217. Decenio Internacional para la Acción, "El agua, fuente de vida", 2005–2015. Organización de las Naciones Unidas.

ONU (2010). Resolución 64/292. El derecho humano al agua y el saneamiento. 108a Sesión Plenaria, 28 de julio de 2010. Organización de las Naciones Unidas.

ONU (2017). *Objetivos de Desarrollo Sostenible, 17 Objetivos para transformar nuestro mundo.* Objetivo 6: Garantizar la disponibilidad de agua y su gestión sostenible y el saneamiento para todos. Organización de las Naciones Unidas.

Osicka R, Agullo N.S., Herrera Ahuad C.E., Giménez M.C. (2002). *Evaluación de las concentraciones de fluoruro y arsénico en las aguas subterráneas del Domo Central de la Provincia del Chaco.* Cátedra de Química Analítica General. Chaco: UNNE, Facultad de Agroindustrias.

Pochat V. (2005). *Entidades de gestión del agua a nivel de cuencas: experiencia de Argentina.* Serie Recursos Naturales e Infraestructura N°96. Santiago de Chile: CEPAL-Organización de las Naciones Unidas.

Proyecto PNUD/ARG/12/019 (2015). *Informe Final. Objetivos de Desarrollo del Milenio.* Argentina: Consejo Nacional de Coordinación de Políticas Sociales / Presidencia de la Nación / Programa de Naciones Unidas para el Desarrollo (PNUD).

Rodríguez A. *et al.* (2008). *Plan Nacional Federal de los Recursos Hídricos.* Buenos Aires: Ministerio de Planificación Federal, Inversión Pública y Servicios.

Ruibal Conti AL, Guerrero JM, Regueira JM (2005). Levels of microcystins in two Argentinean reservoirs used for water supply and recreations: differences in the implementation of safe levels. *Environmental Toxicology*, vol. 20, 263-269.

Sánchez R.M. *et al.* (2016). *Evaluación de las áreas bajo riego afectadas por salinidad y/o sodicidad en Argentina.* Argentina: Ediciones INTA.

SDSyPA (2002). *Segundo Informe Nacional para la Implementación de la Convención de las Naciones Unidas de Lucha contra la Desertificación.* Argentina: Secretaría de Desarrollo Sustentable y Política Ambiental de la República Argentina.

SIPH (2017). Guía de Indicadores e índices de desempeño para prestadores de Agua y Saneamiento. Argentina: Subsecretaría de Recursos Hídricos-Dirección Nacional de Agua Potable y Saneamiento.

SIPH (2018a). *Informe del país. Objetivos de Desarrollo Sostenible.* Meta 6.4. Argentina: Dirección Nacional de Política Hídrica y Coordinación Federal.

SIPH (2018b). *Informe País. Objetivos de Desarrollo Sostenible.* Meta 6.3.2. Argentina: Dirección Nacional de Política Hídrica y Coordinación Federal.

Subsecretaría de Recursos Hídricos de la Nación (2017). *Plan Nacional del Agua*. Argentina: SRHN.

Viglizzo, E. F., Pordomingo, A.J., Castro, M.G. y Lértora, F.A. (2002). La sustentabilidad ambiental del agro pampeano. Buenos Aires: INTA. ISBN 9789875210523

White C. (2012). *Understanding water scarcity. Definitions and measurements.* Water Security, Global Water Forum.

Bolivia

The quality of drinking water in **Bolivia** varies greatly, as reflected in the six physiographic provinces in the country. Due to the considerable socio-economic and cultural differences, water quality is analyzed in three areas: urban, which refers to large cities, intermediate cities, and rural, with small, scattered villages and communities. The Authority for the Supervision and Social Control of Drinking Water and Basic Sanitation is the official inspection entity that enforces water quality rules and regulations. These are not always complied with, leading to limited results and varying drinking water quality.

Sajama National Park, with the Parinacota volcano and the Pomerape in the background, Bolivia, © iStock

Drinking Water Quality in Bolivia

Fernando Urquidi-Barrau and Carlos D. España Vásquez

Abstract

The quality of drinking water in Bolivia varies greatly, as reflected in the six physiographic provinces in the country. At the same time, due to the considerable socio-economic and cultural differences, water quality must also be analyzed in three spheres: urban, corresponding to major cities (Central Axis), intermediate cities, and rural, with agricultural communities and small, scattered populations. Drinking water quality is also closely related to local sanitation and the care and protection of water sources. There is a problematic - and unresolved - cycle with wastewater discharges and their treatment in all three areas.

Providing quality water suitable for human consumption is one of the tasks of the government. The state faces the challenge of balancing the supply and demand of water resources, an especially critical challenge due to the overwhelming population increase of certain cities as a result of internal migration in the quest for better life prospects.

The Authority for the Control and Social Control of Drinking Water and Basic Sanitation (AAPS) is the body that monitors the quality of water for human consumption and sewerage. This authority states that efforts are being made to achieve the objective of effective control of drinking water quality in the country through the enforcement of rules and regulations. Unfortunately, they are not always fully enforced in practice.

1. Water availability in Bolivia

It is important to consider the enormous variation in water availability throughout the country. According to the national average, there is an abundant availability of water flow but, due to its unequal distribution, there are many challenges both in regions where scarcity is evident and in others where there are frequent floods in the rainy season. In fact, the four macro-basins in Bolivia show major differences in rainfall: whereas the Amazon Rainforest receives 1,814 mm/year, the Rio de la Plata Macro-basin receives 854 mm/year, the Endorheic Rainfall has an average of 421 mm/year while the smallest of the four, the Pacific Macro-basin, receives an average of just 59.1 mm/year (Urquidi, 2015). Accordingly this poses challenges for water governance.

These hydrological conditions create a higher proportion of surface water use for human consumption, although groundwater use for the same purpose has also increased. In any case, both surface and groundwater require periodic, sustained monitoring and mea-

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surement to control their quantity and, above all, their quality to prevent possible negative effects on the health of the population and the environment.

There is a growing consensus that the best way to guarantee water suitable for human consumption is the protection and control of water sources. To prevent adjacent contamination points, attention should not only be paid to the point where the extraction of surface or underground water is carried out, but also to protecting the micro-basin, the recharge area and the catchment area of the water collection work (see **Figure 1**).

In this context, the detection of possible contamination sources is more visible and evident in surface waters, making it possible to take preventive or corrective measures. Conversely, in the case of groundwater, contamination advances invisibly and studies are required to determine its source and characteristics. Likewise, decontamination processes require long-term actions that may even force a local source of water supply to be abandoned.

In the past five years (2013-2018), the drinking water and sewerage and health sectors have seen the need to protect water resources and health by controlling the quality of drinking water and its sanitation, and wastewater quality, through adequate treatment oriented mainly towards the reuse of water for agricultural purposes.

As can be seen in **Figure 2**, Bolivia has extremely varied relief and an enormous diversity of eco-systems that have allowed the division of large areas or physiographic provinces, with a specific hydrology and hydrogeology, which will be briefly analyzed below. This figure also shows the nine departmental capitals of Bolivia.

From west to east, these are the areas comprising the physiographic provinces:

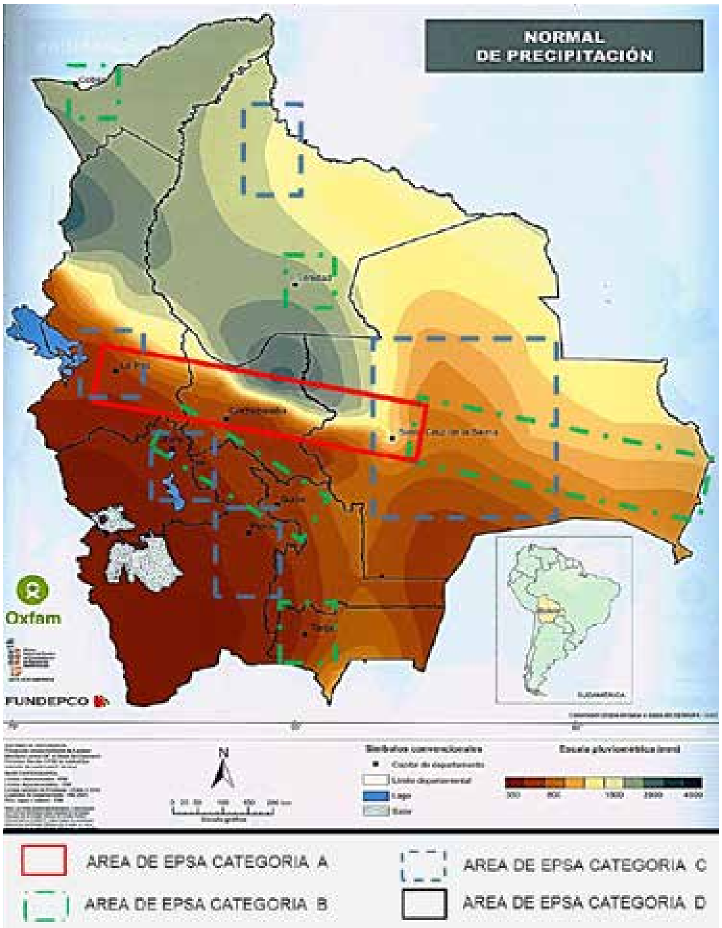
I. Physiographic Province of the Western Andean Cordillera
II. Physiographic Province of the Bolivian Altiplano
III. Physiographic Province of the Eastern Andean Cordillera
IV. Physiographic Sub-Andean Province
V. Physiographic Province of the Chaco - Benianas Plains
VI. Physiographic Province of the Brazilian Shield

Each physiographic province has specific characteristics regarding the availability of the quantity and quality of water in the sources (data obtained from the Surface Water Balance of Bolivia, 1992). However, information on water quality is almost non-existent or unpublished.

I. Physiographic Province of the Western Andean Cordillera

This province, with an approximate area of 43,000 km^2, covers a strip encompassing the entire border with Chile and part of the southern border with Peru. It has desert climate conditions, meaning that it is the least populated area, with limited agricultural development. It has an orographic difference from 3,900 to over 4,500 meters above sea level (masl), with annual precipitation of less than 200 mm. It has a specific flow rate of 0 to 10 lt.s-1.Km-2.

Figure 1. Map of normal precipitation and EPSA areas by category



Most of the inhabitants of this physiographic province are supplied with water through shallow artesian wells dug or built in or around their properties. Another source of water are the high altitude wetlands that store non-saline groundwater and are also used to feed and provide water to their herds of camelids (llamas and alpacas). Water pollution is almost non-existent and limited to former mining works.

II. Physiographic Province of the Bolivian Altiplano

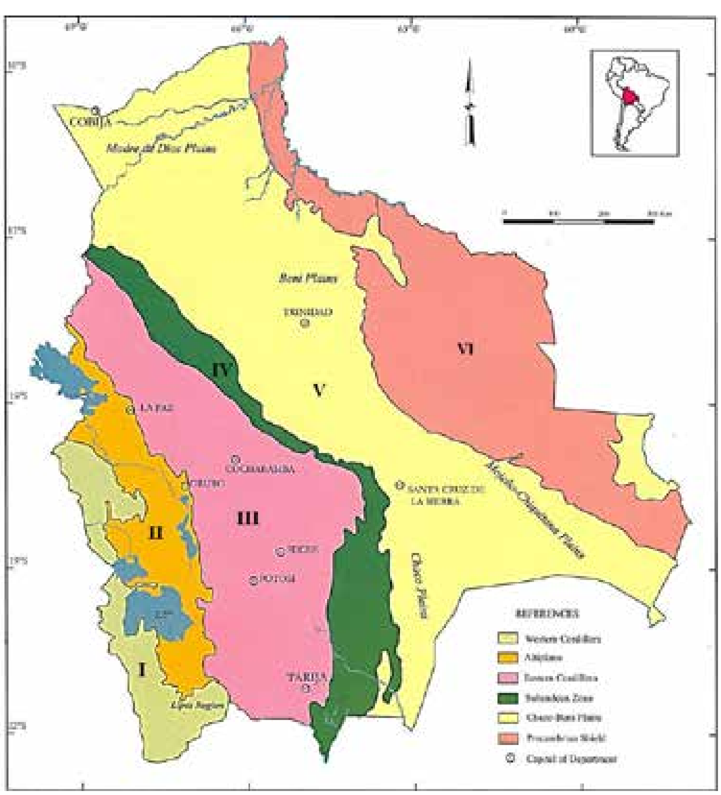
This physiographic province is an intermontane, endorheic basin located at 3,680 and 4,000 meters above sea level and between the two eastern and western Andean Cordilleras. The main hydrological components, Lake Titicaca, Poopó and Uru Uru, are connected by the Desaguadero River. Lake Titicaca is a large freshwater lake in the North Altiplano and the other two are saltwater lakes in the south. They are complemented, at the southern end, by two large, spectacular salt flats: Uyuni and Coipasa. These astonishing natural features developed in several lacustrine episodes related to major climate changes that occurred from the Lower Pleistocene to the Current Quaternary (Argollo & Mourguiart, 1995:360).

The province is approximately 1,000 km long and 120 km wide, with an estimated area of 120,000 km^2. Annual precipitation varies from less than 200 to 800 mm, with a clear downward trend from North to South, as a result of which the climate becomes more arid and salinization more intense (Cardozo, A. *et. al.*, 2004). The Altiplano is subject to the influence of warm air masses from the Amazon basin and cold air masses from the south, which in winter and part of autumn cause cold waves with the condensation of the little humidity that exists. It has a specific flow rate of 0 to 10 lt.s-1.Km-2.

Water quality in the Bolivian Altiplano is extremely variable and has clearly differentiated problems. For example, in the North, thanks to Lake Titicaca, there are no hydrological problems, except for the eutrophication of algae in the bay of Puno (Peru), caused by effluent from untreated wastewater from that city and, to a lesser extent, in the smaller city of Copacabana (Bolivia). At the same time, the surface waters of the Bolivian Altiplano rivers are unsuitable for human consumption because of their high content of heavy metals and natural contamination by arsenic and boron (INTESCA, AIC & CNR, 1993).

The Northern Altiplano is, to a certain extent densely populated; with many smaller towns and cities around Lake Titicaca and along the roads between the cities of El Alto and Patacamaya. There are also important towns in the Central Altiplano with several smaller cities and many smaller, less populated towns. Several mining camps and the capital city of Oruro supply their drinking water needs through groundwater. The Southern Altiplano is the least populated region of the country, and the driest and most arid with less than 100 mm/year of rainfall. Sometimes, it does not receive any rain throughout the year. Lake Poopó has high contamination of 25,000 mg/l of salinity and a high heavy metal content derived from tailings and mine tailings discarded many years ago by state and private mining.

Figure 2. Map of physiographic zones of Bolivia



III. Physiographic Province of the Eastern Andean Cordillera

This physiographic province consists of Andean massifs with heights from 2,000 to more than 4,500 meters above sea level and covers an approximate area of 240,000 Km^2. It has an annual rainfall of 500 to 2,000 mm and a specific flow rate of 50 lt.s-1.Km-2. Five departmental capitals are located in this province, as well as several large and medium-sized cities. The traditional oxides and sulfides mining industry is located in this province and surface flows are highly contaminated by the passive and mining waste from tailings, tailings and others left by the industry (see **Photographs 1a** and **1b**).

A large percentage of the Bolivian population live in the Physiographic Province of the Eastern Andean Cordillera, which is why it has the highest anthropic contamination. However, river pollution is partly compounded by its rapid descent into the plains and high solar radiation due to the height. The main problem is that these waters are used untreated in irrigation projects involving agricultural plots of vegetables and legumes, as well as in the water supply consumed as drinking water in the small towns downstream.

IV. Physiographic Sub-Andean Province

This is a strip with an approximate area of 120,000 Km^2 and an average width of 100 km between the Eastern Andean Cordillera and the Chaco Beniana Plain, with mountains ranging from 500 to 4,000 meters above sea level. It has between 500 and 3,000 mm of rainfall per year and a specific flow rate of 0 to 50 lt.s-1.Km-2. The quality of the water ranges from mediocre to good, and it receives water from the thaws and rains from the eastern flank of the Central and Eastern Andean Cordillera. The capital Sucre and various other large and medium-sized cities located in this province are supplied with surface and groundwater of varying quality, although none of it is completely potable.

Photograph 1a. Contamination from mining waste in the town of Poopó

Photograph 1b. Showing visible contamination in the city of Potosí, towards the Cerro Rico de Potosí

V. Physiographic Province of the Chaco - Benianas Plains

This province has an approximate area of 462,000 km^2 and can be divided into two sectors: the north, with approximately 323,000 Km^2 and the south with approximately 139,000 Km^2. The north sector has almost flat orography with low altitude mountainous areas at a constant height of between 115 and 250 meters above sea level. The south sector is between 250 and 1,000 meters above sea level. Annual precipitation in the north sector varies from 1,600 to 5,000 mm, and in the South sector from 600 to 1,500 mm, and is highly influenced by hot air masses from the Amazon basin. The specific flow in the north is from 10 to 50 lt.s-1.Km-2 and in the south from 0 to 10 lt.s-1.Km-2.

This province is home to the Bolivian Amazon, a region of worldwide interest, because it contains the largest tropical forest and the greatest biological diversity on earth. Hydrographically it covers the Amazon Macro Basin in Bolivia with its basins, sub-basins and micro-basins.

The population of this province depends on riparian water (without quality control) and rainfall for agriculture and the livestock industry. The exception is the city of Santa Cruz de la Sierra, which has good groundwater suitable for drinking, despite being hard water, that supplies a population of over one million inhabitants.

Pollution in the north of the province is largely due to the complex environmental and social problems of the middle and lower basins of Arroyo Bay. Deforestation in the upper and middle watershed has caused the loss of more than half the forest cover of the Arroyo Bay springs. This has facilitated the erosion, sedimentation and clogging of streams, affecting the quality and quantity of water available to the population in the capital city of Cobija (Fundación Natura Bolivia, 2010). Contamination is also caused by the illegal exploitation of gold with the use of mercury, which is found in rivers and is extremely difficult to prevent and eliminate.

Photograph 2. Typical clothes washing on the banks of the Beni River

Photograph 3. Means of transport in the Mamoré river

VI. Physiographic Province of the Brazilian Shield

This large area covers the entire region of the border with Brazil. It has an approximate area of 198,000 Km^2 and an orography ranging from 115 to 250 meters above sea level. Rainfall varies from 1,200 to 1,700 mm per year and its specific flow is from 0 to 20 l. Its limited population is supplied by the numerous river courses that have problems due to the pollution of the waters of the rivers from the cities and Andean population upstream. It has a high risk in terms of health, including malaria, yellow fever and other diseases caused by mosquito bites, as well as those related to ingestion.

In the south of the province, the morphology consists of faulted blocks with gentle slopes. Hydrologically, this area is highly influenced by the Tucavaca Valley through which the Santa Cruz-Puerto Suárez Railroad runs, and is home to the cities of San José de Chiquitos and Roboré (Precambrian Project, 1994).

2. Importance of water quality as a human right

In July 2010, the United Nations General Assembly issued Resolution A/RES/64/292 officially recognizing, for the first time ever, the human right to water and sanitation, emphasizing that both are essential and fundamental needs for the healthy survival of mankind. At the same time, the Plurinational State of Bolivia, Article 16 of the Second Chapter of the new Political Constitution, issued on September 25, 2009, states: *"I. Everyone has the right to water and food". "II. The State has the obligation to guarantee food security through a healthy, adequate and sufficient diet, for the entire population".* On the basis of these two postulates, the state promotes access to drinking water and its sanitation as an essential right of Bolivians.

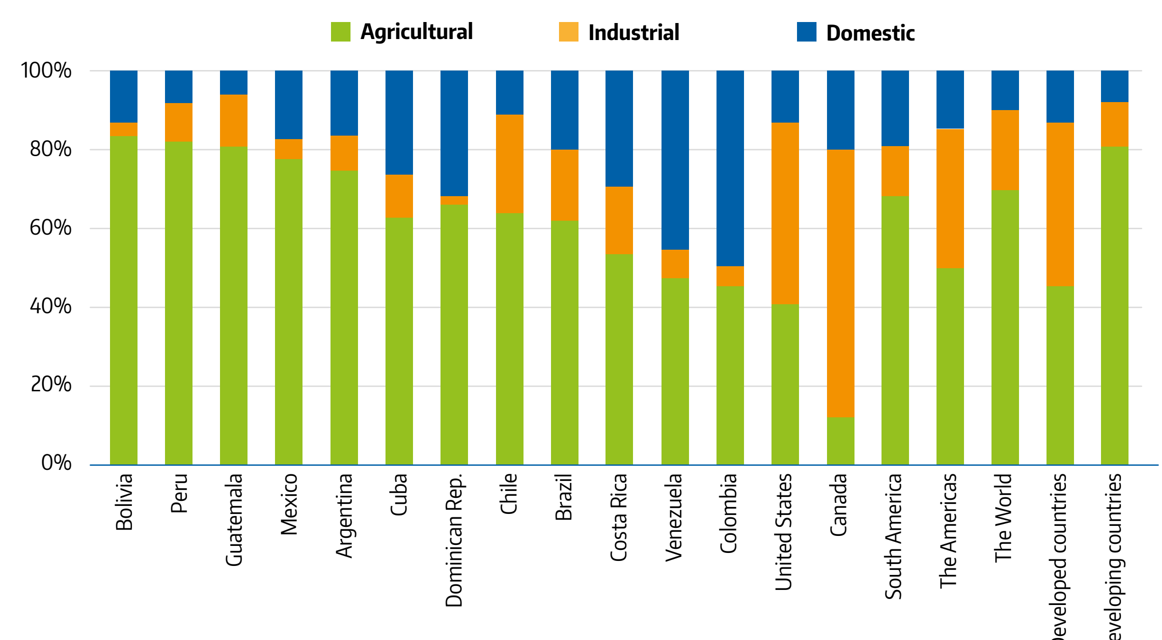
However, the population of the Plurinational State of Bolivia has not optimized the supply of drinking water, including its quality with bacteriological safety, particularly in the rural context. Drinking water and sanitation coverage in the country has steadily increased, but has not kept pace with the growing demand. The quality of drinking water nationwide is low, even compared to the current South American context.

The low coverage and/or lack of sewerage and wastewater treatment plants means that wastewater is discharged into waterbodies with surface flows. This is reflected in the presence of contaminated water in almost all cities and most Bolivian rural towns. This great deficiency is a permanent threat to the health of the population, and results in considerable rates of waterborne diseases with statistical under-recording. Despite this reality, coverage has improved and slowly increased in the past 15 years thanks to state investments and important international assistance in the sector.

Political and social factors have contributed to the weakening of institutions and drinking water service providers, as a result of which they fail to offer optimal drinking water supply service in the nine departments and, above, in areas with intermediate cities and rural communities. It is important to note that during this same period of time, Bolivia has experienced the failure of two privatizations with concessions to foreign private companies and the almost immediate return to the state of these water supply and sanitation services in two major departmental capitals: Cochabamba and La Paz. However, in Santa Cruz de la Sierra, the second most important city in the country, the distribution and private sanitation system is run by a private cooperative with relative success, compared with the systems in other capital and medium-sized cities.

The overriding national concern continues to be the supply of water required for various uses, while overlooking the quality of the latter. In rural

Figura 3. Evaluación global del suministro de agua y saneamiento



Fuente: Global Water Supply and Sanitation Assesment. Report 2012 areas, the greatest use of water is for agriculture (see **Figure 3**), particularly irrigation (see **Table 1**). However, this use fails to consider the quality or the degree of contamination of the water, focusing solely on its chemical condition, in other words, ensuring that it is not salt water (chlorinated and/or sulfated-sodic). For agriculture, surface water from rivers, lagoons and lakes is used.

Water pollution is a major environmental problem because it negatively affects the quality of life of the population. In Bolivia, many rivers and lakes, as well as groundwater near major cities, are beginning to become contaminated. Much of the distribution system for drinking water and wastewater disposal is old and in a state of disrepair. The main barriers or gaps are related to the poor sewage system and wastewater treatment coverage. Garbage and wastewater are therefore released into the flows and bodies of surface water, with little or no treatment, causing their contamination. This causes permanent problems of maintenance and operation for service operators and municipalities.

An additional task is the implementation of excreta and solid waste management. Despite the improvement of the urban solid waste collection system, sanitary and storm sewer systems are affected by the presence of waste mainly dumped in peripheral areas. This is the leading cause of pollution in the country followed by mining and industrial activity. This affects both the water courses and surface storage, and the aquifers used to supply drinking water.

3. Entities responsible for the drinking water and sanitation sector

The responsibility and formulation of policies for the water and sanitation sector corresponds to the Ministry of Environment and Water (MMAyA) comprising three Vice Ministries:

- Vice Ministry of Drinking Water and Basic Sanitation (VAPSB)
- Vice Ministry for the Environment and Climate Change (VMACC)
- Vice Ministry for Water Resources and Irrigation (VRHR)

Unfortunately, MMAyA ministers changed frequently, in some cases in less than a year. The ministerial structure also underwent frequent changes.

The MMAyA, through the Vice Ministry of Drinking Water and Basic Sanitation (VAPSB), is responsible for the formulation and updating of the water resources policy, as well as designing and implementing programmatic approaches, projects and actions to guarantee that the water supplied to the Bolivian population is sufficient and suitable for human consumption.

The VRHR is responsible for contributing to the development and implementation of plans, policies and norms related to Integral Watershed Management. The Authority for the Oversight and Social Control of Drinking Water and Basic Sanitation (AAPS) and the Autonomous Territorial Entities

Table 1. Irrigation systems, users and irrigated area by Department

Province	Systems		Users		Irrigated Area	
	Number	%	Families	%	Hectares	%
Chuquisaca	678	14.5	17,718	8.1	21,168	9.4
Cochabamba	1,035	21.9	81,025	37.6	87,534	38.6
La Paz	961	20.3	54,818	25.1	35,993	15.9
Oruro	372	6.6	9,934	4.6	14,039	6.2
Potosí	956	20.2	31,940	14.7	16,240	7.2
Santa Cruz	232	4.9	5,865	2,6	15,239	6.7
Tarija	550	11.6	15,975	7.3	36,351	16.0
Total	**4,724**	**100.0**	**217,975**	**100.0**	**226,564**	**100.0**

Source: MAGDR – DGSR – PRONAR, 2015.

Table 2. Categorization of EPSA by town

Categories	Population	Territoriality
EPSA Category A	More than 500,000 inhabitants	Main axis of the country (cities of La Paz, Cochabamba and Santa Cruz De La Sierra)
EPSA Category B	Between 50,000 and 500,000 inhabitants	Capital cities, peri-urban areas and other major cities
EPSA Category C	Between 10,000 and 50,000 inhabitants	Intermediate cities
EPSA Category D	Between 2,000 and 10,000 inhabitants	Cities and/or Minor Municipalities
Registers	Less than 10,000 inhabitants or EPSA of Native Indigenous Peasant Constitution	Rural area

Source: Indicadores de Desempeño de las EPSA reguladas, 2016.

(ETA) are the entities responsible for coordinating compliance with these policies.

The national regulation and technical assistance of the Providers of Drinking Water and Sanitation Services (EPSA) is the responsibility of a major government agency: the AAPS. This agency grants licenses for services and establishes the principles to control service quality, based on the Guidelines for the Quality of Potable Water. In turn, it sets service prices, rates and fees. The AAPS also receives complaints and comments from users.

The Drinking Water Quality Guidelines, supervised by the AAPS, are documents that are available to the public, which highlight the link between water quality and health. They state that "diseases related to water pollution have a great impact on the health of people. Measures designed to improve drinking water quality provide significant health benefits". Bolivia draws up its rules and regulations, on the basis of the PAHO-WHO Guidelines, and contextualizes them with the standards and norms of neighboring countries and countries that have socio-economic characteristics similar to those of its population and the same geographical characteristics (ecological macro-floors: Cordillera Andina, Bolivian Altiplano, Valleys and Llano Chaco-Amazónico).

Another of the powers of the APPS is to grant rights of use and exploitation of water sources for human consumption and the provision of drinking water and basic sanitation services to the EPSA, under the Licenses and Registries regime in accordance with the population and territoriality criteria detailed in **Table 2**.

Table 3 shows the type of administration of the EPSAs that operate in the nine departmental capital cities, which the APPS authorized to grant rights of use and exploitation of water sources for human consumption and the provision of drinking water and basic sanitation services. Water supply sources are also given.

The granting of Licenses and Registries by the APPS nationwide seeks to guarantee legal security in the provision of drinking water and sanitation services as well as water sources, infrastructure, investments, including the area of service provision.

The Vice Ministry of Environment, Biodiversity, Climate Change and Forest Management and Development ((VMABCCGDF) is the authority responsible for ensuring the sustainable use of natural resources, including the protection and conservation of the environment, and regulating, preventing and controlling the contamination of surface and groundwater by agrochemicals and industrial waste, limiting deforestation and promoting reforestation.

Bolivia has a Sectoral Development Plan for Basic Sanitation (PSD-SB) that is the sectoral instrument within the National Development Plan (PND). It was updated for the period 2011-2015 and, since then, this plan has been continued. The PSD-SB establishes and lays the foundations for a commitment between the national, departmental and local levels to achieve a substantial increase in access to sustainable drinking water and basic sanitation services, within the framework of Integrated Water Resource Management (IWRM) in the country. It also establishes the participatory and responsible management of the entities providing basic, public and private services, in order to guarantee the sustainability and non-profit nature of the latter. It encourages the participation of users, transparency, equity and social justice, respecting and supporting the community systems of peasant and indigenous groups. It supports the efforts of service providers, including urban, peri-urban and rural EPSAs, Service Provider Cooperatives and Service Providers' Associations, within the framework of the legal guarantees of access to water sources.

The National Service of Support for Sustainability in Basic Sanitation (SENASBA) is responsible for the planning, and to a certain extent the implementation of community development, hygiene promotion and technical assistance to service providers.

In the MMAyA, there is an Executing Unit (EMAGUA), created in 2009, responsible for the execution of all investments in the sectors within the Ministry's sphere of authority. In response to the need to ensure the human right to water, EMAGUA has launched a $215.5 million USD investment program for potable water and irrigation –the "Mi Agua" Project, phases I and II- to achieve the country's millennium goals, drawn up by the Executive Branch of the current government. In parallel, it has launched, particularly in the Departments of La Paz, Potosí and Santa Cruz, irrigation projects in rural areas as a means of strengthening food security, providing water to more than 260,000 families in rural areas, through more than 1,900 water supply projects with 80,579 residential connections and

Table 3. Type of administration and flow offered in Departmental Capital Cities

City	Epsa/Company	Water Supply	Flow (Lt/Sec)
La Paz / El Alto	EPSAS S.A. (Mixed ownership limited liability company. The state has shares in the company)	Eight surface water sources from rain and thawing: Tuni, Condoriri, Huayna Potosí, Milluni, Choqueyapú, Incachaca, Ajan Khota, Hampaturi Bajo. Tilala System (37 Water Wells 90 M Deep)	Range: 2,011-3,000
Santa Cruz	Saguapac (Cooperative)	Groundwater	Range: 347-2,067
	Nine (9) Cooperatives Small Private companies	Surface sources	722
Cochabamba	SEMAPA (Municipal Company)	Surface sources: Escalerani, Wara Wara, Hierbabuenani and Chungara	Range: 191-404
		Groundwater: Quillacollo	462
Sucre	ELAPAS (Municipal Company)	Surface sources: Cajamarca System, including Cajamarca, Safiri, Punilla rivers	80
		Surface sources: Ravelo System, which includes the Ravelo, Mayum Jalaqueri Pears, Murillo And Fisculco rivers.	390
Oruro	Local Aqueduct and Sewerage Service - Sela (Municipal Company)	Surface sources: Sepulturas and Huayña Porto rivers	34
		Groundwater (Challa Pampa, Challa Pampita and Airport)	528
Potosí	AAPOS (Community Company)	Surface sources: San Juan River and 21 Lagoons (Khari, Tarapaya, Irupampa, Illimani, Challuna)	220
Trinidad	COATRI (Cooperative)	Groundwater	118
Tarija	COSAALT (Cooperative)	Surface sources: Rincon, La Victoria, Guadalquivir and San Jacinto rivers	574
		Groundwater	279
Cobija	COSAPCO (Cooperative)	Surface sources: Arroyo Bay	24

Source: Compiled by the authors using data supplied by the service operators.

24,600 hectares with new irrigation, in addition to approximately 2,500 kilometers of pipes with different installed diameters.

Phase III of the "Mi Agua" project, which began in 2013, includes 1,021 new projects (689 involving water and 332 irrigation) with an investment of $163.5 million USD, which mainly included the rural areas of the departments of Cochabamba, Oruro, Chuquisaca, Tarija, Beni and Pando, thus completing projects in the nine Departments of Bolivia.

3.1 Other entities involved

It is important to mention that the Ministry of Health, through the Vice Ministry of Health and Promotion (VSP) and its decentralized entities, is responsible for the work of monitoring the quality of the water supplied by providers. It is in charge of undertaking sanitary surveillance of water for human consumption and epidemiological surveillance of water-borne diseases. It is also responsible for issuing the Declaration of Health Emergency in the event of disasters or risks to public health.

State universities are generators of knowledge and sources of technological innovation. They play a leading role in the Commissions responsible for standardization, given their practical and research experience and the non-occupational migration of their technical-academic staff, as occurs with the technical staff of state entities. They undertake teaching, research and social interaction work in the technical - scientific framework, which provides feedback for the knowledge system specific to the management of water resources from different perspectives. Their potential lies mainly in the provision of water quality laboratory services, wastewater, as well as expertise in the evaluation of water resources, with highly specialized personnel.

4. Bolivian General Regulations on Water Management

At present, there is no framework law in Bolivia related to water resources. The Water Law of 1906 has been severely mutilated and practically repealed. The institutional framework of the sector is defined in the Drinking Water and Sewage Services Act No. 2029 of 1999, revised in 2000 in Law 2066. The current government contemplates the passage of a new law on drinking water and sewerage services, called "Water for Life".

According to the Political Constitution of the State (CPE) of 2009, the Central Government (Executive Branch) of the Plurinational State of Bolivia, at all levels, is responsible for the protection of natural resources and the care of water resources, regarded as strategic for socio-economic development and Bolivian sovereignty.

The institutional framework of the sector is defined on the basis of the following regulations:

- Political Constitution of the Plurinational State of Bolivia, January 2009.
- Law 031, "Andrés Ibáñez" Framework Law on Autonomies and Decentralization , July 2010.
- Decree Law 15629, General Health Law (Health Code), 1978.
- Law 1333, Environmental Law, April 1992.
- National Regulations for the Provision of Drinking Water and Sewage Services for Urban Centers, November 1992.
- Regulation of Law 1333 on Water Pollution, 1995.
- Law No. 2029 on Drinking Water and Sewerage Services.
- Law No. 2029 on Drinking Water and Sewerage Services.
- Law No. 3602 on Drinking Water and Sewerage Services.
- Law No. 300, Framework Law of Mother Earth and Integral Development for Living Well, September 2012.
- Law 2066, Drinking Water and Sewerage Services Law, modifying Law 2029, April 2000.
- Law No. 071, Law of the Rights of Mother Earth, December 2010.
- Supreme Decree 29894.
- Supreme Decree 22965 of November 1991, which creates the National Basic Sanitation Directorate (DINASBA), modified by Supreme Decree 24855 of September 1997, which creates the Vice Ministry of Basic Services, now Vice Ministry of Drinking Water and Basic Sanitation.
- Bolivian Law 512 - Drinking Water (NB 512). 4th revision, October 2010.
- National Regulation for the Control of Water Quality for Human Consumption. Second revision, December 2010.

- NB 495 - Drinking Water-Definitions and Terminology. Second revision, November 2005.
- NB 496-Drinking Water - Sampling. First revision, November 2005.
- NB 689 - Water Installations - Design for Drinking Water Systems, December 2004.
- Technical Regulations NB 689; Design for Drinking Water Systems. Vols. 1 and 2, December 2004.

5. Specific standard for drinking water quality in Bolivia

This section will detail the responsibilities and the follow-up of the norms to determine the water quality offered by the service providers. Since 2004, the Ministry of Services and Public Works, the Vice Ministry of Basic Services and the Bolivian Institute for Standardization and Quality (IBNORCA) have been responsible for enforcing the (NB 512) and its Technical Regulations for Controlling the Quality of Water for human consumption. This responsibility is supervised by the AAPS and was published in the "Performance Indicators of the 2016 Regulated EPSAs".

The fundamental purpose of this regulation is to establish the requirements for the physical, chemical, microbiological and radiological quality of water intended for human consumption. It also establishes the requirements and conditions that must be fulfilled by EPSAs, both public and private. The standard establishes the maximum acceptable values of the various parameters that determine the quality of water supplied for human use and consumption and the methods of application and control.

Photograph 4. Water Quality Laboratory, UMSA, La Paz

Table 4. Minimum Control Parameters

Parameter	Maximum acceptable value
pH	6.5 a 9.0
Conductivity	1,500 µS/cm*
Turbidity	5 UNT
Residual chlorine	0,2 – 1,0 mg/lt
Heat-resistant coliforms	0 UFC/100 ml

* The maximum acceptable value of the conductivity can also be expressed as 1,000 mg Std/l. The temperature parameter must be measured at the sampling point and in the laboratory in time to perform the analyses. It serves as a reference for microbiological analyses and for the calculation of the Langelier Index. Source: NB 512 Regulation.

5.1 Control of the quality of water for human consumption

5.1.1 Water quality control parameters

Bolivian Standard NB 512 establishes the water quality control parameters for human consumption with which EPSAs must comply.

They are grouped according to their technical and economic feasibility into the following categories: Minimum Control, Basic Control, Complementary Control and Special Control.

5.1.2 Minimum Control Parameters

The Minimum Control Parameters for the Quality of Water for Human Consumption EPSAs must comply with are shown in **Table 4**.

5.1.3 Basic Control Parameters

The Minimum Control Parameters for the Quality of Water for Human Consumption EPSAs must comply with are shown in **Table 5**.

5.1.4 Complementary Control Parameters

The Minimum Control Parameters for the Quality of Water for Human Consumption EPSAs must comply with are shown in **Table 6**.

Table 5. Basic Control Parameters

Parameter	Maximum acceptable value
Physical	
Color	15 UCV
Chemical	
Total dissolved solids	1,000 mg/lt
Organic Chemicals	
Total Alkalinity	370 mg/lt $CaCO_3$
Calcium	200 mg/lt
Chlorides	250 mg/lt
Hardness	500 mg/lt $CaCO_3$
Total iron	0.3 mg/lt
Magnesium	150 mg/lt
Manganese	0.1 mg/lt
Sodium	200 mg/lt
Sulfates	400 mg/lt

Source: NB 512 Regulation.

5.1.5 Special Control Parameters

The parameters for the Special Control of the Quality of Water for Human Consumption EPSAs must comply with are shown in **Table 7**. These parameters will be enforced in disaster situations or in special cases according to the history of the source and/or region, or when EPSAs deem necessary.

3.1.6 Minimum number of samples in the network

EPSAs will determine the minimum number of samples in the distribution network, depending on the population supplied, using **Table 8**.

5.1.7 Minimum number of sampling points in the network

For towns with over 5,000 inhabitants, the minimum number of weekly sampling points in the distribution network is obtained by dividing the amount obtained from Table 8 by four. If a decimal result is obtained, it will be rounded up to the next number.

For towns with fewer than 5,000 inhabitants, the minimum number of sampling points will be the one obtained from **Table 8**, and it will not necessary to divide it by four.

Table 6. Complementary Control Parameters

Parameter	Maximum acceptable value
Inorganic Chemicals	
Aluminum	0.1 mg/lt
Ammonia	0.5 mg/lt
Arsenic	0.01 mg/lt
Boron	0.3 mg/lt
Copper	1 mg/lt
Fluoride	1.5 mg/lt
Nitrites	0.1 mg/lt
Nitrites	45 mg/lt
Lead	0.01 mg/lt
Zinc	5 mg/lt
Disinfection byproducts	
Total Trihalomethanes (THM)	100 µg/lt
Pesticides made from Organic Chemicals	
Total pesticides	0.5 µg/lt
Individual pesticides (*)	0.1 µg/lt
Hydrocarbons	
Total hydrocarbons (TPH)	10 µg/lt
Benzene	2 µg/lt
Microbiological Bacteria	
Total coliforms	0 UCF/100 ml
Escherichia Coli	0 UCF/100 ml
Total heterotrophics	500 UCF/100 ml
Pseudomonas aeruginosa	0 UCF/100 ml
Clostridium perfringens	0 UCF/100 ml

* There are pesticides whose individual values may exceed the maximum acceptable individual value or the sum of their individual values may exceed the total maximum value. Source: Nb 512 Regulation.

5.1.8 Location of sampling points in the network

On the basis of the value established in number 5.1.7, EPSAs must locate the sampling points in the distribution network on the basis of the following criteria:

- They must be uniformly distributed and include geographical areas with a risk of contamination, low pressure points, high population density, final sections of pipes.
- They must be representative of the supply area.
- They must be proportional to the population supplied.

Table 7. Special Control Parameters

Parameter	Maximum acceptable value
Inorganic Chemicals	
Antimony	0.005 mg/Lt
Barium	0.7 mg/Lt
Cadmium	0.005 mg/Lt
Cyanide	0.07 mg/Lt
Total Chromium	0.05 mg/Lt
Mercury	0.001 mg/Lt
Nickel	0.05 mg/Lt
Taste and smell	Aceptable
Selenium	0.01 mg/Lt
Organic Chemicals Hydrocarbons	
Toluene	700 µg/Lt
Ethylbenzene	300 µg/Lt
Xylene	500 µg/Lt
Benzo (a) pyrene	0.2 µg/Lt
Radioactive Chemicals	
Global Alpha radioactivity	0.10 Bq/Lt *
Global Beta radioactivity	1.0 Bq/Lt *
Organic Chemicals	
Acrylamide	0.5 µg/Lt
Epichlorohydrin	0.4 µg/Lt
Chloroform	100 µg/Lt

Source: NB 512 Regulation

Table 8. Minimum number of samples of the Minimum Control Parameters (Distribution Network)

Population supplied (inhab.)	Number of samples
≤ 1.000	1/Trimester
1.001 to 2.000	1/ Trimester
2.001 to 5.000	1/Month
5.001 to 10.000	(1c/5,000 inhab)/Month
10.001 to 20.000	(1c/5,000 Inhab)/Month
20.001 to 30.000	(1c/5,000 Inhab)/Month
20.001 to 30.000	(1c/5,000 Inhab)/Month
50.001 to 100.000	(1c/5,000 Inhab)/Month
100.001 to 500.000	(10+1c/10,000 Inhab)/Month
> 500.000	(10+1c/10,000 Inhab)/Month

Source: Nb 512 Regulation.

With these criteria, there is a possibility that the number of sampling points established in the network may be greater than that obtained in section 5.1.7.

5.1.9 Sampling

EPSAs must take water samples in the distribution network according to the number of sampling points obtained in **Table 8** and section 5.1.7. When the number of sampling points established in accordance with 5.1.8 is greater than the number obtained in Section 5.1.7, weekly sampling may be rotated, thus respecting the number of samples defined.

5.1.10 Characteristics of sampling points

Sampling points should be representative of the quality of the water supplied by the EPSAs.

The sampling tap must be located as close as possible to the indoor connection controlled by the EPSAs and free from the influence of an underground storage tank, raised tank or any other type of indoor water storage.

5.1.11 Sampling frequencies

The minimum frequency of sampling per year EPSAs must perform to control water quality is between once a month and once a year, depending on the population served, the control parameters (**Tables 6 to 8**) and the location of the sampling points.

5.1.12. Modification of sampling frequencies

Modification of sampling frequencies is defined as both the increase and decrease in the number of samples to be taken from the parameter (s) under consideration.

5.1.13. Increasing sampling frequencies

EPSAs will proceed with the increase in sampling frequencies, in the following cases:

a. If the result of the analyses obtained, for any parameter, has been exceeded under normal operating conditions or adverse weather conditions.
b. If the result of the analysis has shown that the maximum acceptable value of any parameter has been exceeded, in more than three consecutive samples.

The EPSA must increase the frequency of sampling of the parameter in question, as many times as necessary until the problem has been controlled and the foreseeable risk is low. Otherwise it must suspend the service and report the details of the problem, the solution and/or the actions to be taken to the Competent Authority or the institution delegated by the latter.

5.1.14. Reduction of sampling frequencies

If for two consecutive years the result of the analysis of the parameters of Basic Control and Complementary Control (**Tables 5 and 6**) has values below those established in the NB 512, the EPSAs will be able to process, with the competent authority, the decrease in the frequency of the samplings to be taken in the following year with respect to that parameter. For **Table 5**, this will be done every six months and for **Table 6** it will be done annually. This modification is not applicable to microbiological parameters.

5.1.15 Compliance with quality requirements

The quality requirements EPSAs must comply with for water for human consumption are:

a. In the course of one year, 90 percent (90%) of the results of the analyses corresponding to the compounds that affect the organoleptic, physical and chemical quality of water for human consumption, detailed in Tables No. 1, No. 2 and No. 3 of the Regulation, must not exceed the concentrations or values established in Bolivian Standard NB 512.
b. During a one-year period, the content of thermo-resistant coliforms per 100 milliliters of the total samples taken at the output of the treatment plant, storage tanks and distribution network of the water supply areas must comply with the following: 95% of the samples analyzed should not contain thermo-resistant coliforms.
c. When the concentration of residual chlorine is less than 0.2 mg/l at a terminal point of the network, a sample of water will be taken for bacteriological analysis of thermo-resistant coliforms.
d. The analysis of Special Control parameters, described in **Table 7**, will be conducted by the EPSAs when it is identified, suspected and/or there is a complaint that the source for water consumption has been contaminated.

5.1.16 Mix of water sources

The sampling frequency in the event of the mixing of ground and surface water sources will be determined considering the mixture as surface water.

5.1.17 Periodic control at source

Using the parameters of NB 512, NB 689 and the Water Resources Regulation of Law 1333 as a guide, EPSAs must conduct periodic monitoring of the water quality of the source during the dry season and the rainy season (2 times/ year) and/or in the event of a mixture of sources, in such a way as to control the quality of the water source and/or the efficiency of the treatment process.

5.1.18 Controlling the selection of the source

EPSAs must conduct an analysis of the water quality of the source in accordance with **Tables 5, 6 and 7,** at the start of the activities and/or during the source selection process. In the event that maximum acceptable values are exceeded, EPSAs must consider the costs of treatment and its technological possibilities depending on the values of the parameters, or discard the source to avoid further problems.

5.1.19. Sampling procedure

EPSAs must ensure that the sampling, handling, preservation, transport, storage and analysis of the sample are carried out in accordance with Bolivian Standard NB 496 “Drinking Water – Sampling”. Some of the most important ones are mentioned below:

a. Sampling vials should be prepared according to the procedures used for taking samples.
b. Samples should be representative of the water quality of the source or supply areas when the sample is taken.
c. Samples should not be contaminated during sampling.
d. Samples should be maintained at a temperature and conditions ensuring that there is no natural alteration of the value or concentration, for the measurement or observation for which the sample is intended.

e. Samples should taken by trained, experienced personnel.
f. Samples should be analyzed as soon as possible within a period of no more than 48 hours after being and in keeping with Normalized Procedures.

5.1.20 Standard Analytical Methods

The analytical determinations of the parameters indicated in the regulations must be carried out in accordance with current standards, based on standard analysis methods published by APHA, AWWA, WPCF, ASTM and DIN.

6.Regulation of Drinking Water and Sewerage Services.

The Authority for the Supervision and Social Control of Water and Basic Sanitation (AAPS) was created within the framework of Law No. 2066 of April 1, 2000 and Article 3 of Supreme Decree No. 071 of April 9, 2009. This National Authority regulates water resource administration and management, prioritizing the right of use for human consumption and sanitation, in balance with the environment.

Three major policies are considered: prices and tariffs, b) efficient water use and c) drinking water quality control.

The AAPS is responsible for the control of the quality of water for human consumption in regulated providers, including the records of the sampling and control of the water quality analyses carried out, as well as maintenance work, health inspections and purge programs by regulated providers.

6.1 Regulatory monitoring model

In Bolivia, the regulatory approach is designed to protect the rights of users, because the right of access to drinking water and sewerage should be guaranteed on the basis of the criteria of universality, responsibility, accessibility, continuity, efficiency, efficiency, fair rates and the coverage required to ensure the sustainability of EPSAs.

The regulation of drinking water and sewerage services is supported by a constitutional legal framework, Article 20 Paragraph II of which states that: *The provision of basic services is the responsibility of all levels of the state.* Article 241 paragraph III states that AAPS will *exercise social control over the quantity of public services;* Article 298.II.5 provides instructions on the general water resources and services regime.

Regulatory follow-up is applied through processes of Supervision, Supervision and Control based on current sectoral regulatory regulations on drinking water and basic sanitation, which establishes obligations for both reporting and compliance with conditions in the provision of services EPSAs have in relation to the regulator in their capacity as concessionaires. EPSAs are obliged to have short-term and medium-term service planning, reflected in Five-Year Development Plans (PDQ), Transitional Service Development Plans (PTDS), Contingency Plans (PdC) and Annual Operating Plans (POA).

Actions for the control and follow-up of EPSAs are undertaken through the management of semi-annual and annual reports, in addition to financial statements. On-site inspections are also carried out of the various components of the services provided by EPSAs.

The technical, economic, financial and commercial performance of the EPSA is evaluated and translated into management indicators, which allow observations, recommendations and instructions to the EPSA to correct the distortion factors that negatively affect service provision over time, making it possible to perceive the trends in indicators and the historical performance of EPSAs. In extreme cases of noncompliance or underperformance, the AAPS formulates charges of infringement, which results in the imposition of economic sanctions that may lead to intervention processes when high levels of risk are established in the provision of the service or the revocation of the license. Likewise, performance evaluation contributes to entities in the Sector and Territorial Institutions directing their Policies, Programs and Projects towards the improvement of services based on the fulfillment of goals and institutional objectives.

The APPS has instructed EPSAs to prepare and implement their respective Contingency Plans since March 31, 2016. This is a preventive measure against the potential effects of climate change (drought), designed to mitigate impacts, which could have an impact on the reduction of the availability of water resources to provide the service to the population.

It is necessary to take into account the fact that

Table 9. Regularized EPSAs by Department until the 2016 administration

Department	Licenses	Registers	Temporary Authorization	Total
Cochabamba	64	415	1	480
La Paz	25	438	1	464
Potosí	15	277	1	293
Santa Cruz	65	222	0	287
Chuquisaca	15	205	0	220
Oruro	12	140	0	152
Tarija	9	71	1	81
Beni	5	60	2	67
Pando	1	54	0	55
Total	**211**	**1882**	**6**	**2099**

Source: Indicadores de Desempeño de las EPSA reguladas, 2016.

Table 10. Number of EPSAs with regulatory follow up by Department

Department	Category					
	A	B	C	D	Total	%
Santa Cruz	1	6	24	6	37	52.9
Cochabamba	1	1	0	5	7	10.0
Beni	0	2	3	0	5	7.1
Potosí	0	2	3	0	5	7.1
La Paz	1	1	2	0	4	5.7
Oruro	0	1	2	1	4	5.7
Tarija	0	3	1	0	4	5.7
Chuquisaca	0	1	0	2	3	4.3
Pando	0	1	0	0	1	1.4
Total	**3**	**18**	**35**	**14**	**70**	**100.0**

Source: Indicadores de Desempeño de las EPSA reguladas, 2016.

"El Niño" and "La Niña" phenomena correlate with floods and intense droughts in various regions of the country. In the event of floods, the deterioration of the quality of water at source is critical due to the mixing of drinking water and wastewater. Likewise, during the dry season, there is an increase in the concentration of pollutants in water receiving bodies due to the reduction of contributions that contribute to their dilution.

The most important results expected, after the implementation of the respective Contingency Plans in the EPSAs, are as follows: a) maintain the availability of water resources in acceptable ranges, b) maintain the quality of the water resource within the parameters of the norm, c) provide users with potable water supply in the event of extreme rationing, and d) avoid potential contamination with wastewater, thereby preventing the "crises" experienced in previous years.

As a result of the passage of Supreme Decree DS 726 in 2010, all concessions are transformed into Special Transitory Authorizations, the APPS having made the promotion to license of those with acceptable levels of sustainability but not of those that had risks in service provision, which is why they are only in the Transitory Authorizations category.

6.1.1 EPSAs with regulatory monitoring

APPS regulates 56 EPSAs nationally, three of which belong to category (A), 18 to category (B) and 35 to category (C). Another 14 EPSAs are in the process of being incorporated into the regulatory system (**Table 10**, 2016).

6.1.2 Population with regulatory coverage

Regulatory coverage (RC) results from the relationship between the sum of the populations within the service areas authorized by the APPS and the total population of the country, yielding a result for the 2016 administration of 70.48% coverage (**Table 11**).

6.2 Regulatory coverage-number of connections

The three cities on the central axis of Bolivia are in Category A: EPSAS (La Paz-El Alto), SEMAPA (Cochabamba) and SAGUAPAC (Santa Cruz), and account for 55.1% of the drinking water connections out of a total of 1,237,789 connections nationwide, and 66.3% of sewerage connections out of a total of 772,864 connections nationwide (see **Table 12**).

7. Performance indicators by goals, parameters and optimal ranges

The following are considered performance indicators by objectives, parameters and optimal ranges by category:

7.1 Objective: Reliability of resource

7.1.1 Assessment

Current performance of source: Relationship between the volume actually exploited during the pe-

Table 11. Population under regulatory coverage of the APPS

Year	Population In Area Authorized To EPSAS	Population according to INE*	Regulatory Coverage in %
2013	7.137.735	10.507.789	67.93
2014	7.274.884	10.665.841	68.21
2015	7.524.750	10.825.013	69.51
2016	7.742.791	10.985.059	70.48

Source: Indicadores de Desempeño de las EPSA reguladas, 2016.

Table 12. Regulatory coverage-number of connections

Category	Number of EPSA	Drinking water connections	%	Sewerage Connections	%
Category A	3	682,165	55.1	512,241	66.3
Category B	18	399,222	32.3	201,053	26.0
Category C	35	138,715	11.2	52,338	6.8
Category D	14	17,187	1.4	7,232	0.9
Totales	**70**	**1,237,289**	**100**	**772,864**	**100**

Source: Indicadores de Desempeño de las EPSA reguladas, 2016.

Table 13. Objective – Reliability of Resource

Indicator	Category A	Category B	Category C	Category D
Current performance of source	<85%	<85%	<85%	<85%
Efficient use of resource	>65%	>60%	>60%	>60%
Drinking water samples coverage	100%	95%	90%	85%
Compliance of drinking water analyses undertaken	95%	95%	95%	95%

Source: Adapted from: Indicadores de Desempeño de las EPSA Reguladas, 2016.

riod and the volume authorized by AAPS; optimal value: <85%

Category (A): Central axis, comprising three EPSAs: Cochabamba-La Paz-Santa Cruz; 77.14%-78.07%-88.29%, respectively. Only one EPSA records volumes of more than optimal exploitation of sources.

Category (B): They comprise 18 EPSAs, of which 15 (83%) have values below 85%.

Category (C): This category comprises 35 EPSAs, with 30 showing consistent data, eight (27.6%) exceeding 85% and 72.4% meeting the optimal parameter.

Category (D): This category comprises 14 EPSAs, seven of which report information, three of which exceed 85% and four of which comply with the optimum parameter.

Efficient water use Relationship between the volume of water that actually reaches users and the volume extracted from the source; optimal value: 65%

Category (A): Central axis, comprising three EPSAs: Santa Cruz-La Paz-Cochabamba; 81.56%-60.78%-53.34%, respectively. Only one EPSA presents information on compliance with the optimal indicator. Non-compliance is due to the decrease in volumes of potable water billed during the administration due to the drop in flows in its surface sources owing to the drought that occurred in both cities.

Category (B): This comprises 18 EPSAs, 14 of which (77.8%) comply with the optimal indicator and four of which (22.2%) have values below 60%.

Category (C): This category comprises 35 EPSAs, 26 of which report data, 24 (92.3%) reach the optimal parameter, and two (7.7%) have values below 60%.

Category (D): Of the 14 EPSAs, only seven report information, and comply with the optimal parameter.

Drinking water sample coverage: The indicator measures compliance with the number of samples for water quality monitoring according to the provisions of Standard NB 512 Potable Water-Requirements and its Regulations.

Category (A): Central Axis, comprising three EPSAs: Cochabamba-Santa Cruz-La Paz; 222.48%-183.72%-98.59%, respectively. Those that exceed 100% are EPSAs that take a greater number of samples than specified in the standard.

Category (B): This category comprises 18 EPSAs, 17 of which report records; seven of which (39%) comply with the optimal indicator (>95%), while the remainder fail to comply with the sample coverage indicator.

Category (C): Of the 35 EPSAs, only 25 present information; eight comply with the optimal parameter (>90%), and the remaining 17 fail to comply with the optimal parameter.

Category (D): Of the 14 EPSAs, only six report information and only three EPSAs comply with current regulations (>85%).

EPSAs that fail to comply with the number of samples for the quality control of drinking water established by the indicator are exposing their users to health risks.

Drinking water analysis compliance: This indicator verifies that the water produced meets the quality requirements established in Bolivian Standard NB512 Potable Water-Requirements.

Category (A): Central Axis, comprising three EPSAs: Cochabamba-La Paz-Santa Cruz; 99.12%-99%-95.70%, respectively comply with the water quality standards.

Category (B): 61% of EPSAs comply with the indicator and NB 512. The other 39% must control certain inorganic parameters such as iron and manganese, pH and compliance with residual chlorine standards, and register values below the minimum level of 0.2 mg/l.

Category (C): Only 25 of the 35 EPSAs present information; 12 comply with the optimal parameter (>90%), and the remaining 13 fail to comply with the optimal parameter. EPSAs must improve the quality control of water they provide to users and, if necessary, improve water treatment infrastructure, including disinfection.

Category (D): Of the 14 EPSAs, only six present information on the indicator, three of which comply with the water analysis standards.

EPSAs with drinking water analysis results below the parameter established by the APPS must take specific actions to guarantee the quality and safety of the water they provide to their users, preventing the health risk factors of the water supplied. They must also implement a Potable Water Quality Control Plan, as indicated by the Water Quality Policy.

7.1.2 Objective: Stability of Supply

7.1.3 Assessment

Supply: The indicator reflects the amount of drinking water produced by the EPSA per inhabitant supplied.

Category (A): Central axis, optimal parameter> 150 liters/room/day; Cochabamba-Santa Cruz-La Paz, 161.85-137.53-92.49 Liters/room/day respectively. Cochabamba apparently complies with the indicator, although this result is distorted by the high percentage of physical water losses in its distribution network. Santa Cruz and La Paz fail to exceed the parameter established by the APPS, with the latter having an impact on the decrease in water availability in one of its authorized water sources (Incachaca and Hampaturi Basins), due to the drought aggravated by the effects of climate change.

Category (B): In general, EPSAs in this category comply with the optimal parameter of over 100 liters/inhab./day. However, in most EPSAs, the result achieved is affected by the high rates of water not accounted for in the drinking water distribution network. In some EPSAs, the per capita provision tends to decrease due to the reduction in the supply of its surface sources.

Category (C): Only 24 of the 35 EPSAs comply with the optimal parameter (> 80 L/inhab./day). Only three EPSAs have a capacity of over 190 l/ inhabitant/day above the optimum parameter, attributable to the fact that these EPSAS do not have micro measurement or macro measurement. The volume of water produced is estimated by its operators and unmetered consumption is estimated in the same way.

Category (D): Only six of the 14 EPSAs, comply with the optimal parameter (> 50 L/inhab./day). Non-compliance is due to the reduction of reserves or water flows in their sources with respect to the authorized amount.

Continuity due to rationing: The indicator reflects the degree of continuity of the service considering the number of hours of supply to the user population in the authorized area, according to the capacity of sources and infrastructure

Category (A): Optimal parameter> 20 hours/day; Central axis; Santa Cruz - La Paz - Cochabamba, 24 hours - 22.38 hours -13.06 hours, respectively. The last value of continuity due to rationing is recurrent from previous administrations to 2016, due to water scarcity in its authorized sources, taking into account climate factors and high water losses in the network.

Category (B): Fifty-five per cent of EPSAs comply with the optimal parameter. Operators that supply water using surface sources have continuity limitations on the provision of water for more than 20 hours/day, due to their limited production capacity and storage infrastructure.

Discontinuous service affects the management of distribution. The operation of networks incorporates air, causing the removal of material from the internal walls of the pipes, in addition to the inaccurate measurement of consumption, causing complaints and delayed payment by customers.

Table 14. Objective: Supply Stability

Indicator	Category A	Category B	Category C	Category D
Supply	>150 l/hab/day	>100 l/hab/day	>80 l/hab/day	>50 l/hab/day
Continuity due to rationing	>20 hr/day	>20 hr/day	>12 hr/day	>8 hr/day
Continuity by cut-off point	>95%	>95%	>95%	>95%
Drinking water service coverage	>90%	>90%	>80%	>70%
Sewer service coverage	>65%	>65%	>65%	>65%
Micromeasurement coverage	>90%	>90%	>90%	>80%

Source: Adapted from: Indicadores de Desempeño de las EPSA reguladas, 2016.

Category (C): Twenty of the 35 EPSAs report information and comply with the optimal parameter (>12 hours/day).

Category (D): Only 6 of the 14 EPSAs provide information and meet the optimal parameter (>8 hours/day).

Continuity by cut-off point: Continuity by cut-off point is the expression as a percentage of continuity by rationing. And the cut-off point is established as a rationing measure, although it is also due to infrastructure maintenance.

Drinking water service coverage: The indicator establishes the percentage of the population supplied with potable water service with household connections and registered in the EPSA.

Category (A): The Central Axis, La Paz-Santa Cruz-Cochabamba have coverage of 97.52%-96.91%-66.67% respectively; the optimal parameter being (>90%).

Category (B): Sixty-seven per cent of EPSAs comply with the optimal parameter (>90% of coverage). EPSAS are not meeting requirements in peri-urban areas, due to infrastructure limitations and water supply.

Category (C): Only 22 of the 35 EPSAs comply with coverage >80%, and lack the financial resources to expand their water networks.

Category (D): 13 EPSAs present information, 12 of which comply with the optimal coverage parameter (>70%).

As a result of the new government policies, EPSAs must implement new investment projects to achieve the proposed coverage, especially in peri-urban areas, in coordination with their local governments.

Sewerage Coverage: The indicator measures the percentage of the population served with a household connection to the sewerage service.

This indicator is included, since it is directly related to the quality of water in the receiving bodies that can be or are potential sources of supply for downstream populations, in addition to establishing basic sewerage conditions.

Category (A): Central axis; Cochabamba, La Paz and Santa Cruz have values of 84.08%-70.77%-60.93%, respectively. In the first two cases, they comply with the optimal parameter (> 65%).

Category (B): Only 5 of the 18 EPSAs show compliance results; the rest do not attend their peri-urban areas due to infrastructure and financial limitations.

Category (C): Only 20 the 35 EPSAs provide sanitary sewer service and only four of these comply with the optimal coverage parameter (> 65%).

Category (D): Seven of the 14 EPSAs provide sewerage service and only four comply with coverage > 0.65%.

It is essential for EPSAs that fail to provide sanitary sewer services to implement projects to increase their coverage.

Micromeasurement coverage: The indicator determines the percentage relationship between the number of household connections with a meter in their homes and the total number of EPSA users.

Category (A): The Central Axis, La Paz, Santa Cruz and Cochabamba have values of 100%, 99.75% and 86.85%, respectively. The indicator should be > 90%. The city of Cochabampa has a high percentage of unaccounted for water.

Category (B): Fifty-six per cent of EPSAs meet the optimal parameter; the rest fail to comply with the Efficient Water Use Policy.

Category (C): Only 30 of the 35 EPSAs have micro measurement information and 24 comply with the parameter (> 90%).

Category (D): Only 9 of the 14 EPSAs have micro measurement of over 80% and only six comply with 100% micro measurement.

7.2 Objective: Environmental Protection

7.2.1 Assessment

Incidence of groundwater extraction: Detailed information is unavailable in the publication "Performance Indicators of Regulated EPSAs".

Wastewater Treatment Index: The indicator shows the percentage relationship between the volume of wastewater treated and the total estimated volume of wastewater produced in the water service area, in order to minimize impacts on the environment and the health of the population.

Category (A): The Central Axis, La Paz, Santa Cruz and Cochabamba have values of 100%, 99.75% and 86.85%, respectively. The optimal parameter is set as >60%.

The low percentage in the case of the city of La Paz is due to the lack of a treatment system; 27.49% corresponds partly to the City of El Alto, a city adjacent to La Paz.

Category (B): Seven of the 18 EPSAs have sewage treatment plants, six of which comply with the indicator.

Category (C): only 13 of the 35 EPSAs have treatment plants, 10 of which comply with the optimum parameter.

Category (D): No data are available, but it is assumed that there is no wastewater treatment.

Quality control of waste water: The indicator shows the relationship between the number of satisfactory analyses of treated wastewater and the total number of samples analyzed.

Category (A): Central axis; Santa Cruz, La Paz and Cochabamba have values of 91.93%, 60.48% and 59.42%, respectively, with an optimal indicator of (>95%), which is not complied with.

Category (B): Only 2 of the 18 EPSAs comply with the optimal parameter of satisfactory analyses.

Category (C): Only 8 of the 13 EPSAs have treatment plants, and none of them meet the optimal parameter (>95%).

No information on category D is reported. The absence of treatment systems is assumed.

7.3 Proper handling of the drinking water and sewerage system

7.3.1 Assessment

Installed capacity of drinking water treatment plant: The indicator shows the relationship between the treated volume of water in potabilization plants with respect to the installed capacity of the potabilization system.

Table 15. Environmental Protection

Indicator	Category A	Category B	Category C	Category D
Incidence of raw groundwater extraction	<85%	<85%	<85%	<85%
Wastewater Treatment Index	>60%	>60%	>50%	>50%
Wastewater Quality Control	>95%	>95%	>95%	>95%

Source: Adapted from: Indicadores de Desempeño de las EPSA reguladas, 2016.

Table 16. Appropriate handling of the Water and Sewerage System

Indicator	Category A	Category B	Category C	Category D
Installed capacity of drinking water treatment plant	<90%	<90%	<90%	<90%
Installed capacity of drinking water treatment plant	<90%	<90%	<90%	<90%
Drinking water service coverage	>95%	>95%	>95%	>95%
Water index not accounted for in production	<5%	<10%	<10%	<15%
Water index not accounted for in production	<30%	<30%	<30%	<30%
Density of faults in potable water pipes	20-50 Faults/100 km	20-50 Faults/100 km	20-50 Faults/100 km	20-50 Faults/100 km
Density of faults in potable water pipes	20-50 Faults/1000 connections	20-50 Faults/1000 connections	20-50 Faults/1000 connections	20-50 Faults/1000 connections
Density of faults in wastewater pipes	2-4 Faults/100 km	2-4 Faults/100 km	2-4 Faults/100 km	2-4 Faults/100 km

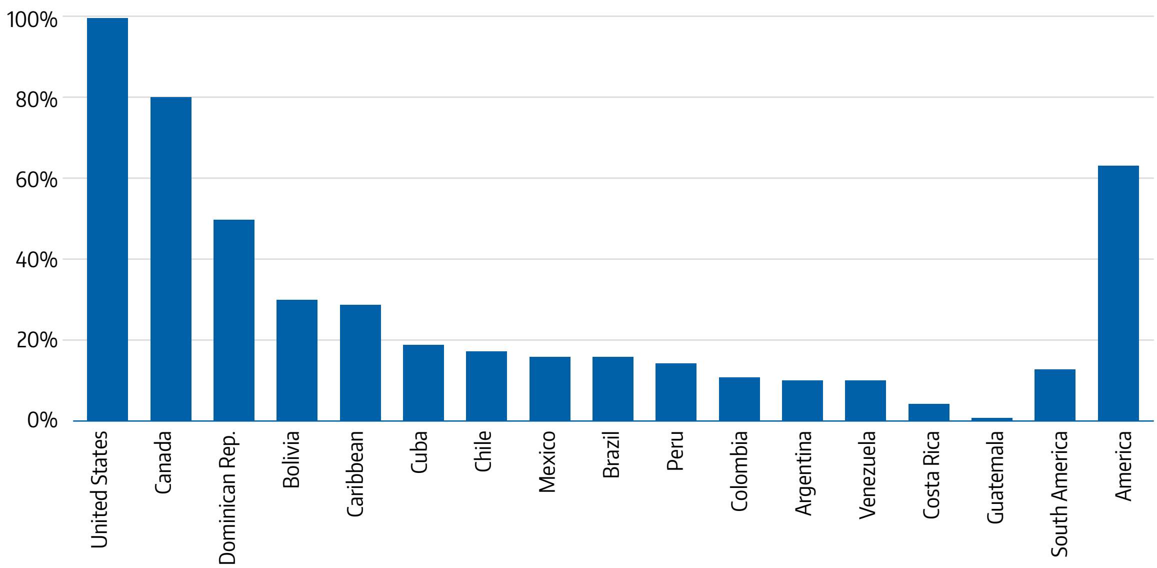
Source: Adapted from: Indicadores de Desempeño de las EPSA reguladas, 2016.

Table 17. Wastewater Treatment Volume by Capital City (in l/sec)

City/Year	2008	2009	2010
La Paz / El Alto	s.d.	s.d.	s.d.
Santa Cruz	1,009	1,053	1,116
Cochabamba	795	655	522
Oruro	245	750	750
Sucre	140	152	145
Potosí	13	125	132
Tarija	162	167	174
Trinidad	74	76	76
Cobija	s.d.	s.d.	s.d.
Total	2,478	3,022	2,966

Source: Nb 512 Regulation.

Figure 4. Percentage of wastewater treatment in plants



Source: Global Water Supply and Sanitation Assesment. Report 2012

Category (A): Central axis: Cochabamba and La Paz; with values of 55.78% and 79.91%, for an optimal value (<90%). La Paz treats 100% of the water extracted from its surface sources, which accounts for 79.91% of its production; the equivalent of 20.09% corresponds to water extracted from deep wells, subjected to disinfection. The city of Santa Cruz disinfects 100% of the water from its wells.

It is necessary to have a study on the overall efficiencies of the plants.

Category (B): Four EPSAs report information below the optimal parameter (<90%).

Category (C): Only eight of the 35 EPSAs have water purification plants, three of which are above the optimal parameter of the indicator and five of which require investment to expand capacity.

Category (D): Only two of the 14 EPSAs have water purification plants, which comply with the optimal parameter of the indicator.

Installed Capacity of Wastewater Treatment Plant: This section details the relationship between the volume of water treated in Wastewater Treatment Plants with respect to the installed treatment capacity.

Category (A): Central axis; La Paz, Cochabamba and Santa Cruz, have values of 69.6%, 77.22% and 98.45%, the optimal parameter being <90%. Santa Cruz is reaching the limit of its capacity, compromising the goal of achieving 100% coverage in the medium term. La Paz and Cochabampa have achieved the optimal parameter; however, La Paz treats the wastewater discharged at the plant in the city of El Alto. Cochabamba decreased the volume of treatment due to a reduction in the amount of drinking water it supplies to users.

Category (B): Only eight of the 18 EPSAs, have treatment infrastructure and only two of them comply with the optimal parameter (<90%).

Category (C): Only 13 of the 35 EPSAs have treatment plants, 10 of which comply with the optimum parameter.

Category (D): There are no available data.

The wastewater treatment plants (WWTP) identified in Bolivia urgently require a strategy that will enable them to progressively achieve effective operation, since many of them do not operate due to the lack of resources and capacities of the operators. However, they have the potential to reuse wastewater for irrigation purposes (see **Figure 4** and **Table 17**).

Pressure on Drinking Water Service: The indicator shows the degree of compliance of pressure ranges between 13 and 70 mca at representative points of the drinking water network, in order to guarantee service in the concession area.

Category (A): Central Axis, Santa Cruz-La Paz-Cochabamba have values of 100%-89.41%-11.19%, the optimal parameter being >95%. Due to its topography, La Paz has pressure difficulties in its high zones. Cochabamba does not comply due to maintenance deficiencies and a deficit of water resources: high unaccounted for water.

Category (B): Only 30% of the 18 EPSAs comply with the indicator (>95%).

Category (C): Only 19 of the 35 EPSAs present information, nine of which comply with the pressure range.

Category (D): Only two of the 14 EPSAs present information on monitoring service pressures, complying with the optimum parameter. Twelve EPSAs are recommended to perform pressure controls.

The following are not evaluated: the index of water not accounted for in production, the index of water not accounted for in the network, the density of faults in potable water pipes, the density of faults in drinking water connections and the density of faults in wastewater connections, since these are highly specific to each system.

8. Conclusions

The following entities are responsible for contributing to the implementation of the policy, protecting natural resources and the environment, and providing support to the providers of drinking water for due compliance in the supply of water for human consumption:

1. Governorships (departmental governments), are responsible for implementing the general policy of conservation and protection of watersheds and aquifers, in their sphere of jurisdiction.
2. Autonomous Municipal Governments are responsible for ensuring the provision of potable water and sewerage services within their jurisdiction.
3. SENASBA, in charge of the development of the sector's capacities, is responsible for:
   i. Providing technical assistance and institutional strengthening to providers in terms of drinking water quality.
   ii. Training human resources and providers in various sectoral issues, including operational control plans and others related to drinking water quality, as well as promoting a certification system for labor competencies in the sector.
   iii. Helping, during the implementation of potable water works, to inform the population of the importance of drinking wa-

ter quality. It has the Plurinational Water School as a coordination platform for knowledge management through training and applied research processes.

4. The Executing Entity of Environment and Water (EMAGUA) under the MMAyA, the Fund for Productive and Social Investment (FPS) and the Program and Project Coordinating Units that administer investment in drinking water and sanitation, as well as the Units dependent on the Autonomous Departmental or Municipal Governments, which build hydraulic and health infrastructure works on their own or through third parties, must ensure that the designs and public works meet the requirements to ensure the supply of drinking water, in keeping with the policy and technical regulations corresponding to the National Development Plan (PDN), which includes the Basic Sanitation Plan.
5. IBMETRO, affiliated to the Ministry of Productive Development and Plural Economy, is the national reference entity for all measurements and, as such, protects and maintains national measurement standards. It also provides calibration, accreditation and verification services for equipment in metrological aspects. Based on the above, it is the entity in charge of the accreditation of laboratories for water analysis, as well as the calibration and metrological verification of equipment used in the drinking water and basic sanitation sector.

There is a growing consensus that the best way to guarantee water suitable for human consumption is through the protection and control of water sources, avoiding nearby contamination points, which results in not only attending the point where the extraction of water, whether surface or groundwater, is carried out, but also protecting the micro basin, the recharge area and the catchment area of the collection works.

In this context, the detection of possible sources of contamination is more visible and evident in surface waters, which makes it possible to take preventive or corrective measures, whereas in the case of groundwater, contamination advances without being able to be visualized and studies to determine the source and characteristics of the contamination, as well as the decontamination processes, require long-term actions that may even force the abandonment of the local source of water supply. It is therefore necessary to establish more analysis, monitoring and protection of groundwater, given the obvious lack of care in the management of facilities near the wells for water extraction.

This is a marked tendency towards urban growth in the main cities of Bolivia, located in areas with a water deficit. This is driving the need for potable water, but also requires a strategy to be able to afford major investments in the construction of wastewater treatment plants, since many of them are overloaded and there is less sewerage than drinking water coverage.

The wastewater treatment plants (WWTP) identified in Bolivia urgently require a strategy that will enable them to progressively achieve effective operation, since many of them do not operate due to the lack of resources and capacities of the operators. However, they have the potential to reuse wastewater for irrigation purposes. Downstream of the WWTPs, mainly in places with agro-productive characteristics, treated (or partially treated) water and, in some cases, untreated waters are being used for complementary irrigation. However, very little has been done to explore the solution to the problems of pollution and health that may be caused by its use in irrigation.

Although there is a regulatory framework in Bolivia, the Environment Law and the Sectoral Laws (Drinking Water Law and Irrigation Law), in order to comply with the norm, it is necessary to meet several needs such as the following: 1) greater quantity and quality of information, which implies financial resources and advice, 2) coordination between the sectors according to the roles and competencies of each of them for greater effectiveness, and 3) capacity development in the various levels of government and entities involved with the problem.

Although it is estimated that in Bolivia there are 303,000 million m^3/year of renewable internal water resources, 40% of the territory experiences dry periods. It is estimated that 1,054 million m^3/year of water are used for irrigation, 124 million m^3/year for population use and 62 million m^3/year for industrial use.

Over five million inhabitants of Bolivia lack sewerage systems. The final disposal of untreated wastewater collected amounts to 70%, contaminating water courses, land and aquifers. A study of 111 populated centers nationwide, where water is reused for irrigation in an area of 5000 ha, shows that 84 have a WWTP with operational problems while the remainder have no form of treatment.

A Mixed Wastewater Commission has been created as a space for generating proposals and guidelines to find solutions to the problem of reuse. The commission is producing technical assistance and information for making future decisions. It is essential to invest in the construction of wastewater treatment plants, since many of them are overloaded and there is less sewerage than drinking water coverage. A strategy is also required to ensure that it works properly.

Downstream of the WWTPs, treated and untreated wastewater is being used for complementary irrigation. However, very little research has been done to find a solution to the problems of pollution and health that could be caused by its use for irrigation. Although there is a regulatory framework, it is necessary to ensure the following to achieve greater effectiveness, namely: 1) greater quantity and quality of information, in addition to its systematization and 2) coordination between the sectors according to the roles (in addition to their recognition).

According to the AAPS, there is 70% drinking water coverage in Bolivia (equivalent to seven million residents), whereas 30% (three million) lack access this benefit, the majority of whom live in rural areas. During a public event held at the seat of government, the regulatory authority explained that there is 55% basic sanitation service - sewer connection – coverage, equivalent to approximately 5.5 million residents.

The oversight body informs social organizations, departmental and national representatives, with the aim of making management transparent and strengthening social control in the sector by receiving suggestions from participants.

The AAPS supervises the EPSA linked to the water and sanitation service, which are under the regulatory system throughout the country.

According to the projections of the institution, the short-term goal is to achieve 75 to 80% percent drinking water coverage and up to 60% sewerage coverage. Within this framework, all the investments made by the state, through various institutions, are geared to this objective.

According to data from the Ministry of Environment and Water, the country requires an investment of one billion dollars to expand coverage, and improve and maintain the quality of drinking water and sewerage service nationwide.

One of the AAPS policies is to become an information reference to identify the sectors in which basic sanitation, treatment plants and water sources are required, among other needs.

The main factor in the quality of water for human consumption and irrigation in the three components of the Bolivian hydrographic system is the negative impact of mining and industrial activity on water resources, which in many cases have exceeded the maximum limits allowed for concentrations of harmful substances, causing social and economic problems in depressed sectors of society. In the major water courses of the Amazonian and Plata slopes, the deterioration of water quality is reflected in a high concentration of sediments, caused by laminar erosion and mass movement in the upper basins, as well as by the high levels of concentration of the substances used in gold mining.

References

Argollo J. y Mourguiart P. (1995). *Climas Cuaternarios en América del Sur.* La Paz: ORSTOM.

Autoridad de Fiscalización y Control Social de Agua Potable y Saneamiento Básico (AAPS) (2016). *Indicadores de Desempeño de las EPSA Reguladas.* La Paz: MMAyA.

Cardozo, A., Montes de Oca, I., Rodrigo, L. A., Saavedra, A. (2004). *Procesos de salinización en el Altiplano Central. Una contribución a su conocimiento.* La Paz: Academia Nacional de Ciencias de Bolivia.

Constitución Política del Estado (CPE) (2009). Recuperado de: https://www.oas.org/dil/esp/Constitucion_Bolivia.pdf

España, Carlos (2004a). *Norma Boliviana NB 689, Para el Diseño de Sistemas de Agua Potable y Plantas Potabilizadoras de Agua.*

España, Carlos (2004b). *Reglamentos Técnicos de Diseño para Sistemas de Agua Potable.* NB 689; Vols. 1/2 y 2/2.

Fundación Natura Bolivia (2010). *Manejo integral en la cuenca de Arroyo Bahía-Pando.* Santa Cruz, Bolivia.

INTESCA, AIC & CNR (1993). *Plan global binacional de protección-prevención de inundaciones y aprovechamiento de los recursos del lago Titicaca, río Desaguadero, lago Poopó y salar de Coipasa (Sistema T.D.P.S.).* Convenios ALA/8603 y ALA/87/23 – Perú y Bolivia.

Norma Boliviana NB 512 – Agua Potable Requisitos (2005).

Organización Mundial de la Salud (OMS) / ONU Agua (2015). *Saneamiento, Agua de Consumo e Higiene.*

Reglamento Nacional para el Control de la Calidad de Agua para Consumo Humano - NB 512.

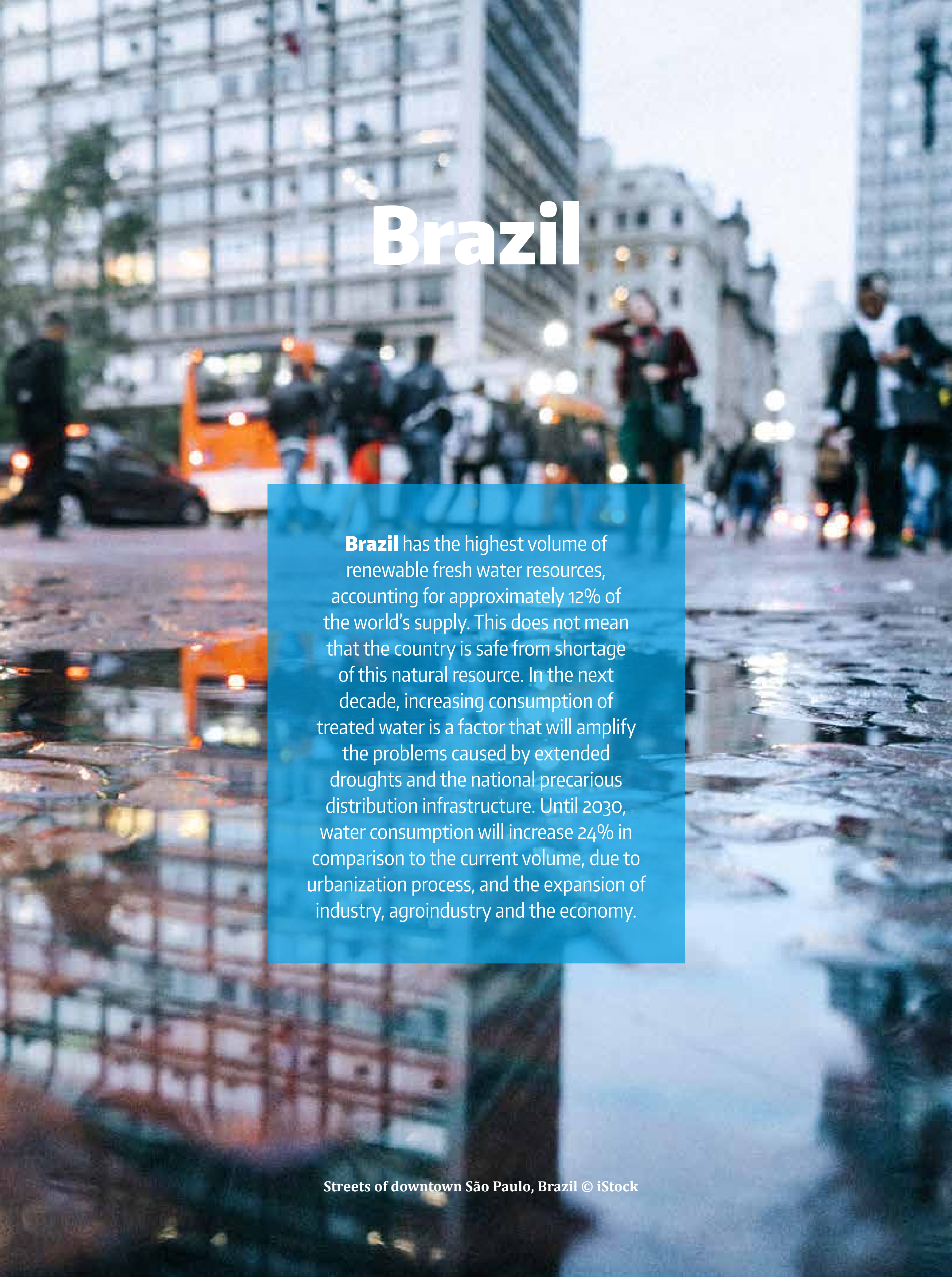
Servicio Geológico de Bolivia / British Geological Survey (1994). *Proyecto Precámbrico.*

Urquidi, Fernando (2012). Los recursos hídricos en Bolivia: un punto de vista estratégico sobre la problemática de las aguas transfronterizas en *Diagnóstico del Agua en las Américas.* México: IANAS-FCCyT.

Urquidi, Fernando (2013). Water Resources in Bolivia: A Strategic Viewpoint of the Issues Associated with Transboundary Waters in: *Diagnosis of Water in the Americas.* México: IANAS, AMC, II-UNAM.

Urquidi, Fernando (2015). Compendio de la situación de los recursos hídricos en las ciudades capitales departamentales de Bolivia, en *Desafíos del agua urbana en las Américas.* México: IANAS-UNESCO.

Urquidi, Fernando (2015). Compendium of the Water Resources in the Capital Cities of the Departments of Bolivia, in *Urban Water Challenges in the Americas.* Mexico: IANAS-UNESCO).



Brazil

Brazil has the highest volume of renewable fresh water resources, accounting for approximately 12% of the world's supply. This does not mean that the country is safe from shortage of this natural resource. In the next decade, increasing consumption of treated water is a factor that will amplify the problems caused by extended droughts and the national precarious distribution infrastructure. Until 2030, water consumption will increase 24% in comparison to the current volume, due to urbanization process, and the expansion of industry, agroindustry and the economy.

Streets of downtown São Paulo, Brazil © iStock

Water Quality In Brazil

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1. The Water Quality In Brazil: Historical Perspective

Industrial development, urbanization, and agricultural activities in the last 50 years contributed extensively to the complex and delicate situation of water quality in Brazil. The historical process of water quality degradation somewhat followed the worldwide path described in Tundisi *et al.* (2015) and was clearly described in Bicudo & Bicudo (2017). First, the industrial development produced effluents with heavy metals, dissolved organic substances, and other toxic materials. Accelerated urbanization after the year 1950 together with inadequate wastewater treatment contributed to the accumulation of organic matter and the eutrophication of rivers, reservoirs, and lakes. The extensive agricultural activities, the heavy application of pesticides and herbicides, and the uncontrolled use of fertilizers, especially in regions of widespread sugar cane and soy bean plantation, also contributed to water quality degradation. Today, eutrophication is one of the major environmental problems in Brazil with enormous economic, ecological, and human health consequences.

Mineral exploitation of iron, gold, and other metals is another cause for the degradation of the water quality in several regions of Brazil. Arsenic, mercury, and lead are all typical contaminants that may be related to this activity. Mozetto *et al.* (2003) described how metals and nutrients are weakly bound in sediments of the Tietê River (São Paulo) and what this would cause to human health. In the last few years, floods, large disasters such as the Doce River contamination by a tailing dam failure, and other intense discharge of toxic substances aggravated the picture of the water quality degradation. Deforestation activities all over the country, including removal of riparian vegetation also affect water quality of water bodies and contribute to deterioration. Urban rivers and reservoirs are environments of particularly high impact on water quality due to increasing exploitation.

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Consequences of this large-scale process are very relevant. First, the economy of municipalities and states are negatively impacted. Second, the impact on human health is also not totally understood yet. Deteriorated water quality results in high costs for water treatment to provide adequate drinking water to the human population. Deterioration of biodiversity is yet another consequence of low water quality and environmental disasters affecting rivers, reservoirs or lakes. Due to this scenario, few watersheds of Brazil can be considered pristine. Therefore, the restoration of water quality in Brazil, the protection of the few pristine watersheds left, and the enforcement of environmental laws are some of the important actions necessary to promote better life quality, reduce risks and vulnerability to water security and promote economic growth. It is fundamental to monitor all regions consistently with the maintenance of permanent and public databases to support public policies.

In this volume, we outline the current state of water quality in all regions of Brazil including some of the main challenges for surface and groundwater. Furthermore, we present some specific challenges, such as the emerging risks of pesticides, herbicides, hormones, and climate change. Lastly, we discuss the economic implications of water quality degradation and make some remarks about the reduction of water vulnerability in Brazil.

2. Water Quality: North Region

In the Amazon everything is great and diverse. The extensive watershed originates in the Peruvian Andes, specifically in the Nevado Mismi, and spreads across all the countries of northern South America, covering an area of seven million square kilometers. The Amazonas River, the main water course, reaches the Atlantic Ocean after flowing for 6,992 km, where it discharges 20% of all the fresh water that reaches all marine environments of the world. This volume of water is five times greater than that of the Congo River (Africa) and 12 times than that of the Mississippi River (United States of America). Each small space is unique in the Amazon. This holds true for water too. It was the German limnologist Harald Sioli who initially described the three basic water types of the Amazon: the white waters of the Solimões/Amazonas river; the black waters of the Negro River; and the clear waters of the Tapajós (Sioli, 1950). These distinctions are not just based on color, but mainly on physicochemical and biological characteristics. The white, or rather muddy, waters of the Solimões-Amazonas River have a near neutral pH, a large amount of suspended sand from the Andes and riverbanks, low concentration of dissolved organic carbon (DOC), and higher nutrients relative to other water bodies of the Amazon. Black water rivers (*i.e.* Negro River) differ in that they show an acid pH ranging from 3.2 to 5, high levels of DOC, and very low levels of sodium, potassium, and calcium. The clear waters (*i.e.* Tapajós River) have a pH between 6 and 7, low levels of DOC, sodium, potassium, calcium, and high transparency (Furch, 1984).

A remarkable feature of the Amazon basin is the seasonal variation of river water levels, appropriately called flood pulses (Junk *et al.*, 1989). In the banks of Manaus, the level of the Negro River can vary more than 15 m between low and high-water seasons. Other environmental parameters also show diurnal, seasonal, and even geographic variation, influenced by the interaction with the various environmental characteristics, such as the dissolved oxygen level. Of course, these different characteristics impose challenges of all orders of aquatic organisms. In the case of fish, for example, a broad set of adaptations at all levels of the biological organization has been developed throughout the evolutionary process, so that they can cope with environments that exhibit significant variation in oxygen availability over short periods of time (Val & Almeida, 1995; Val, 1995; Val *et al.*, 2015). Similarly, fish from the Negro River can maintain ionic homeostasis despite the acidity and ion poor characteristics of their environment (Gonzalez *et al.*, 2002; Wood *et al.*, 2014). Today it is known that DOC has a relevant role in this process (Duarte *et al.*, 2016).

There is still much to be said about the adaptations and abilities of the aquatic biota of the Amazon. However, many aquatic organisms are already facing challenges posed by man-made environmental changes. We highlight here, very briefly, three of these challenges. First, the presence of metals from mining in several bodies of water in the region, which endanger several species of fish that are very sensitive to these metals, such as copper (Crémazy *et al.*, 2016; Duarte *et al.*, 2009). Second, the effect of climate change on aquatic environments, making them warmer, more acidic and with less dissolved oxygen, conditions that represent an intensification of the challenges that many aquatic organisms of the Amazon already face (Oliveira & Val, 2017). Third, the urban impact on the rivers that cross the cities, when they receive a vast amount of new chemical compounds and debris that represent new challenges for the aquatic biota. In this case, two groups of compounds are worth mentioning: plastics and leachate from landfills. Lastly, while on the one hand a great challenge to expand what we know about the pristine Amazonian aquatic environment is needed, on the other hand there is also a gigantic and urgent need for robust information to reduce the anthropic impacts of all orders on the unique aquatic environments that occur in the Amazon.

3. Water Quality: Northeast Region

In order to contextualize the issue of water quality in the Brazilian Northeast, the distinction between hydrochemical quality and quantity of surface water and groundwater must be highlighted. Considering the surface water issue, Northeastern Brazil contains only 3% of Brazilian water and has only two perennial large rivers, the São Francisco, which concentrates 63% of the Northeast water, and the Parnaíba, with 15%. All other somewhat large rivers are intermittent, *i.e.* they only flow in the rainy season. In the coastal region, perennial rivers of small extension are present and are of great importance to water supply for the population and productive activities, chiefly since the majority of the population and industrial production is concentrated up to 150 km from the coastline. In this range closer to the coastline, the biggest problem for river water quality is pollution from domestic sewage and solid waste, particularly along rivers and canals that flow through cities. Although important sewage treatment programs have been partially implemented in the region, especially in the larger urban centers, the economic crisis that began in 2014 and which still affects public policies in the country has decreased the effort to expand the treatment of domestic sewage. The result is that sewage collection is in most Northeastern cities less than 40% of the volume produced, and effective treatment of sewage in major cities, with few exceptions, is below 30%. The issue of solid waste pollution from rivers and canals that cross the poorest regions of the cities is alarming; the deficiency of waste collection services and the lack of environmental awareness of the riverine population transform these small watercourses into floating solid waste reservoirs. Diffuse industrial pollution is another cause for concern as industrial clusters such as garment production growing in areas close to temporary rivers that receive high net waste from production.

Upstream of urban centers and still considering the wettest regions of the Northeast, water quality is usually satisfactory, although there are problems in some rivers resulting from contamination by agricultural activities (*i.e.* sugarcane). In the region crossed by the São Francisco River, despite a relatively higher level of sewage treatment in the main cities compared to other parts of the Northeast, eventual algae proliferation accidents have occurred, damaging the water supply of the cities. It must be considered in this case the presence of many irrigation systems along the river, whose drainage systems can affect water quality.

Concerning groundwater formations, the water stored in sedimentary aquifers are generally of good quality in all aspects. In coastal sedimentary aquifers there is a risk of salinization in many wells as a consequence of high exploitation or vertical infiltration in poorly sealed wells. On the other hand, water quality is greatly impaired by the high concentration of salts in the so-called fissure aquifers in which water percolates between rock fractures. Alarmingly, these salts dominate more than 80% of the region.

4. Water Quality: Central-West Region

The Central-West region of Brazil contains springs of five hydrographic regions (Amazon, Paraguay, Araguaia-Tocantins, Paraná and São Francisco). Besides supplying the Central-West and all the other regions in Brazil, these hydrographic regions also contribute to Paraguay and Argentina. This is the second least populated region, where pristine waters can be found in different locations such as the Formoso River basin in the state of Mato Grosso do Sul (municipalities of Bonito, Jardim, and Bodoquena) and the Federal District (Águas Emendadas Ecological Station). Also, in different places of the Goiás state (especially in the Chapada dos Veadeiros Park region) and Mato Grosso (Poconé) (Tundisi & Matsumura-Tundisi, 2011; Cunha-Santino & Bianchini Jr., 2008; O'Sullivan & Reynolds, 2004). As in the North region, waters can be classified in some types described below.

Thermal waters occur due to natural geothermal gradients in the Earth's crust (Goiás, 2006). Thermal localities exist in Mato Grosso (Barra do Garça, Rondonópolis, Juscimeira, Primavera do Leste and Santo Antônio do Leverger cities) and Goiás, the latter being the state with the greatest number of hot springs in Brazil. Thermal springs originate through different aquifers (Araxá, Paranoá, Serra Geral, Serra da Mesa, Aquidauana, Cristalino Noroeste and Guarani). There are 19 natural upwelling sources in the state classified as isothermal (36-38°C) and hyperthermal (> 38°C) springs. The largest hot water complex in the country is concentrated in the Caldas Novas and Rio Quente municipalities (Goiás, 2006), but thermal upwellings also exist in Chapada dos Veadeiros Park, Lagoa Santa, and Goiás city. Quente River (Goiás) is the largest hyperthermal river in the country and runs through a Cerrado region.

Acidic or black waters are composed of dissolved acids of plant origin with a brownish color and pH < 6. They are registered in different localities of all Central-West Brazil states. Specifically, the Chapada dos Veadeiros Park presents an extensive area covered by acidic water rivers, among which the Negro River in the state of Mato Grosso do Sul and Suia-mixu River in the state of Mato Grosso. Salt and brackish waters are recorded in the Pantanal (Santos & Sant'Anna, 2010; Barbiero *et al*. 2008), in the northeast region of Goiás (Bambuí aquifer that promotes brackish springs, Goiás, 2006). These waters originate in the soil containing these water bodies. Muddy or brown waters are recorded for most of the rivers that run through latosol regions. In Central-West Brazil, the most common type is the ferruginous latosol (Resck, 1991). Waters flowing in this region contains a great amount of iron. During the rainy period, most of the rivers become muddy due to erosion and deforestation.

The region also has a great groundwater reserve. The Guarani Aquifer expands through south, southeast, and central-west regions and contributes to the water supply of a significant portion of the watersheds in the southern Central-West region. Several springs originate from this groundwater system and are exploited for irrigation and public supply. One can also observe cave lakes that are common at the north of Goiás and south of Mato Grosso do Sul states.

Aquatic environments in Central Brazil are important and attractive for tourism and recreation (water sports, waterfalls, pristine lagoons, rivers with rapids). Unfortunately, they are experiencing serious erosion problems, silting, construction of waterways and hydropower plants, and water pivots as well as water pollution (rural and urban). The most damaging of all has been the advance of agricultural and agribusiness frontiers that began with government projects in the 1970s (Miziara, 2006; Rodrigues & Miziara, 2008) and was intensified in the first decade of the 21st Century, promoting intense deforestation, especially in Goiás and Mato Grosso do Sul states. The lack of sanitation and water treatment also contributed for the serious mischaracterization of the watersheds that changed to meet population growth, agricultural, industrial, and commercial supplies.

Currently, there are about 700 hydropower plant (HPP) reservoirs and/or small HPP that modifies the rivers morphology, the water quality, and/or the type of water. The most modified river is the Tocantins with eight reservoirs of various shapes in its course, the largest one being in the state of Goiás (Serra da Mesa Reservoir). The only river not yet fragmented is the Araguaia due to its origin. This river is the largest in central Brazil (Valente *et al*., 2013) and borders the states Mato Grosso and Goiás. There also is the Mato Grosso's Pantanal, the largest continuous wetland on the planet. Nonetheless, some of the rivers that flow into this ecosystem are under some sort of impact (*i.e.* livestock, deforestation, and gold-mining) that affect their water quality.

Another process of extreme importance is the climate impacts, which have been increasing in the last 10 years. Seasons have changed to the point of producing excessive rains and extreme droughts. These conditions lead to processes of large floods and rivers that once were perennial and now dry up during the drought period. For example, in 2017 only in Goiás, more than 15 rivers had total or partial absence of water in their beds, damaging the aquatic biota and the public supply.

Water is an excellent indicator of environmental quality since it is directly influenced by the water regime to which the ecosystems are subjected. Furthermore, volume and flow are also affected by deforestation which is being intensified by climate change (Coe *et al*., 2011). Currently, the concept for sustainable water use in the Central-West Brazil is still anthropocentric and harmful (*i.e.* numerous reservoirs and licensed grants) (Tundisi, 2002; 2014), thus conceptualizing water sustainability in an environmental sense is necessary. Together with the intensive use of water comes the concept of virtual water (Tundisi, 2014), which is used because of its presence in the final product of the food production process, which is ultimately exported to other regions of the country and to the world. This concept is well applied in a region whose economy is based on agriculture and livestock production, and water is therefore fundamental for its economic development. Investigation of water quality in Brazil abides by specific legislation by the National Environmental Council (CONAMA, 357; Brasil, 2005), by the National Water Resources Policy (Brasil, 1997), and by an integrated water resource management system (ANA, 2005). In the Central-West region, application of these laws is still precarious and raises many conflicts such as the indiscriminate use of water and lobby of the agribusiness companies. The only legislation effectively applied focuses on public supply (Consolidation Ordinance, 5/2017; Brasil, 2017). As highlighted here, there are different types of water in the Central-West region and their multiple uses lead to a complex scenario with strong human interference. It cannot be denied that water supports sustainable development in the Central-West region.

5. Water Quality: Southeast Region

The southeast of Brazil is the most populated and urbanized area of the country with about 120 million people. Water quality is affected mainly by the lack of waste water treatment, the discharge of fertilizers from agriculture and effluents of industrial plants, and the contamination of groundwater.

Although the southeast treats a large volume of sewage it is not sufficient for a complete cleaning up of surface waters. About 40 % of sewage is still discharged without any treatment in continental water bodies such as rivers, reservoirs, coastal lagoons, and coastal regions. As a consequence, blooms of cyanobacteria are frequent in the inland and coastal waters. Eutrophication of reservoirs in São Paulo State, for example is very frequent, even a permanent feature in some cases (Tundisi 2018, in press).

Several diffuse sources of water quality degradation also originate in abandoned solid waste residues. These diffuse impacts affect not only surface waters but also underground waters. Deforestation of vegetation mosaics and riparian forests is another main cause of degradation, increasing discharge of pesticides, herbicides, fertilizers to rivers and reservoirs impairing water quality and increasing the cost of water treatment for potable uses. (Tundisi & Matsumura-Tundisi, 2010; Tundisi *et al*., 2015).

Contamination of groundwater in the southeast is an additional impact on water quality. Part of the southeast region uses water resources from the Guarani Aquifer. These resources are used by several small to midsized towns (50.000 to 200.000 inhabitants) as source of public supply of water.

Protection of water quality in the region would therefore include recovery of vegetation in the watersheds, restoration of riparian forests, treatment of 100% of wastewater, and reduction of the open air solid-waste sites in order to avoid contamination of surface and groundwater. Integrated management of watersheds with a systemic vision, strong environmental education of the population, and capacity building of managers are some of the fundamental steps in the recovery and conservation of water quality. Also, strong conservation measures in existing pristine waters could be an excellent tool to maintain a scientific information basis on the original water quality in the Southeast. Preparation of water quality management for recovery and conservation is also essential to adapt to climatic change (Jorgensen, Tundisi, Matsumura-Tundisi, 2013).

6. Water Quality: South Region

The Southern region of Brazil consists of three states, namely Paraná, Santa Catarina and Rio Grande do Sul. The region is occupied by approximately 28 million inhabitants and the climate is primarily subtropical. Industrial activity occurs in large urban centers of the sector, the most frequent being associated with the metal-mechanic industry, clothing, footwear, and food. The vast plains are occupied by large plantations of soybeans, rice, maize, and cattle ranching, whereas the rural mountainous regions are occupied by small farms involved in dairy, swine, and poultry production chains. Educational and income levels are usually above the Brazilian average, although great disparities exist. Paradoxically, the South is often noted for its high human development indicators but is also facing deeper problems regarding water quality which is being impacted by many different pollution sources. Water resources are impacted by the excessive use of agrochemicals, supplementary nutrients (N and P) applied to crops, and industrial effluents from a variety of sources, including metals and other wastes. In the latter case, there are significant cases of contamination by organic solvents and others from processing industries, such as tanneries and paper mills, many times leading to shortening of water supply. However, the greatest impact on water bodies is related to deficits in environmental sanitation: although almost 90% of the population receives treated water, up to 30% of the total domestic sewage is not treated before being discharged onto rivers and lakes. These statistics are even more serious considering that only the state of Paraná has 70% of the treated sewage in its major cities, while only 10% of the sewage is treated before it is released to the rivers in the states of Santa Catarina and Rio Grande do Sul.

This situation of contamination and losses in water quality is even aggravated by several socio-economic and institutional issues that came along with the economic crisis of the last decades by the state governments within this region. The western areas of Paraná and Santa Catarina states, on the border with Paraguay and Argentina, are impacted by industrial swine manure as well as domestic sewage. The large metropolitan areas of the region, especially Florianópolis and Porto Alegre, are highly impacted by low levels of sewage treatment and a consequent increase in costs related to water treatment and waterborne diseases. In the case of Florianópolis, losses in water quality represent a constant threat to the tourism economic activity; the beaches of the city are often closed due to inadequate disposal of untreated debris leading to risks for recreational use. In the city of Porto Alegre, Lake Guaíba, the main reservoir of drinking water in the city, is impacted annually by large algae blooms, resulting from the disposal of untreated sewage from the city itself and its hydrographic basin, which comprises more 5 million inhabitants along all the rivers draining into the lake. The larger cities in the region, those with more than 200 thousand inhabitants, often report more than 6,000 cases of gastroenteritis per year, this being one aspect of the severe impact of water contamination in public health. The whole picture is further hampered by the industrial contamination already mentioned. The municipalities in the Brazil-Uruguay border (most of them crossed by the Uruguay River) are often impacted by no sewage treatment and lack of funds to increase their sewage treatment infrastructure.

In addition to these water quality problems, there are also periodic droughts, especially in the summer months, which threaten the water security of large areas of Southern Brazil. Inefficient management of multiple uses of water has already generated conflicts, especially between the urban population and the agrarian sector, aggravated at times of scarcity. This is worsened by a problematic management and surveillance system. The structure of environmental monitoring, especially in the state of Rio Grande do Sul is largely depleted. The current inspection bodies do not have the financial resources and sufficient staff to carry out their activities.

7. The Water Quality Of Brazilian Groundwater Resource

Groundwater plays an essential role in public water supply in Brazil. According to the National Water Agency (ANA, 2010), half of the country's municipalities is totally (39%) or partially (13%) supplied by aquifers, with a high predominance in small and medium-sized cities. In private water supply, the importance is even more significant, since it has been used to alleviate the severe problems of lack of water of the public system, which is recurrent in almost every Brazilian city, or even a low-cost water alternative. Unfortunately, there is no estimate on this exploitation and local studies have shown that this value is considerably higher than the perception of society and government. This importance is well exemplified in the Metropolitan Region of São Paulo where public water supply is only 1%, but 12,000 private wells (60% illegal) extracting about 10 m^3 s^{-1}, provide water for 20% of the population. This "hidden statistic" is one of the causes of the government's low attention, including the lack of initiatives to protect the quality of aquifers.

The lithological, tectonic, and climatic characteristics of Brazil create excellent conditions for good groundwater quality and mostly naturally potable. Except for high salinity observed in fractured aquifers of the northeastern semi-arid region, natural geochemical anomalies of toxic substances such as F, Cr, and Ba are very limited in area. However, Fe and Mg have a more extensive occurrence and are generally associated with unconfined sedimentary aquifers. In terms of anthropogenic contaminant sources, the situation is more complex and deserves more attention by the government. Nitrate is the single contaminant with a more significant presence in Brazilian aquifers. In urban areas it is almost ubiquitous. This reflects the lack of sewage networks, which only covers 50% of the urban population in the regions where these systems exist, due to the lack of maintenance or age. The problem is not worse because the contamination has been restricted to the shallower portions of the aquifer (usually down to a depth of some tens of meters), also allowing the use of its water in the deeper parts.

Other contaminants in urban areas are petroleum-derived liquid fuels from leaks and poor operation of service stations. Studies by CETESB (2009) in the state of São Paulo have shown that more than 50% of these installations had leaks reaching the aquifers; however, the plume had limited dimensions and impacts. Chlorinated solvents and heavy metals are products that are quite common in industry and are responsible for the most massive and most complex plumes of aquifer contamination in the country. The high toxicity and large volume of product handled by the industry and even disposed of in open dumps and landfills have made these compounds a new and real concern in urban aquifers, especially when present in free phase (pure product) reaching complex aquifers such as fractured ones (Hirata *et al.*, 2015).

There is no information on the situation of groundwater degradation in urban areas. Although Brazil has been a major agricultural producer, there is a real risk of aquifer degradation involving nitrogen fertilizers and some agrochemicals, mainly herbicides and some insecticides. The lack of monitoring networks in critical areas and the deficiency of systematic studies still compromise the understanding of the real situation on water quality. The scarcity of planning and control of territorial occupation in Brazilian municipalities has also contributed to increase the problem of aquifer degradation.

8. Water Quality And Human Health

Safe and adequate water supply is a key resource for social and economic development validated by many international organizations like the World Health Organization (WHO), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and and the Food and Agriculture Organization of the United Nations (FAO). The United Nations General Assembly and the United Nations Human Rights Council recognized in 2010 the human right for safe water and sanitation with a strong participation of Brazilian government (Heller, 2015). However, the WHO & UNICEF (2017) report recently pointed out that only 71% of the global population (5.2 billion people) is supplied with a safe drinking water service available when needed and free from contamination. Therefore, 29% of the global population (2 billion people) still does not have access to this service. Data showed that only 65% of the population in Latin America uses safe drinking water. Sanitation service data are more critical. Only 39% of the global population (2.9 billion people) uses a safe, managed sanitation service (*i.e.* excreta safely disposed of 'in situ' or treated off-site). For Latin America this percentage drops to 22%, the smallest value among all regions analyzed.

Human health is both directly and indirectly impacted by the water quality. Outbreaks of waterborne diseases (cholera and infections as leptospirosis and viruses) common in urban areas may occur as a result of contaminated or inadequate water supply, sometimes affecting thousands of people and causing many deaths. Outbreaks of vector-borne diseases such as malaria and dengue fever, mosquitoes and intermediate hosts (snails) that harbor the worm that causes schistosomiasis can also occur. Globally, there are nearly 1.7 billion cases of childhood diarrheal disease every year. This disease remains as one of the leading causes of child mortality and morbidity in the world, killing around 525,000 five-year-old and younger per year. However, a significant proportion of the diarrheal disease can be prevented through safe drinking water and adequate sanitation and hygiene (WHO & UNICEF, 2017).

Besides this classical scenario of hazards related with water quality, other impacts on human health through unsafe water use may arise from natural toxic agents (e.g. biological toxins, such as those from cyanobacteria and arsenic) or from anthropogenic sources (pesticides, pharmaceutical compounds or other chemical contaminants). Indirect impact is also related with water availability in food production. For example, agricultural productivity is tied to food security consequences in regions where severe droughts or flooding are frequent.

Considering water availability as the first step to guarantee safe drinking water and sanitation services, knowledge that Brazil has 12% of the world's water availability leads to a false concept of a wealthy water supply for different services as human consumption, agricultural and industrial use, recreation, and energy production. As reported in this document, there are important regional disparities. While the North region reaches 68.5% of national water storage with 6.8% of Brazilian population, water availability for human use in the Northeast region is only 3.3% for 28.9% of the Brazilian population. In the most populated and developed region of Brazil (*i.e.* Southeast), only 6% of Brazil's water availability supplies the highest percentage of Brazilian population (42.7%) (Augusto *et al.*, 2012). On average, 83.3% of Brazilian people is supplied with safe drinking water, but the disparities are great. In the Southeast region, this percentage is 91.24% and in the North region, only 55.38% (SNIS 2016). It is important to point out that 34 million Brazilians still do not have access to drinking water pipelines in their houses. Recent data on sanitation service reinforces this regional discrepancy. On average, 51.92% of the population has access to sanitation facilities connected to a sewer system from which only 44.92% of wastewater is treated. At the North region only 10.45% of wastewater is connected to a sewer net, while this service covers 78.57% in the Southeast region (SNIS, 2016).

The link between poverty and occurrence of waterborne diseases is very notorious. Population that lacks these services is predominantly located in the peripheral areas of urban centers and in areas of informal urbanization, which indicates the need for adopting integrated programs for urban development. This picture is in accordance to some public health data. In 2013, 340 thousand people were hospitalized with gastrointestinal infections. If 100% of the population had access to sewage system there would be a reduction, in absolute terms, of 74.600 hospitalizations, 56% of which would occur in the Northeast region (Instituto Trata Brasil-DATASUS, 2014). Among waterborne diseases, diarrhea is the most frequently registered. Diseases related to faecal-oral transmission as diarrhea, enteric fever and hepatitis A were responsible for 87% of the hospitalizations caused by inadequate sanitation service from 2000 to 2013.

Water resources contamination including drinking water supplies by human excreta remains a major human health concern. In contrast, the importance of toxic natural microorganisms and their toxins as cyanobacteria/cyanotoxins and toxic compounds, such as heavy metals and synthetic organic contaminants, has only emerged in the last half of the XX century. This concern is connected to the recognition of artificial eutrophication as a developing problem since the 1950s. Human-led increased eutrophication in fresh and coastal water has caused enrichment of nutrients and other pollutant. It has become much more widespread in some regions where the advance rates of agriculture, industry, and urbanization has experienced rapid increase, but without being followed by an improvement in wastewater treatment. This artificial eutrophication affects water quality, including higher incidence of microalgae and cyanobacteria blooms, and has negative consequences to the efficiency and cost of water treatment. In Brazil, bloom occurrence is intensified by the fact that most aquatic ecosystems have the necessary characteristics for an intense growth of cyanobacteria throughout the year.

Cyanobacteria cannot be considered pathogenic microorganisms in the classical sense because although several strains of different species can produce bioactive and toxic secondary metabolites for mammalians, a large part of these compounds will only be released into water after the cyanobacterial cell lysis. The quality of water may be more compromised by the presence of dissolved cyanotoxins than by viable forms of cyanobacterial cells, which could potentially be removed during the conventional water treatment. However, this procedure may lead to rupture of the cells of these microorganisms due to the chemicals used during the treatment process. Cyanobacteria are also often associated with the production of compounds that are responsible for taste and odor in drinking water. Although these compounds cannot be considered as toxic as the cyanotoxins, their presence concerns health authorities given that such compounds frequently result in rejection of the potable water by the population, which in turn leads them to seek alternative sources of water supply. Aquatic environments located in areas of strong anthropogenic impact had a high dominance of cyanobacteria and occurrence of blooms. Potentially toxic species of cyanobacteria have been identified in at least 11 out of 26 Brazilian states, the majority of these records coming from multiple use reservoirs (Azevedo, 2005). In some cases, the cyanobacterial bloom can disappear from the reservoir before health authorities consider them a human health risk. This happens because the authorities may be unaware of the potential damages resulting from cyanobacteria blooms and therefore they assume that the conventional water treatment system is capable of removing any potential problem.

Water contamination by heavy metals and synthetic organic compounds as pesticides or pharmaceutical drugs occur due to the inadequate wastewater discharge into aquatic environments. Only recently human exposure to certain heavy metals, such as methyl mercury (MeHg), cadmium (Cd), and lead (Pb) was considered a health risk. Aquatic systems are particularly sensitive to synthetic organic pollutants due to their chemical characteristics, which may favor bioaccumulation along the aquatic food chain. Reservoirs are more susceptible to contamination by metals and other pollutants because of their mobilization from flooded soils. One important potential consequence of damming is the intensification in the production of methyl mercury, associated to the anaerobic degradation of organic matter. In tropical reservoirs, the Hg methylation process is favored by the high water temperature that favors the intensified microbiotic activity and the reducing conditions in the hypolimnium (Confalonieri *et al*., 2010).

It is also important to consider that water availability in Brazil largely depends on the weather. Climate change studies have already indicated a reduction in the amount of rain in the North and Northeast regions of the country of up to 20% by the end of the XXI Century (Marengo, 2008). Changes in weather and climatic patterns are affecting human health by increasing morbidity, mortality, disabilities, and by the emergence of diseases in previously non-endemic regions. Multiple factors are associated with the region's vulnerability to climate change, water quality and sanitation services. It is well known that water scarcity in the Northeast region affects health of the population, and most of the health problems derive from socio-environmental processes caused by drought. Outbreaks of vector and waterborne diseases can be triggered by extreme events. There is some good epidemiological evidence of human health risk linked to climate variability. Most of that evidence comes from malaria studies. The number of cases of malaria has increased in urban and rural Amazonian area undergoing large environmental changes. El Niño drives malaria outbreaks and linkages between ENSO and malaria is also reported for Amazonia (Oki & Kanae, 2006, Field *et al*., 2014). The link between malaria and El Niño is due, in part, to the increasing amount of surface water providing breeding sites for mosquitoes. Unlike malaria, dengue fever (DF) is mostly an urban disease whose vector is also affected by climate. In Rio de Janeiro, a 1°C increase in the monthly minimum temperature led to 45% increase of DF in the subsequent month, while a 10-millimeter rise in precipitation led to a 6% increase in DF in the following month (Gomes *et al*., 2012). Schistosomiasis (SCH) is endemic in rural and peripheral urbanized regions of Brazil. It is highly likely that SCH will increase in a warmer climate. Hantaviruses as well have their prevalence increased due to El Niño and climate change events. Also, incidence of visceral leishmaniosis has increased in Brazil in association to El Niño and deforestation (Field *et al*., 2014).

The data discussed here shows that the relationship between water and health conditions is usually very complex and mediated by several factors of physical-geographical, socio-environmental, economic, and cultural nature. Indeed, all sectors of the development nexus are interlinked through water. The growth of population and economic activities are linked to water availability and use in agriculture, industry, energy consumption, and domestic purposes. These factors contribute to an increasing demand on the local and regional water supplies. These forces are rapidly accelerating, often with unpredictable changes that represent new uncertainties for water managers, which poses an increasing risk for public health. At the same time, climate change is generating new uncertainties regarding freshwater supplies and to the multiple sectors of water use. As water availability becomes more uncertain, society will become more vulnerable to a wide range of risks associated with inadequate water supply, including hunger and thirst, high rates of disease and death, loss of productivity and economic crises, and degraded ecosystems. Therefore, these challenges require an urgent implementation of policies that will be able to serve as a tool for monitoring the access and use of good-quality and its relations with health indicators.

9. Water Quality And Economic Impact

Identifying and estimating the significance of impact on water quality is of relevance to policy makers seeking to promote sustainable water resources management and wider economic development. A failure to account for externality effects leads to a misallocation of resources to an inappropriate mix of land uses and inappropriate management of individual parcels of land (Moxey, 2012). The economics of clean water is strictly related to its different uses and shall be valued accordingly for: agricultural irrigation, industry, households, water-based recreation (fish, wildlife habitat and navigation), water load dilution, hydroelectric power generation, conservation of biodiversity, and health. In Brazil, a whole set of problems resulting from the intensification of human activities such as urbanization, industrialization, agriculture, and energy production leads to economic impacts of major proportions not yet properly measured but certainly very significant (Tundisi *et al*., 2015). For example, water treatment for potable water production is extremely expensive. About US$ 60.00 to US$ 90.00 is required for the production of 1,000 m^3 of drinking water from degraded sources. Instead, the cost to treat pristine and uncontaminated waters may reach a maximum of US$ 3.00 (Tundisi & Matsumura-Tundisi, 2010). However, there are other externalities' effects: hospitalizations due to waterborne diseases as well number of hours lost in school due to absence; number of hours of work lost due to illness from contaminated water or intoxication by toxic substances.

Recreation, tourism, public supplies are threatened by eutrophication and silting, which represents the impact of nitrogen and phosphorus on untreated sewage and soil erosion. Between 30 and 40 percent of the world's food comes from the irrigated 16 percent of the total cultivated land; around one-fifth of the total value of fish production comes from freshwater aquaculture; and current global livestock drinking-water requirements are 60 billion liters per day (forecasts estimate an increase of 0.4 billion liters per year). In Brazil, only 5.4 million hectares are under irrigation considering its potential of 29.6 million hectares. Runoff, soil loss, and leaching of chemicals are particularly of great concern considering the tropical climate with its high intensity rainfalls in areas under fragile soils and inadequate management practices.

Regarding chemical contamination of water from non-point pollution sources such as the agriculture ones, the Brazilian market for pesticides is in the world's top level. The industry of pesticides accounted for US$ 9.71 billion dollars, according to 2012 data, referring to 823,226 tons of commercial product and 346,583 tons of active ingredient added to a total of 29.53 million tons of fertilizers. In addition, the impact of climate change, demography, land use and the impact of new and emerging contaminants on surface and groundwater must also be considered. These pollutants are the result of the addition of drugs, cosmetics, antibiotics, hormones, nanomaterials, paints and coatings dissolved in river waters, dams and groundwater and constitute the most recent threat to human health, biodiversity, and ecosystem functioning (Boxall, 2012).

Reliable water resources database to promote recovery and conservation policies (ex. water and nutrients reuse) is a must. Economic assessment of water pollution must be prioritized. Finally, advanced technologies as big data, robotics, internet of things, and 3-D manufacturing is making real the integration of urban, rural, and industrial spaces and societal activities. Predictive models and simulations using big data tools shall be exploited to promote intelligent and long-term water quality management.

10. Water Quality And Surrogate Variables: The Alto Tietê River Basin

Several plans and studies have recently been made to critically evaluate the drinking water supply in Brazil. Among them, there are different security plans for water supply in Brazil and internationally (SUS, 2012; Bensousson *et al*., 2012; PAHO/WHO, 2012; BRAZIL, 2014). Even though these publications outline good proposals, they did not consider fundamental aspects of normalization, criteria for water treatment, and the traditional Brazilian operational procedures adopted by water companies. So, the Ordinance MS-2914/2011 was based on foreign standards or from the WHO Guidelines, without being adapted to social, technical, and public health of Brazilian conditions.

The evolution of guidelines and standards related to public health are not based only on epidemiological and toxicological studies. Technological development, socioeconomic, cultural, and hygiene practices as well as public sensitivity and perception play an imperative role on stablishing guidelines for quality criteria to ensure health protection of consumers (Hespanhol & Prost, 1994). The work done by WHO is divided in two phases. The first phase is the preparation of WHO Guidelines, which are done based on a risk-benefit approach by the Collaborating Centers of WHO (all of them situated in industrialized countries), according to their specialty on one or several variables. These guidelines specify maximum concentrations of various bioactive substances in drinking water by considering a minimum or tolerable reference risk (risk equal to 10^{-6} of developing the disease in 70 years). The second phase, risk management, is to assist developing countries in the preparation of their own national standards and regulations considering their specific environmental, social, economic, and cultural conditions. However, excessively restrict considerations and policies may endanger public health by not allowing their effective application due to economic reasons.

In relation to traditional procedures within water companies, many industrialized countries recycle filtered backwash waters into the water treatment plant with previous treatment to avoid bacteria, protozoa (mainly *Cryptosporidium* sp.), solids and organic matter to return to the plant. In Brazil, on the other hand, filter's backwash waters are recycled to the plant without treatment. This generate a build up of those pollutants in the plant, jeopardizing the production of safe water. This and other practices lead to severe problems in public water supply. For example, during the drought that affected São Paulo in 2015 (Kelman, 2015), water distribution companies adopted the emergency measure of stopping the water distribution to some sectors of the city in a time span ranging from a few hours to a couple of days. When water distribution is interrupted and users continue to draw water from the network it causes negative pressure inside pipes and, due to precarious conditions (e.g. cracks), external matter is sucked inside the tubes. When the water distribution restarts, a huge mass of pollutants is delivered to users. Therefore, intermittent supply operation should be officially forbidden.

The Metropolitan Region of São Paulo (MRSP) comprises the city of São Paulo and 38 adjacent cities. The whole area is 700 m above sea level and most of it is situated in the Alto Tietê river basin (upper Tietê River basin). Currently, the population size is about 21 million people and is estimated to reach 25 million by 2025. Surface water from superficial reservoirs for drinking supply (Cantareira, Guarapiranga, Alto Tietê, etc.) totals 74 $m^3\ s^{-1}$. Adding another 10 $m^3\ s^{-1}$ of ground water, the overall available water is around 84 $m^3\ s^{-1}$. About 80% of this water (67 $m^3\ s^{-1}$) becomes raw wastewater. Since the installed capacity of wastewater treatment is only 18 $m^3 s^{-1}$, the difference of 49 $m^3 s^{-1}$ is discharged without any treatment into the waterways (*i.e.* rivers and reservoirs). This critical situation will become worse when the transposition of new waters from other water bodies (*i.e.* São Lourenço River, Paraíba do Sul Reservoir, Billings Reservoir, Taiaçupeba, Itatinga-Jundiaí, Guaió, Juquiá-Santa Rita and Itapanhaú) bring an additional 20 $m^3 s^{-1}$ of water to the MRSP. Considering water losses between 20% to 80% as change from water to wastewater, this operation will generate an extra 13 $m^3 s^{-1}$ of raw wastewater.

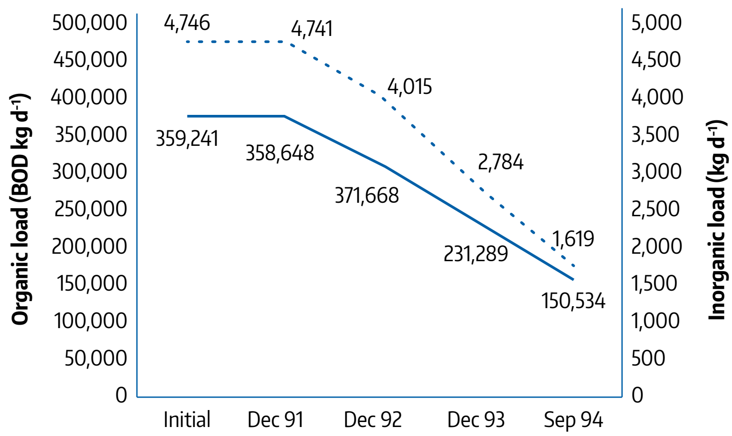
Several attempts were made to control water pollution in this river basin. As early as 1953, a plan involving the construction of six wastewater treatment plants at secondary level was proposed by the city of São Paulo. Since then, many other plans were proposed, however, only in the late 1980s and early 1990s, did the construction of the SANEGRAN Project take place. This project included, among other features, a wastewater plant with a treatment capacity of 63$m^3 s^{-1}$. With exception of the SANEGRAM Project, none of the other projects were accomplished.

In the mid 70's, a state law in São Paulo (State Law nº 997, 1976) required industries to discharge wastewater into the public sewer network whenever possible. The organic load of 370,000 kg BOD d^{-1} at the outlet of the process was reduced to 150,000 kg BOD d^{-1} in September 1994, and the inorganic load from 4,700 to 1,600 kg d^{-1} (**Figure 1**; BOD - Biological Oxygen Demand). This program was abruptly ended by September 1994.

In September 1991, the State Government launched the Tietê Project and the STAR (Sistema de Tratamento de Águas Residuárias or Treatment System for Raw Wastewater) to clean up the rivers and reservoirs of the Metropolitan São Paulo (**Figure 2**).

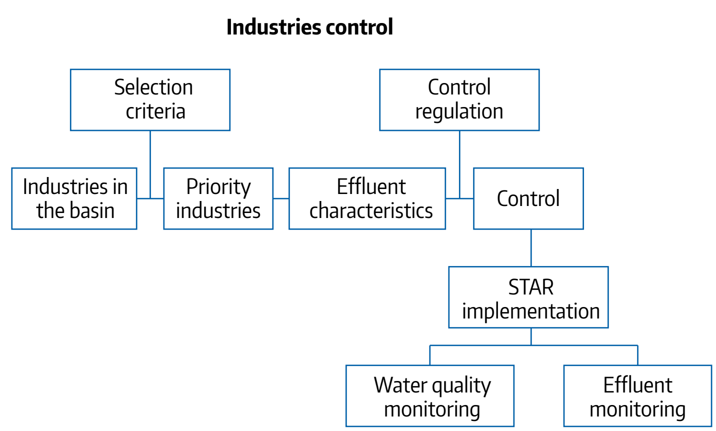
The plans for drinking water are essential for making the direct potable reuse a reality. Direct potable reuse should consider multiple complementary barriers for water treatment, such as ultrafiltration, double pass reverse osmosis, advanced oxidative process, active carbon, and disinfection. This would make it possible to produce high quality water free from organic and inorganic matter, endocrine disruptors, pharmaceutical pollutants, and nanoparticles. The creation of technical groups to study, discuss, and elaborate regulations and standards for water quality is strongly recommended. These studies must be supported by scientists, microbiologists, epidemiologists, toxicologists, biologists, and environmental engineers from Brazil and abroad to produce regulation under Brazilian conditions and not only the biased viewpoint from specialists from water companies and from entities for health and environmental regulation. In addition, if decision makers do not consider the source control, the quality of water produced by conventional systems will degrade even faster. This is why source control must be mandatory in all water quality plans.

Figure 1. Reduction of industrial loads between 1991 and 1994



Source: Herman & Braga, 1997.

Figure 2. Scheme of STAR program



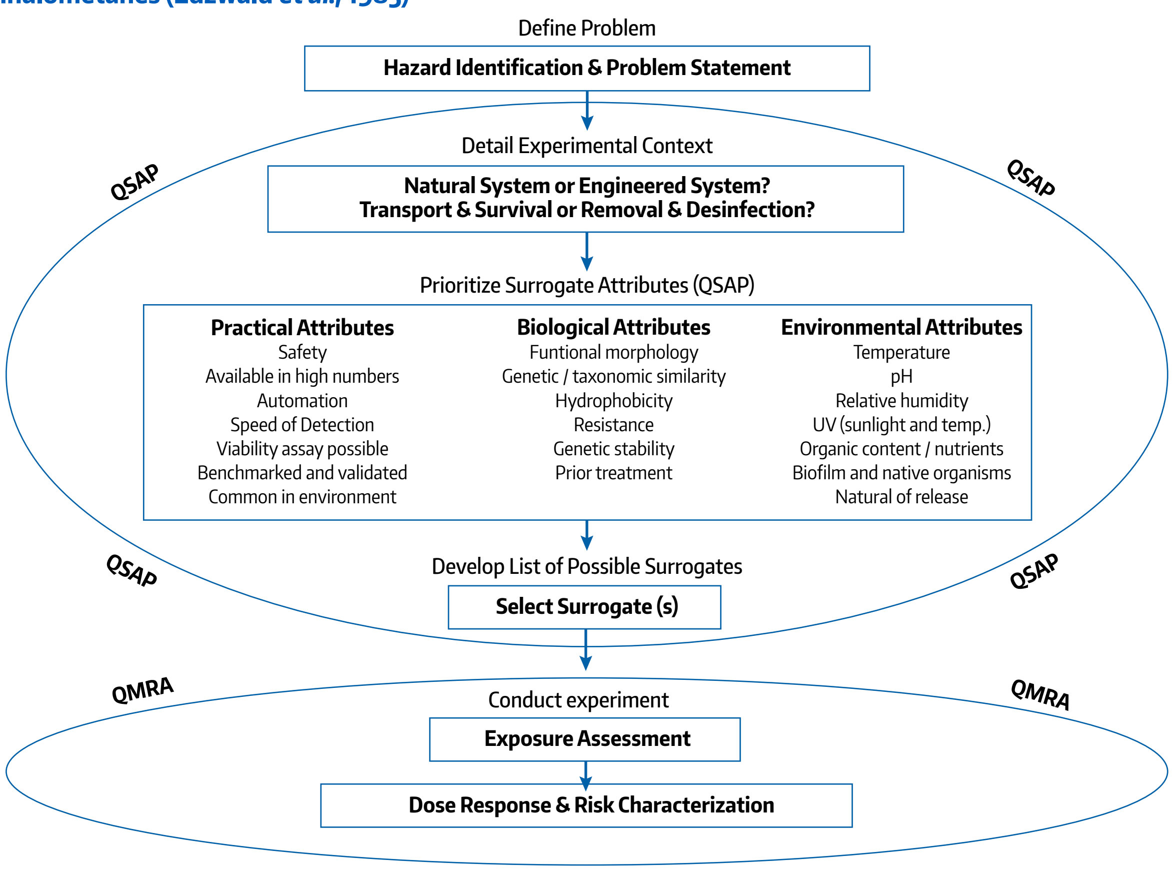
Source: Herman & Braga, 1997.

A new generation for regulations is presented focusing on a new paradigm to reformulate the conventional methodology and criteria to evaluate programs associated with public health, such as drinking water, water reuse, and sludge uses in agriculture. This new generation of standards will make the water security plans more realistic and will reduce monitoring costs. The term surrogate is used to indicate a substitute for a group of variables. Surrogate variables such as microorganisms, particles or substances are used to evaluate the fate of pathogens in the environment. The discovery of the coliform *Escherichia coli* in feces and the methods used for its identification in contaminated waters revolutionized the sanitation field as the *E. coli* could be used as a simple indicator of many waterborne pathogenic organisms. If there is *E.coli* in water, it is likely to have other contaminants as well. Therefore, its use as surrogate variable helps to evaluate the efficiency of water treatment (Sinclair *et al*., 2012). Several surrogate variables are in use today. The most widely known is the Biological Oxygen Demand (BOD), which is used to evaluate the concentration of biodegradable organic matter in water, wastewater and industrial effluents.

Surrogate variables should be evaluated by their correlation with groups of variables represented in terms of Qualitative Surrogate Attribute Prioritization (QSAP), which are to be certificated by Qualitative Microbial Risk Assessment (QMRA). They should be no longer based in proposal of variables by "specialists". **Figure 3** shows a conceptual scheme for decision-making starting from the definition of the specific theme to be regulated and the elaboration of a list of possible surrogate variables as a function of practical, biologic, and environmental aspects of interest. QMRA selects the most adequate variables, determines the exposure level, the dose-response, and the risk.

Surrogate variables have been used to evaluate the quality of reuse waters for potable uses. In Perth, Australia, the Beenyup Advanced Waste-

Figure 3. Conceptual structure of decisions to select surrogate variables (Sinclair *et al.*, 2012) trihalometanes (Edzwald *et al.*, 1985)



water Treatment was equipped with ultrafiltration membranes, reverse osmosis, and UV radiation disinfection. The effluent is infiltrated through managed aquifer recharge into the sandy aquifer of Leederville, acting as environmental buffer, to produce drinking water (Australian Water Corporation, Project Water Forever-Whatever The Weather, Beenyup Advanced Wastewater Reclamation Plant, Perth, Australia, 2013).

This discussion is relevant to introduce some basic aspects about regulations in Brazil, focusing on the Alto Tietê River Basin in São Paulo. A deep evaluation on how the command and control mechanics work in São Paulo led this discussion to question whether the parameters adopted to control water quality are coherent to the current reality or not. This evaluation focused on how the Environmental Sanitation Technology Company of the state (CETESB) monitors the industrial effluent discharges. In practical terms, it is notorious that the standards adopted as reference in São Paulo, as well as in the rest of the country, are copied from WHO guidelines and USEPA guidelines (whichever is the most restrictive, sometimes rounding some numbers). This premise goes, unfortunately, against what WHO advocates about adapting their guidelines to local standards for risk evaluation related to water consumption. Hence, using pre-established international values without further evaluation may jeopardize the main purpose of the risk analysis, which is to guarantee the safety of the consumers. The main questions that come up in the current scenario are: (1) are there compounds in Brazil that offer a risk to human health but are not considered by either WHO or USEPA? and (2) are people in Brazil investing precious resources to monitor compounds that may not even be present in local waters?

11. Emerging Risks For Water Quality: Climate Change

Over the last 50 years, nutrient enrichment (particularly nitrogen and phosphorus) due to human activities promoted accelerated eutrophication rates. Urban, industrial, and agricultural developments are the main causes of this process. In freshwater ecosystems, phosphorus availability has been viewed as a key factor to limit algal growth. Proliferation of cyanobacteria is thus prevented by the lack of phosphorus in the freshwater ecosystems (Schindler *et al.*, 2008). However, the increase in nitrogen load at higher rates than phosphorus can also stimulate eutrophication of estuarine, coastal, and freshwater ecosystems around the world (Paerl & Dawnl, 2012). Besides eutrophication due to excess of phosphorus and nitrogen, another process is effectively acting as a stimulator of cyanobacterial growth and water quality deterioration: the climatic changes in the hydrological system affecting the physical and chemical environment, metabolism, growth rates, and bloom formation (Paerl *et al.*, 2011).

An increase of 2°C of the surface water temperature can affect the growth rate of all phytoplankton species and promote rapid increase in cyanobacterial growth rates, causing bloom formation (Paerl & Huismain, 2008). Large masses of cyanobacteria will considerably change the water quality due to the production of antioxidant enzymes and other excreta. This deteriorates the water quality in water bodies and has negative consequences to society as described earlier in this document.

Toxic substances produced by some cyanobacteria species can also be added to the dissolved organic matter content of the water and interfere with pH and the physic-chemical equilibrium. This can also lead to mass killing of fish and aquatic birds and consequently impact human health. Evidences of the impacts of climatic changes and its effects on the hydrological and water quality conditions in lakes and reservoirs are accumulating during the last 20 years. For example, a survey of 143 lakes along a latitudinal gradient from Northern Europe to Southern South America revealed an increase in cyanobacteria-driven phytoplankton biomass that was directly related to temperature (Kosten *et al.*, 2011). As for the geographic distribution, *Cylindrospermopsis raciborskii* has a strong capacity of adaptation, prefers water temperatures above 20°C, and is adapted to low light conditions. Today, it is widespread in all continents. In Brazil, Tundisi *et al.* (2005) reported an effect of global change detected at Lobo-Broa reservoir, in São Paulo State. Changes in the hydrological cycle due to climate change, causing extreme events such as longer drought periods followed by heavy rains also has an impact on phytoplankton growth. This relation is described in more detail latter in this text (16. Case Study: Broa Reservoir).

12. Emerging Risks For Water Quality: Agriculture (Pesticides, Herbicides, Hormones)

In recent years, there has been increasing concern over the environmental risks of the Emerging Contaminants (EC). ECs originate from a variety of product types including human pharmaceuticals, veterinary medicines, nanomaterials, personal care products, paints, and coatings. Some ECs are not necessarily new chemicals; they may be pre-existing substances in the environment, but whose presence and significance are only now being recognized. Some examples are natural and transformation products of synthetic chemicals formed in the environment by biochemical processes in animals, plants, and microbes. Data on ECs are often scarce and methods for detection in the natural environment may be non-existent or in its infancy.

Evaluating the environmental fate and effects of ECs includes research on compounds such as surfactants, antibiotics and other pharmaceuticals, steroid hormones and other endocrine-disrupting compounds (EDCs), fire retardants, sunscreens, disinfection byproducts, new pesticides and its metabolites, and naturally-occurring algal toxins. Detection of these contaminants in environmental matrices (water, wastewater, soils and sediments) is particularly challenging because of the low detection limits required, the complex nature of the samples, and difficulty in separating these compounds from interferences. New extraction and cleanup techniques coupled with improvements in instrumental technologies to provide the needed sensitivity and specificity for accurate measurements are very promising.

Relevant contaminants are ECs (particularly hormones and anabolic steroids), antibiotics and other pharmaceuticals associated with wastewater, and antibiotic resistance genes in bacteria and prions (Snow *et al*., 2009; 2017). In Latin America and tropical countries, very few studies exist and none of those is specifically targeted to agricultural environments (Sodré *et al*., 2010; Campanha *et al*., 2015; Machado *et al*., 2016). The related studies in agricultural systems have detected a range of ECs generally reporting very low concentrations (*i.e.* in the ng L^{-1} range) (Boxall, 2012). ECs of different classes were detected in waters, such as triclosan, caffeine, atrazine, paracetamol, atenolol, estrone, 17-β-estradiol, stigmasterol, cholesterol, and bisphenol. The impacts of ECs in and from agricultural systems will be increasingly relevant in the near future under the scenario of land use, demographic growth, climate change, global increase of food, fiber and energy demands and its impact on agricultural supply. In addition, intensification of agriculture practices is expected for the next decades. Natural resources such as land, water, air, and biodiversity will be highly scarce and the spatial border separating urban from rural areas will disappear. Finally, policy-makers and scientists will have to cooperate to create an initial environmental ECs priority list, to address the consumer demands for safety and the lack of conceptual models for ECs in the environment. Environmental risk assessment schemes already exist in certain regions, however research and policy strategies for ECs and agriculture in the tropics are urgently needed.

13. Reducing Vulnerability: Urban Areas

Today, cities are the engine of the economic development of several developed and developing countries. More than 50% of the world human population is urban. In Latin America, 82% of the human population is living in large metropolis, medium sized, or small cities. Therefore, water quality in urban regions is fundamental for sustainability. Vulnerability in cities is related to lack of sanitation especially in periurban regions and low percentage of wastewater treatment (in Latin America approximately 20% of wastewater is treated). Another vulnerable region of the urban ecosystem is the deforestation of uptown watersheds that supply water for the city. Deforestation leads to losses in the quantity of water due to lack of replenishment of surface and ground supplies. At the same time, deforested areas also reduce water quality and more chemical treatment is needed to produce potable water. (Tundisi *et al*., 2010).

Integrated water resources management accounting for water quality and quantity in surface and underground sources are fundamental to reduce the vulnerability of cities to water security. The protection of riparian vegetation and the vegetation at the sources of supply is an important measure and promotes water replenishment and actively produces better water quality (Tundisi *et al*., 2015). Wastewater treatment and water reuse are other important measures of management with economic and human health impacts. Water reuse is a low-cost opportunity to increase the current supply of water (Nasiri *et al*., 2013). Monitoring water sources around towns and in urban rivers is another consistent sustainability measure. With such monitoring the information flows and people's involvement can be optimized and stimulate communication in water science and water planning.

The implementation of urban forest parks could increase the sustainability and promote the creation of green areas in cities while creating new opportunities for education, research, water supply, atmosphere, and clean air. Equally important is the protection of natural wetlands at the watersheds of the urban areas. Introduction of new and advanced legislation at the municipalities could considerably advance the reduction of urban vulnerability as well as 1) stimulate programs of re-vegetation of urban areas; 2) decentralize wastewater treatment systems; 3) use rain water in new buildings and houses; 4) introduce new environmental courses at schools. Reducing vulnerability to water security at urban ecosystems implies in biogeophysic, economic, and social measures with a strong scientific and technological background and a robust participation of the people.

14. Reducing Vulnerability: The Mineral Sector

Water has been recognized as a strategic issue for the mining sector as most processes need considerable amounts of water to operate. The participation of the mineral sector in the overall water consumption is small (< 10%) compared to the agribusiness (> 70%) (ANA, 2017). However, the local interferences on water resources cannot be neglected, especially in light of the events of water scarcity in places where water resources have been traditionally considered abundant. Water has also emerged as one of the most significant causes of social and economic tension between industry and local communities, who in turn are often concerned with the risks of depletion and deterioration of surface and groundwater resources. These conflicts directly influence how society perceives mining operations and in turn, the sector's ability to achieve the social license to operate. There are, in summary, several reasons for decreasing vulnerabilities by improving water management: (1) increase access to water resources; (2) reduce management risks (e.g., by reducing water consumption and creating self-sufficient water use, with decreasing need of new resources); (3) decrease competition with other users, especially during events of scarcity and other extreme conditions; (4) saving drinking water for the preservation of life; and (5) build a positive relationship with stakeholders to ensure the license to operate, among other factors.

As a result, increasing the efficiency of water use has been perhaps the main driving force for the recent advances we have witnessed in the mineral sector. The increase in water recycling and use of saline, brackish, sewage and rain water, thus decreasing the use of noble water; the minimization of leakages and losses in industrial operations are some improvements that deserve to be highlighted. The increasing participation of the mineral sector in finding solutions for water scarcity in nearby urban areas is worth mentioning as well (Ciminelli *et al*., 2015). There are various industrial experiences showing that increasing efficiency in the use of water results in the reduction of costs and generation of new revenues. This creates a virtuous cycle and stimulates new and ambitious investments.

What are the main challenges? The first one is perhaps the fact that the sector is quite heterogeneous and therefore good practices should be disseminated among all. Another topic to be addressed is the increasing number of artisanal mining or *garimpo*, often illegal, in many regions in Latin America. This creates uncontrolled impacts on water resources and great vulnerability in the mined territories. The impacts of artisanal mining are not caused by the lack of technology. It is rather a social and economic issue related to the lack of education and infrastructure, poverty and inequality, prevalence of economic interests, and the failure of the state to implement public policies and law enforcement. The 2015 failure of a tailings dam in Brazil added pressure on water/tailings management, and more emphasis on less-dependent water operations, such as dry processing and dry tailing disposal.

Finally, it is clear that water security is essential for the mineral industry to remain competitive and cannot be achieved without a commitment of all stakeholders. Cooperation between different production chains, between industry, society, and governmental agencies is required. An integrated, systemic, and multidisciplinary approach to assess water quality and availability should rely on a sound, well-designed, and reliable database (e.g. real-time metrics). Sharing experiences, knowledge, competencies, information, and responsibility should be expected in the future. This approach is increasingly needed to guarantee a good quality of life and the sustainability of shared territories.

15. Reducing Vulnerability: Biodiversity

Brazil is well known to be one of the richest countries in the world in terms of biodiversity. We are very proud to know Brazil as a megadiverse country. However, what is effectively known about this megadiversity? Since 2009, Brazil is showing some concern about the preservation of its biodiversity, mainly the aquatic one. Also in 2009, a research project carried out by the Brazilian Institute of Geography and Statistics (IBGE) warned the risk of extinction of at least 238 species, which created some concern of governmental, non-governmental, and private institutions. This concern was also demonstrated by the Federal Ministry of Environment that admitted, at the time, that failed the country's attempt to improve the fishing resources management to significantly benefit the sustainable process and, consequently, the aquatic biodiversity scenario in the country.

In 2018, still very little was done to improve this scenario such that Brazil may start a cycle of great progress in fishing activities without being properly prepared. However, biodiversity is not restricted to fish and other marine products, but it is a very broad term that considers, in the case of aquatic biodiversity, both the set of the continental, coastal and marine aquatic ecosystems and the organisms living or spending part of their biological cycle in such environments. Compared to knowledge about diversity loss in the oceans, mainly of fish species of economic interest, little or almost nothing is known about other marine animals, and much less indeed about freshwater species.

Only very recently did Brazil wake up to the biodiversity crisis. Perhaps, the only attempt to measure biodiversity loss in light of the continuous aggravation of the eutrophication problem is the Garças time-series. This record includes 21 years of uninterrupted monthly phytoplankton sampling and simultaneous evaluation of environment characteristics of the Garças reservoir, a system located at the Parque Estadual das Fontes do Ipiranga located in the southern part of the São Paulo municipality. Furthermore, it revealed that of the 36 species of Cyanobacteria known to occur in the reservoir in 1997, only four remained after an abrupt loss between December 2003 and October 2008, which resulted in loss of species richness and diversity. Among those remaining, *Planktothrix agardhii* formed 97-98% of the total biomass in November-December 2005. *Microcystis aeruginosa, Microcystis panniformis* and *Cylindrospermopsis raciborskii* were the other species, all of them Cyanobacteria that resisted the reservoir's rising eutrophication.

Some measures are broadly used in various parts of the world in an attempt to mitigate eutrophication and loss of biodiversity. Among them are: better management practices with optimization in the use of fertilizers, reduction of intensive livestock, improvement of sewage treatment, restoration of lost wetlands in order to increase P and N retention capacity (mitigation of nutrient diffuse loads), reestablishment of buffer zones along rivers (riparian forests) and the water restriction by humans (intensive agriculture retreating in more vulnerable areas, improvement of the water recycling in hydrographic basins, improvement of efficiency of water allocation for their distinct uses and more consistent drought control)

The challenges to be faced in Brazil will demand a lot more effort than that taken in Europe. The Brazilian situation is aggravated by the lack of a consolidated scientific base for the country and the warmer climate, a fact that may lead to ineffective management strategies of the aquatic ecosystems. It is absolutely urgent, therefore, to establish extensive multidisciplinary research programs that will pursue, as far as possible, syntheses, inferences, and the production of information based on the monitoring of time-series, as well as the definition of possible scientific gaps regarding the Brazilian biodiversity.

16. Case Study: Broa Reservoir

The Carlos Botelho Hydroelectric Power Plant-UHE (Lobo/Broa reservoir) was selected in 1971 for a program of ecological research. In the last 47 years, continuous sampling and studies allowed a thorough characterization of this artificial ecosystem and its watershed (Tundisi & Matsumura Tundisi, 2013). The functioning mechanisms of the reservoir were well studied which allowed for measures to maintain good quality of water (*i.e.* low conductivity – average 10-20µScm^{-1}) by means of periodic turbulence with re-oxygenation of the whole water column, high saturation of oxygen (80-100%), low retention time (< 20 days), and an extensive macrophyte growth in the headwaters, ultimately preventing high nutrient load and eutrophication. The phytoplankton composition was consistent with the oligomesotrophic characteristic of the reservoir: predominance of diatoms and chlorophyceae with a maximum of 10µg/l chlorophyll. However, in the winter of July 2014 the following changes were observed: a heavy bloom of cyanobacteria occurred for the first time in the reservoir. This cyanobacteria (*Cylindrospermopsis raciborskii*) is an invasive species. Very high chlorophyll levels (up to 100µg/l) were measured and high concentration and input of phosphorus was also detected. The explanation for this sudden appearance of blooms can be attributed to the following factors: 1) increase of up to 2°C above the average water temperature during the winter; 2) lower rainfall during summer (30% less of the yearly average of 1.500 mm) and increase in the retention time (from <20 days up to 60 days) in order to maintain volumes for hydroelectricity production (Tundisi & Matsumura-Tundisi, 2018). Effects on the overall economy of the region and on the ecosystem services were already quantified (Periotto & Tundisi, 2013).

As described by Paerl & Huisman (2008), global warming affects patterns of precipitation and drought. The changes in the hydrological cycle enhanced cyanobacterial dominance. Heavy rains after extensive drought periods increased nutrient input promoting phytoplankton growth. During periods of drought, residence time increases and promotes blooms. Another consequence of this process is the prevention of silica discharge into the reservoir reducing diatom growth due to extensive periods of drought. The Lobo/Broa reservoir had a predominance of *Aulacoseira italica* during many years due to silica concentrations of up to 5mg/l. This effect of silica reduction was described by Schindler (2006) in a review of eutrophication. As a result, the Lobo/Broa reservoir is currently eutrophic. To our understanding this is a clear evidence of an effect of global changes at a local and regional freshwater ecosystem.

The concepts and the scientific information produced in last 47 years form the basis of the environmental planning. The selection of criteria was based on general mechanisms of functioning and the hierarchical structure of the sub-systems. These criteria were chosen on the following principles:

i. The maintenance of basic processes in the watershed such as the input of allochthonous material of organic origin in the rivers, and the low residence time in the reservoir.
ii. The maintenance of spatial heterogeneity based on the diversity presented by the gallery forests along the streams, and the compartments with macrophytes in the upper reservoir.
iii. The maintenance of adequate water quality in surface water (rivers, small shallow wetlands, reservoir) and groundwater.
iv. The regulation by law and projects of environmental education on the use of (1) the reservoir and (2) the watershed for recreation or other activities.
v. The stopping of all activities known to cause severe damage to the regional ecosystems, such as mining operations; removal of vegetation; introduction of exotic fish species in the reservoir (introduced at first in the decade of 1960); overfishing, and activities that could disturb wildlife in general.

This planning produced a comprehensive synthesis of activities based on the following systems and compartments:

i. The watershed
ii. The reservoir itself and its interaction with the watershed
iii. The small rivers and streams, and the pattern of drainage
iv. The vegetation and the gallery forests
v. The macrophyte vegetation in the small rivers
vi. The soil conservation
vii. The water quality; its conservation; sanitary problems

Considering the wider context, the environmental planning of the watershed consisted in permanent assistance of small communities in monitoring the quality of water supply (surface or groundwater) and in techniques of studying regional ecosystems. Recreation, small scale agriculture, and fishing, are the main activities in progress in the watershed and the reservoir. The guidelines for these actions as well as the programs of environmental education introduced a permanent system of monitoring aiming to reestablish the lost environmental services.

17. Case Study: Guarapiranga Reservoir

Guarapiranga is an emblematic reservoir in Brazil and represents a challenging scenario between good water quality and urbanization. Construction of this reservoir for the generation of electric power for the city of São Paulo started in 1906 and finished two years later. Due to the rapid growth of the Metropolitan Region of São Paulo (MRSP) with a population reaching about 800,000 inhabitants, Guarapiranga became one of the most important water public supply systems in 1929, besides being responsible for other environmental services to the region. Until the mid-60s, changes in the soil use and occupation did not affect the rural scenario that dominated the reservoir margins. Despite the population and urban growth having changed their pace between 1940 and 1960, it was largely after the 70s that an augmented urban occupation developed and accumulated high densities of piled-up allotments and slum nuclei all in parallel to the absence of adequate environmental occupation sanitation infrastructure. Therefore, from the 70s on, this formerly isolated reservoir started to be a part of its urban mesh.

Historical recovery of the environmental changes was obtained from "clues" provided by distinct environmental markers recorded in the sedimentary cores that included 100 years of reservoir history. The eutrophic state dated since 1960 and was strongly associated with the input of domestic effluents and the growth of the land use and occupation impact. Eutrophication triggered the occurrence and increase of potentially toxic Cyanobacteria blooms in the reservoir. Such organisms merit some great preoccupation since they are the cause of several economic, environmental, and health problems as described earlier in this volume. Historically, at the beginning of the 80s, Cyanobacteria blooms started to be much more frequent, impairing the treatment process of the water intended for public supply. Throughout years 1990 and 1991 a phase of severe eutrophication in the reservoir accompanied the first reports of gastrointestinal disorder cases due to Cyanobacteria (*Dolichospermum solitarium*) that affected the population that relied on the reservoir water. Contamination markers related to inorganic micropollutants concentration (e.g. APH, aromatic polycyclic hydrocarbons) were also detected in the reservoir. Decrease in the C:N ratio from upstream to downstream in the reservoir and the consequent increase in the total nitrogen, $\delta^{15}N$ values suggested an increase in the sewage discharge at the final portion of the reservoir. High coprostanol (fecal sterol) values confirmed the sewage presence in 70% of the sampling stations used for the reservoir water ecological quality evaluation. In the upstream area of the reservoir, superficial layers presented lower fecal influence and a mixture of C and N sources ranging between algae and macrophytes. These sources were represented by intermediate values of C:N ratio and $\delta^{13}C$ and by the dominance of campesterol, an algal sterol.

Inefficiency of collection and treatment system for domestic effluents showed that the reservoir has been punctually but intensively receiving high organic loads from its contributing watersheds during the last three decades. Added to the scenario of a decrease of water availability between the years 2013 and 2015, the Guarapiranga reservoir is close to overcoming its depuration power. Thus, the reservoir will transition from an eutrophication and intense sewage influence to a fecal contamination situation in which its ecological functions will collapse. Very detailed information about the reservoir can be obtained in Bicudo & Bicudo (2017). The Guarapiranga reservoir is a legacy of challenges and lessons to be strongly considered during the preservation and recovery of all reservoirs threatened with urbanization.

References

Agência Nacional de Águas (ANA) (2005). *Cadernos de Recursos Hídricos. Panorama do enquadramento dos corpos d'água.* Ministério do Meio Ambiente.

Agência Nacional de Águas (ANA) (2010). *Atlas Brazil. Urban water supply.* http://atlas.ana.gov.br/Atlas/forms/Home.aspx (in Portuguese).

Agência Nacional de Águas (ANA) (2017). *Water resources in Brazil 2017: full report. Conjuntura dos recursos hídricos no Brasil 2017: relatório pleno.* Brasília: ANA. 169 pp. (in Portuguese).

Alonso, L.R. & Serpa, E.L. (1994). *O Controle da poluição Industrial no Projeto Tietê, 1994*. São Paulo: Companhia de Tecnologia de Saneamento Ambiental (CETESB).

Augusto, L.G.S., Gurgel, I.G.D., Câmara Neto, H.F., Melo, C.H. & Costa, A.M. (2012). The global and national context regarding the challenges involved in ensuring adequate access to water for human consumption. *Ciência & Saúde Coletiva* 17(6): 1511-1522.

Australian Water Corporation, Project Water Forever-Whatever the Weather (2013). *Beenyup Advanced Water Treatment Plant: The Perth, Australia.*

Azevedo, S.M.F.O. (2005). South and Central America: toxic cyanobacteria. En: Codd, G.A., Azevedo, S.M.F.O., Bagchi, S.N., Burch, M.D., Carmichael, W.W., Harding, W.R., Kaya, K. & Utkilen, H.C. (eds.). *Cyanonet: a global network for cyanobacterial bloom and toxin risk management.* Paris: UNESCO-IHP. pp. 115-126.

Barbiero, L., Queiroz Neto, J.P., Gionei, G., Sakamoto, A.Y., Capellari, B., Fernandes, E. & Valles, V. (2002). Geochemistry of water and ground water in the Nhecolândia Pantanal of Mato Grosso, Brasil: variability and associated processes. *Wetlands* 22(3): 528-540.

Barbiero, L., Rezende Filho, A., Furrquin, S.A.C., Furian, S., Sakamoto, A.Y., Valles, V., Graham, R.C., Fort, M., Ferreira, R.P.D. & Queiroz Neto, J.P. (2008). Soil morphological control on saline and freshwater lake hydrogeochemistry in the Pantanal of Nhecolância, Brazil. *Geoderma* 148: 91-106.

Bicudo, C.E.M. & Bicudo, D.C. (2017). *100 anos da Represa de Guarapiranga: lições e desafios.* Curitiba: Editora CRV. 504 pp.

Bourgeois, J.C., Walsh, M.E. & Magnon, G.A. (2004). Treatment of drinking water residuals: comparing sedimentation and dissolved air flotation performance with optimal cations ratios. *Water Research* 38: 1173-1182.

Boxall, A.B.A. (2012). *New and emerging water pollutants arising from agriculture.* OECD study. 49 pp. www.oecd.org/agriculture/water

BRASIL. Lei nº 9.433, de 8 de janeiro de 1997. Institui a Política Nacional de Recursos Hídricos, cria o Sistema Nacional de Gerenciamento de Recursos Hídricos, regulamenta o inciso XIX do art. 21 da Constituição Federal, e altera o art. 1º da Lei nº 8.001, de 13 de março de 1990, que modificou a Lei nº 7.990, de 28 de dezembro de 1989.

BRASIL. Portaria da Consolidação no 5 de 28 de setembro de 2017. Consolidação das normas sobre as ações e os serviços de saúde do Sistema Único de Saúde. O Anexo XX dispõe sobre o controle e vigilância da qualidade da água para consumo humano e seu padrão de potabilidade. Ministério da Saúde.

BRASIL. Resolução CONAMA nº 357/2005, de 17 de março de 2005. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes; e dá outras providências.

Campanha *et al*. (2015). A 3-year study on occurrence of emerging contaminants in an urban stream of São Paulo State of Southeast Brazil. *Environ Sci Pollut Res Int.* 22(10): 7936-7947.

CETESB (2016). Contaminated areas. Portal do Governo do Estado de São Paulo. http://cetesb.sp.gov.br/areas-contaminadas/relacao-de-areas-contaminadas/ (in Portuguese).

Ciminelli, V.S.T., Salum, M.J.G., Rubio, J., Peres, A.E.C. (2015). Water and Mining (Água e mineração). En: *Águas Doces no Brasil- Capital Ecológico, Uso e Conservação.* Braga, B.; Tundisi, J.G.; Tundisi, T.M.; Ciminelli, V.S.T. (orgs.), 4a ed., Escrituras Editora, 2015, pp. 425-455 (in Portuguese).

Confalonieri, U., Heller, l. & Azevedo, S. (2010). *Água e Saúde: aspectos globais e nacionais,* cap. 2 en: Bicudo, C.E.M., Tundisi, J.G. & Scheuenstuhl, M.C.B. (orgs.). Bicudo, C.E.M., Tundisi, J.G. & Scheuenstuhl, M.C.B. São Paulo: Instituto de Botânica. 224 pp.

Crémazy, A., Wood, C.M., Smith, D.S., Ferreira, M.S., Johannsson, O.R., Giacomin, M. & Val, A.L. (2016). Investigating copper toxicity in the tropical fish cardinal tetra (*Paracheirodon axelrodi*) in natural Amazonian waters: measurements, modeling, and reality. *Aquatic Toxicology* 180: 353-363.

Cunha-Santino, M.B. & Bianchini Jr, I. (2008). Humic substances cycling in a tropical oxbow lagoon (São Paulo, Brazil). *Organic Geochemistry* 39: 157-166.

Duarte, R.M., Menezes, A.C.L., Rodrigues, L., Almeida-Val, V.M.F. & Val, A.L. (2009). Copper sensitivity of wild ornamental fish of the Amazon. *Ecotoxicology and Environmental Safety* 72: 693-698.

Duarte, R.M., Smith, D.S., Val, A.L. & Wood, C.M. (2016). Dissolved organic carbon from the upper Rio Negro protects zebrafish (Danio rerio) against ion regulatory disturbances caused by low pH exposure. *Scientific Reports* 6: 20377.

Edzwald, J.K., Becker, W.C. & Wattier, K.L. (1985). Surrogate parameters for monitoring organic matter and THM precursors, Journal AWWA, *Research and Technology* 77(4): 122-132.

Environmental Protection Agency (EPA) (2002). *Filter backwash recycling rule: technical guidance manual.* EPA 816-R-0-014, Office of Groundwater and Drinking Water (4606 M), U.S, Environmental Protection Agency, p. 165, December, Washington, DC, USA.

Fair, G.M., Geyer, J.C. & Okun, D.A. (1968). *Water and wastewater engineering, 2: water purification and wastewater treatment and disposal.* New York: John Wiley & Sons, Inc.

Field, C.B., Barros, V.R., Mach, K.J., Mastrandrea, M.D., van Aalst, M., Adger, W.N., Arent, D.J., Barnett, J., Betts, R., Bilir, T.E., Birkmann, J., Carmin, J., Chadee, D.D., Challinor, A.J., Chatterjee, M., Cramer, W., Davidson, D.J., Estrada, Y.O., Gattuso, J.-P., Hijioka, Y., Hoegh-Guldberg, O., Huang, H.Q., Insarov, G.E., Jones, R.N., Kovats, R.S., Romero-Lankao, P., Larsen, J.N., Losada, I.J., Marengo, J.A., McLean, R.F., Mearns, L.O., Mechler, R., Morton, J.F., Niang, I., Oki, T., Olwoch, J.M., Opondo, M., Poloczanska, E.S., Pörtner, H.-O., Redsteer, M.H., Reisinger, A., Revi, A., Schmidt, D.N., Shaw, M.R., Solecki, W., Stone, D.A., Stone, J.M.R., Strzepek, K.M., Suarez, A.G., Tschakert, P., Valentini, R., Vicuña, S., Villamizar, A., Vincent, K.E., Warren R., White, L.L., Wilbanks, T.J., Wong, P.P. & Yohe, G.W. 2014. Technical summary. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. & White, L.L. (eds.). *Climate change 2014: impacts, adaptation, and vulnerability. part a: global and sectoral aspects. contribution of working group ii to the fifth assessment report of the intergovernmental panel on climate change.* Cambridge: Cambridge University Press. pp. 35-94.

Furch, K. (1984). Water chemistry of the Amazon basin: the distribution of chemical elements among fresh waters. En: H. Sioli (Ed.), The Amazon: limnology and landscape ecology of a mighty tropical river and its basin. *Junk Publishers,* Dordrecht, pp. 167-200.

Goiás (Estado) (2006). *Hidrogeologia do Estado de Goiás.* Série Geologia e Mineração, 1, por Leonardo de Almeida, Leonardo Resende, Antônio Passos Rodrigues, José Eloi Guimarães Campos. Goiânia: Secretaria de Indústria e Comércio. Superintendência de Geologia e Mineração. 232 pp.

Gomes, A.F., Nobre, A.A. & Cruz, O.G. (2012). Temporal analysis of the relationship between dengue and meteorological variables in the city of Rio de Janeiro, Brazil, 2001-2009. *Cadernos de Saúde Pública* [Online] 28(11): 2189-2197.

Gonzalez, R.J., Wilson, R.W., Wood, C.M., Patrick, M.L. & Val, A.L. (2002). Diverse strategies for ion regulation in fish collected from the ion-poor, acidic Rio Negro. *Physiological and Biochemical Zoology* 75: 37-47.

Heller, L. (2015). The crisis in water supply: how different it can look through the lens of the human right to water? *Cadernos de Saúde Pública* 31(3): 447-449.

Hespanhol, I. (2008). Herman, R.H. & Braga Jr., B.P.F. 1997, The Upper Tietê Basin, Case Study 6, p. 387-396, in *Water Pollution Control: a guide to the use of water quality management principles,* Helmer, R. & Hespanhol, I. Eds., p. 510. UNEP, WHO, E & FB Spon, London.

Hespanhol, I. (2012). Poluentes emergentes, saúde pública e reúso potável direto, cap. 20, p. 501-537, in: *Engenharia Ambiental: conceitos, tecnologia e gestão,* Coords. Maria do Carmo Calijuri & Davi Gasparian Fernandes Cunha, Elsevier Campus. 789 pp.ISBN: 978-85-352-5.

Hespanhol, I. (2015). A inexorabilidade do reuso potável direto, *Revista DAE* 194: 6-23.

Hespanhol, I. & Prost, A.M.E. (1994). WHO Guidelines and national standards for reuse and water quality. *Water Research* 28(1): 119-124.

Hirata, R., Foster, S. & Oliveira, F. (2015). *Urban groundwater in Brazil: evaluation for sustainable management.* Instituto de Geociências e FAPESP, São Paulo. vol. 1. 112 p. 1st ed.

Instituto Trata Brasil-DATASUS (2014). http://www.tratabrasil.org.br/saneamento-e-saude-3

Jørgensen, S.E., Tundisi, J.G. & Matsumura-Tundisi T. (2013). *Handbook of Inland Waters Ecosystem Management.* CRC Press London 422pp.

Junk, W.J., Bayley, P.B. & Sparks, R.E. (1989). The flood pulse concept in River-Floodplain Systems. In: D.P. Dodge (Ed.), Proceedings of the International Large River Symposium. *Can. Spec. Publ. Fish. Aquat. Sci.* p. 110-127.

Kelman, J. (2015). A crise da água na Região Metropolitana de São Paulo. En: *Apresentação do Presidente da SABESP à Comissão de Infraestrutura, em debate sobre a Crise Hídrica no Estado de São Paulo.*

Kosten, S. & Huszar, V. (2011). Warmer climates boost cyanobacterial dominance in shallow lakes. *Global Change Biology.* Discussion paper 1213. doi:101111/j.1365-2486.201102488.

Lampert, W. & Sommer, U. (2002). *Limnoecology*. Oxford: Oxford University Press, 335 pp. (2a ed.).

Machado *et al*. (2016). A preliminary nationwide survey of the presence of emerging contaminants in drinking and source waters in Brazil. *Science of the Total Environment* 572: 138-146.

Marengo, J.A. (2008). Água e mudanças climáticas. *Estudos Avançados* 22: 83-96.

Mierzwa, J.C. (2009). *Desafios para o tratamento de água de abastecimento e o potencial de aplicação do processo de ultrafiltração.* Tese apresentada à Escola Politécnica da Universidade de São Paulo para a obtenção do Título de Livre-Docente, pelo Departamento de Engenharia Hidráulica e Ambiental, 127 pp. São Paulo, SP.

Miziara, F. (2006). Expansão de Fronteiras e Ocupação do Espaço no Cerrado: o caso de Goiás. En: Guimarães, L.D., Silva, M.A.D. & Anacleto, T.C. (Orgs). *Natureza Viva Cerrado.* Goiânia: Editora da UCG, pp. 169-196 (1ª ed.).

Miziara, F. & Ferreira, N.C. (2008). Expansão da fronteira agrícola e evolução da ocupação e uso do espaço no Estado de Goiás: subsídios à Política Ambiental. En: Ferreia, L.G. (Org.). *A encruzilhada socioambiental: biodiversidade, economia e sustentabilidade no Cerrado.* Goiânia: Canone/CEGRAF-UFG, 1: 67-75.

Moxey, A. (2012). *Agriculture and water quality: monetary costs and benefits across OECD countries.* OECD study. 68 pp. www.oecd.org/agriculture/water

Mozetto, A.A., Silvério, P.F., De Paulo, F.C.F., Bevilacqua, J.E., Patella, E. & Jardim, W.F. (2003). Weakly-bound metals and total nutrient concentrations from some water reservoirs in S. Paulo State, Brazil. En: Munawar, M. (eds). *Sediment quality assessment and management: insight and progress.* Ecovision world monograph series. pp. 221-240.

Muller, A.P.B. (1999). *Detecção de oocistos de* Criptosporidium spp. *em águas de abastecimento superficiais e tratadas na RMSP.* Tese apresentada ao Instituto de Ciências Biomédicas, USP, para obtenção do título de Mestre em Ciências (Microbiologia). 109 p., São Paulo, SP.

Nasiri Nasiri, F., Savage, T., Wang, R., Barawid, N. & Zimmerman, J.B. (2013). A system dynamics approach for urban water reuse planning: a case study of the Great Lakes Region. *Stochasic Environmental Research and Risk Assessment,* 27(3): 675-691.

Nogueira, S.H.M., Ferreira, M.E., Fernandes, G.W., Callisto, C., Bezerra Neto, J.F., Macedo, M.N. & Latrubesse, E.M. Brazilian energy strategy damming rivers further threatens the Cerrado Hotspot. *Science of the Total Environment* (submitted).

Oki, T. & Kanae, S. (2006). Global hydrological cycles and world water resourses. *Science*, 313, 1068-1072.

Oliveira, A.M. & Val, A.L. (2017). Effects of climate scenarios on the growth and physiology of the Amazonian fish tambaqui (*Colossoma macropomum*) (*Characiformes, Serrasalmidae*). *Hydrobiologia* 789: 167-178.

O'Sullivan, P.E. & Reynolds, C.S. (2004). *The lakes handbook. Limnology and limnetic ecology.* Vol. 1. Malden: Blackwell Science Ltd. 711 pp.

Paerl, W.H. & Dawl, U.P. (2012). Climate Changes: links to global expansion of harmful Cyanobacteria. *Water Research*, 46: 1349-1363.

Paerl, H.W. Huisman, J. (2008). Blooms like it hot. Science, 32: 57-58. http://dx.doi.org/10.1126/science.1155398. PMid:18388279

Paerl, H.W., Xu, H., McCarthy, M.J., Zhu, G., Qin, B., Li, Y. & Gardner, W.S. (2011). Controlling harmful cyanobacterial blooms in a hypereutrophic lake (Taihu, China): the need for a dual nutrient (N&P) management strategy. *Water Research*, 45: 1973-1983.

Periotto, N. & Tundisi, J.G. (2013). Ecosystem Services of UHE Carlos Botelho (Lobo/Broa): a new approach for management and planning of dams multiple-uses. *Revista Brasileira de Biologia*, vol. 73, no. 3, p. 471-482. http://dx.doi.org/10.1590/S1519-69842013000300003. PMid:24212686

Rodrigues, D.M.T. & Miziara, F. (2008). Expansão da fronteira agrícola: a intensificação da pecuária bovina no estado de Goiás. *Pesquisa Agropecuária Tropical* 38(1): 14-20.

Santos, K.R.S. & Sant'Anna, C.L. (2010). Cianobactérias de diferentes tipos de lagoas ("salina", "salitrada" e "baía") representativas do Pantanal da Nhecolândia, MS, Brasil. *Revista Brasileira de Botânica* 33(1): 61-83.

Schindler, D. (2006). Recent advances in the understanding and management of eutrophication. *Limnology and Oceanography,* vol. 51, no. 1 part 2, pp. 356-363. http://dx.doi.org/10.4319/lo.2006.51.1_part_2.0356

Schindler, D.W., Hecky, R.E., Findlay, D.L., Stainton, M.P., Parker, B.R., Paterson, M.J., Beaty, K.G., Lyng, M. & Kasian, E.M. (2008). Eutrophication of Lakes cannot be controlled by reducing nitrogen input: results of a 37-year whole ecosystem experiment. *Proceedings of the National Academy of Sciences,* 105: 11254-11258.

Sinclair, R.G., Rose, J.B., Hashaham, S.A., Gerba, C. & Haas, C.N. (2012). Criteria for selecting of surrogates used to study the fate and control of pathogens in the Environment. *Appl. Environ Microbiol.* 78(6): 1969-1977.

Sioli, H. (1950). Das wasser im Amazonasgebiet. *Forschung Fortschritt* 26: 274-280.

Sistema Nacional de Informações sobre Saúde (SNIS) 2016. http://app3.cidades.gov.br/snisweb/src/Sistema/index

Snow *et al*. 2009. Detection, Occurrence, and Fate of Emerging Contaminants in Agricultural Environments. *Water Environment Research* 81(10). Water Environment Federation.

Sodré *et al*. (2010). Occurrence of emerging contaminants in Brazilian drinking waters: a sewage-to-tap issue. *Water Air Soil Pollution* 206: 57-67.

Tundisi, J.G. (2003). *Água no século XXI: enfrentando a escassez.* São Carlos, Brasil: RiMa, Instituto Internacional de Ecologia.

Tundisi, J.G. (Coord.) (2014). *Recursos hídricos no Brasil: problemas, desafios e estratégias para o Futuro.* Rio de Janeiro: Academia Brasileira de Ciências. 76 pp.

Tundisi, J.G. Reservoirs (2018). New challenges for ecosystem studies and environmental management. *Water Security* (Elsevier) in press.

Tundisi, J.G. *et al*. (2015). Water availability, water quality and water governance: the future ahead. *Hydrological Sciences and Water Security. Past, Present, Future.* IAHS Publ. vol. 366 pp.75-79.

Tundisi, J.G. & Matsumura-Tundisi, T. (2010). Impactos potenciais das alterações do Código Florestal nos recursos hídricos. *Biota Neotropica* 10(4): 67-76.

Tundisi, J.G. & Matsumura-Tundisi, T. (2018). Integrated management plan for the Itaqueri-Lobo watershed and UHE Carlos Botelho (Lobo/Broa) reservoir. Pp 125-128. In: Tundisi, J.G. & Matsumura-Tundisi, T. (eds). *Water Resources management.* Academia Brasileira de Ciencias; Unesco; IANAS; Fapesp: 248 pp.

Tundisi, J.E. & Matsumura-Tundisi, T. (2013). The ecology of UHE Carlos Botelho (Lobo/Broa reservoir) and its watershed, São Paulo, Brazil. *Freshwater Biology* 6: 75-91.

Tundisi, J.G., Matsumura-Tundisi, T., Ciminelli, V.S. & Barbosa, F.A.R. (2015). Water availability, water quality and water governance: the future ahead. In: Cudeneca *et al*. (eds). *Hydrological Sciences and Water Security: past, present, future.* PIALTS, 366: 75-79.

Tundisi, J.G., Rebouças, A.C. & Braga, B. (2002). *Águas doces no Brasil: capital ecológico, uso e conservação.* São Paulo: Escrituras Editora. (2ª ed.).

Val, A.L. & Almeida-Val, V.M.F. (1995). *Fishes of the Amazon and their environments. Physiological and biochemical features.* Heidelberg: Springer Verlag.

Val, A.L., Gomes, K.R.M. & Almeida-Val, V.M.F. (2015). Rapid regulation of blood parameters under acute hypoxia in the Amazonian fish Prochilodus nigricans. *Comparative Biochemistry and Physiology,* pp. 125-131.

Valente, C.R., Latrubesse, E.M. & Ferreira, L.G. (2013). Relationships among vegetation, geomorphology and hydrology in the Bananal Island tropical wetlands, Araguaia River basin, Central Brazil. *Journal of South American Earth Sciences* 46: 150e-160.

Viegas, M. & Hespanhol, I. (2002). Auditorias de certificação de sistemas de gestão ambiental: um estudo de caso. *Boletim Técnico da Escola Politécnica da USP,* BT/PHD/98, ISSN 1413-2192, CDU 502.35-657.6, 15 pp., São Paulo.

WHO & UNICEF (2017). *Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines.* Geneva: WHO and UNICEF. Licence: CC BY-NC-SA 3.0 IGO.

Wood, C.M., Robertson, L.M., Johansson, O.E. & Val, A.L. (2014). Potential linkage in native Rio Negro tetras (Paracheirodon axelrodi, Hemigrammus rhodostomus, and Moenkhausia diktyota). *Journal of Comparative Physiology,* ser. B, 184: 877-890.

World Health Organization-WHO (1990). *Basic Documents.* Geneva: WHO. 416 pp. 38th Ed.

World Health Organization-WHO (2011). *Guidelines for Drinking Water Quality.* Geneva: WHO. 541 pp. 4th ed.

Canada

Despite Canada's low population density and its vast land mass, it experiences considerable problems in relation to water pollution in some areas. Although the country's freshwater is relatively abundant, much of it is found in the lakes or rivers of the north that flow into that area, while over 90% of the human population lives on a narrow strip of the southern border with the United States, where water is relatively scarce. The few smaller rivers and lakes in southern **Canada** are used as drinking water sources as well as for waste disposal, which increases water quality problems. The growing scarcity of water as a result of climate change and the increased use of water by men portend greater problems for the future.

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Past, Present and Future Challenges to Management of Freshwater Quality in Canada

D. W. Schindler

Summary

Despite Canada's low population and large land mass, there are significant water pollution problems in some areas. While the country's freshwater is relatively abundant, much of it is in northern lakes or rivers that drain north, over 90% of the human population lives in a narrow band along the country's southern border with the USA, where water is relatively scarce. The few modest size rivers and lakes of southern Canada are used for both drinking water sources and waste disposal, amplifying water quality problems. Increasing scarcity of water as the result of climate change and increasing human water use promise increased problems in the future. A diversity of large polluting industries cause water quality problems even in northern areas with low populations, often via long-range atmospheric transport of pollutants that biomagnify to toxic levels in aquatic organisms that are used as human food. A poor and disjointed Canadian regulatory framework has caused a history of weak water policies, where protecting water quality has been subsumed by protecting industrial development. Droughts, floods and fires caused by climate warming and increasing populations are expected to exacerbate future water quality problems, even in remote areas. Increasingly complex effluents, population and industrial growth and climate change make it imperative that streamlined and coherent national water policies are developed, and investments in water research are increased.

Introduction

Water Quantity- a factor in water quality

Incredible as it may seem, many of Canada's water quality problems occur because of insufficient water quantity, causing the same water bodies to be 5used for both water withdrawals and disposal of wastes. As population and per capita water demand increase, climate is slowly sapping the amount of available water in some areas, intensifying usage of the remainder. There are historical reasons for this.

Before the mid-20th century, little attention was paid to either water quality or quantity issues in Canada. Perhaps lulled by the seeming abundance of freshwater and the rela-

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tively low human population in a large country, water quality was generally considered as a secondary policy issue, and priority was given to developing cities and industries while ignoring their water demands or water polllution. This "Myth of Abundance" has caused many important regional Canadian problems to be obscured. For example, the southern parts of Saskatchewan and Alberta known as "Palliser's Triangle" are effectively semi-deserts, where average evapotranspiration exceeds average precipitation, so that there is no net runoff. The area was settled in the early 20th century as a result of overly optimistic marketing by the Canadian Pacific Railroad during a series of wetter than average decades. The railway was anxious to promote agriculture in order to have customers to make it profitable. After rapid settlement in the early 20th century, since the late 1920s there has been a steady exodus of people, leaving numerous abandoned ghost towns" (Jones 1987; http://www.googlesightseeing.com/2011/06/ghost-towns-of-the-palliser-triangle/). A similar area where evapotranspiration equals or exceeds average precipitation is in British Columbia's Okanagan Valley, where rapid population growth and increasing orchard and wine industries compete for scarce water.

In the Laurentian Great Lakes basin, although water is abundant, only about one percent of the lakes' water is renewed on average each year. If water withdrawal exceeds this value, lake levels will decline. As a result, high population density and industrial demand require conservation measures, as will become obvious later in this chapter. Canadians tend to forget that 85% of the human population and industry occur in a 100 km band along the US border, whereas most large rivers in Canada flow north, with only their headwaters in populous latitudes (**Figure 1**). Outside of the Laurentian Great Lakes, research and monitoring of freshwater in Canada has been sporadic. Finally, the large proportion of Canada's surface covered with water is deceptive, with low temperatures and evaporation masking the fact that precipitation is low to moderate. The true measure of water that can be used sustainably is the annual runoff per unit area. In this respect, Canada does not rank unusually high. Canadian areal runoff is similar to the USA and China, two countries that have rather severe water quality problems. Canada's runoff per unit area is only about half that of truly water-rich countries like Finland, Brazil and Russia (Sprague 2007).

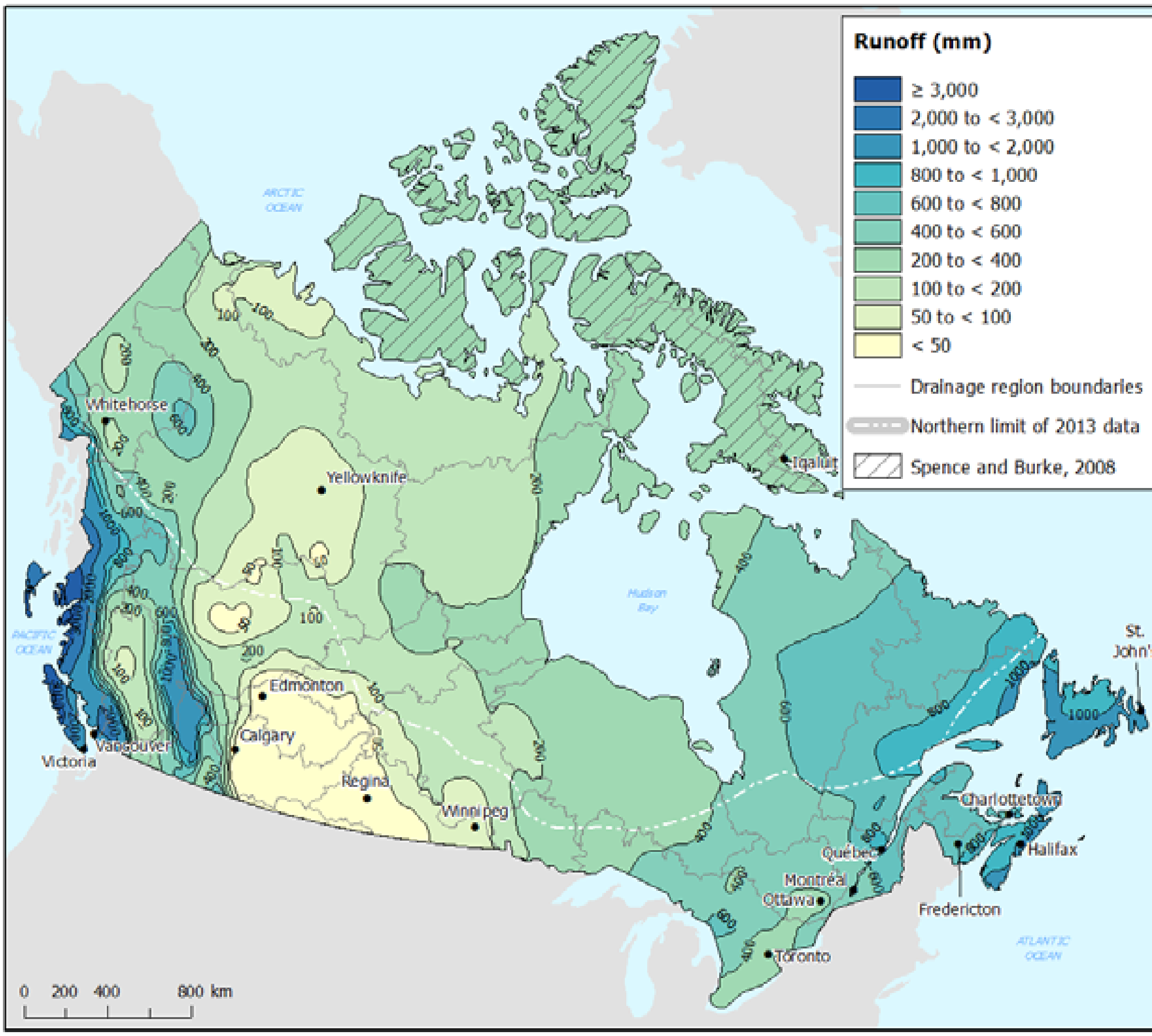
There were some astute early measures to protect freshwaters. The Boundary Waters Treaty of 1909 and the subsequent International Joint Commission (IJC) were set up by the governments of Canada and the USA to resolve water disputes in the Laurentian Great Lakes and other cross-border lakes and rivers. As mentioned earlier, the Great Lakes watershed is home to 33 million people in the USA and Canada, and is a center for industrial expansion. As a result, it has been the focus of Canadian water issues for most of the past century.

In the early years of the 20th century, disputes resolved by the IJC were primarily related to water use and modification of water flows rather than water quality. This changed in 1969 when the IJC reported a several year study of pollution in the Great Lakes that became a cornerstone of freshwater research in Canada. The above study (IJC 1969) warned that both the US and Canada needed to devote more effort to identifying and solving Great Lakes pollution problems. Most urgent at the time was the rapid proliferation of algal blooms in lakes Erie and Ontario, which were the subject of public concern on both sides of the border.

Canada's response to the IJC 1969 recommendations was to form two completely new institutes devoted to freshwater research. One, the Canada Center for Inland Waters (CCIW), was to be devoted primarily to work on the Great Lakes. It opened its doors in 1967 as a part of the federal Department of Energy, Mines and Resources. It was eventually placed within Environment Canada, a new federal government department that was formed in 1971.

The second institute, the Freshwater Institute (FWI), had a broad general mandate for freshwater research. It was initially managed by the venerable Fisheries Research Board of Canada (FRBC), but had a branch housed in CCIW to supply biological expertise to the physical and chemical units at CCIW. The FRBC liked to place its institutes on university campuses. The FWI was placed on the University of Manitoba campus, as the result of the university offering to lease the FRBC a building until it could construct its own. The FWI opened in September,1966. Its first director was Waldo E Johnson,

Figure 1. Average annual runoff in Canada, 1971 to 2013



Note(s): Runoff data were derived from discharge values from hydrometric stations with natural flows for the period 1971 to 2013 below the boundary delineated on the map and 1971 to 2004 above the boundary line with the exception of the Arctic Islands where estimates were taken from Spence and Burke, 2018.
Source(s): Statistics Canada, Environment, Energy and Transportation Statistics Division, 2017, based on data from Environment and Climate Change Canada, 2015, *Water Survey of Canada, Archived Hydrometric Data (HYDAT),* www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1 (accessed December 3, 2015); Spence, C. and A. Burk, 2008, "Estimates of Canadian Arctic Archipelago runoff from observed hydrometric data," *Journal of Hydrology*, vol. 362, pp. 247-259.

a senior fisheries scientist. About 1/3 of the FWI's personnel were initially devoted to the study of eutrophication, a new venture for the FRB. Fortunately, the Board was not bound by civil service rules, and was able to assemble an excellent staff in a very short time, largely by international recruiting. Johnson recruited J. R.Vallentyne, then a professor at Cornell University, and Richard Vollenweider, a very experienced Swiss scientist, to lead the Eutrophication Section and the branch at CCIW, respectively. A conspicuous feature of the FWI plan was to form a field station where experimental nutrient control policies could be tested in whole ecosystem settings.

The Fisheries Research Board of Canada (FRBC) was founded as the Biological Board of Canada in

1912, changed to the FRBC in 1937. The FRBC was managed by a group of prominent aquatic scientists at arms-length from government. The FRBC was world renowned for its excellent science to back sound water policies, both with respect to fisheries and more generally (Hayes 1973). With the IJC's 1969 report, policy makers were concerned that the many issues identified transcended the expertise and mandate of the FRBC. The organization was also considered aberrant by politicians, in that it did not report to a government ministry. This was changed in 1973, when FRBC personnel were transferred to Environment Canada and the FRBC was reduced to an advisory role. By 1979, the Department of Fisheries and Oceans was separated from Environment Canada, leaving different agencies in charge of water and fish, a strange dichotomy that exists to this day. The FRBC was disbanded, leaving federal research on water subject to political whim.

The Province of Ontario also had concerns about freshwater. Its new Ministry of Environment was formed in 1972 with water as its primary mandate, and a field station in Dorset, Ontario was added soon after. Some of Canada's most valuable research on eutrophication and acid rain was done at the Dorset Field Station, which exists today as the Dorset Environmental Research Consortium, a government-university-NGO partnership that still specializes in freshwater research.

Also in the1960s, Ontario started several new universities, including Laurentian (1960), Lakehead (1965) and Trent (1966) which would also develop strong environmental and aquatic programs. Older universities in Canada also began to strengthen their water programs about that time.

Aided by rapid developments in chemical methods and equipment during the mid 20th century, talented individuals in these groups made rapid progress in identifying and solving water pollution issues in Canada. All in all, the 1960s were the age of awakening in Canadian concern about freshwater.

Canada's Regulatory Nightmare

One of Canada's long-term water policy problems is that the Canadian Constitution does not explicitly recognize water, or which agencies are responsible for administering it. Formed in 1967 as part of the British North America Act proceedings, the Canadian Constitution is much weaker in many respects than most national constitutions. It reflects the fact that the various Canadian provinces, which had independently controlled their own resources until that time, jealously insisted on retaining most of their former rights. After constitutional deliberations, provincial retained control over natural resources, including water, except for national parks, indigenous reserves, military bases and northern territories, which are federal responsibilities. The federal government retained the regulation of fisheries and cross-border waters, although in some cases management was transferred later to provinces under federal-provincial agreements. Some municipalities have also formed their own regulations. The result has been an incoherent and inconsistent hodge-podge of standards, guidelines and objectives, with some jurisdictions less protective than others. The environment is general and water in particular are considered by all levels of government to be of secondary importance to economic development.

In 1970, in response to continuous disputes over provincial vs federal jurisdiction over water, and increasing public concern, Parliament passed the Canada Water Act, which formulates how federal and provincial jurisdictions are to share the responsibilities over water. It has been moderately successful (Booth and Quinn 1995) and remains in effect, with some minor changes from the original version. It remains subject to the personal whims and relative aggressiveness of federal and provincial politicians, and is generally still too weak to reliably protect freshwater.

Canadian water quality is generally protected by guidelines and objectives rather than regulations. These are not legally enforceable, and are often much more lenient than studies of toxicology or human health recommend. "It is apparent that water-related policies were more often incidental to other pursuits like fisheries, transportation and agriculture than a coherent subject area in their own right until after the Second World War (Quinn 2013).

Quinn (1985) provides a more detailed account of early water policies, and (Boyd (2003) discusses in detail many of the flaws in Canadian environmental laws that result of jurisdictional discrepancies. An attempt was made to gain consistency in the treatment of water issues across the country with the federal water inquiry of 1984 (Pearse *et al*. 1986) which crafted 55 recommendations that became the basis for draft federal legislation. The legislation was tabled in 1987, but an election intervened and it was never passed. It was subsumed by more inclusive but ill-defined policy foci, such as the "Green Plan," the "Ecosystem Approach" and the concept "Sustainable Development," which were (and still are) so vague and ill-defined that almost any treatment of water can be justified. Since that time, cutbacks to federal freshwater research and a new emphasis on resource development have slowly de-emphasized freshwater relative to other resources, despite repeated warnings that this is foolish (Pearse and Quinn 1996; Bakker and Cook 2011).

Another problem has been that most of the provinces do not have either high calibre water research institutions or officials capable of interpreting cutting edge aquatic science. In an era of rapid increases in industrial development, as well as rapid increases in scientific understanding, the result has been a record of unreliable, unsound and unpredictable decisions that affect freshwaters.

Despite all of these problems, Canada has maintained a reputation as one of the countries with the best water quality. The OECD ranks Canada fourth among 17 countries in water quality, with only Sweden, Norway and Austria ranked above Canada, all receiving an "A" grade (the USA ranked much lower on the OECD list, earning only a C). https://www.conferenceboard.ca/hcp/Details/Environment/water-quality-index.aspx .

With expanding population and industry, plus the regional or global threats of climate change, acid rain and long-range atmospheric transport of toxins, it is urgent for Canada to improve its environmental policies and their scientific underpinnings. This has been the topic of a number of scholarly books (most recently Bakker 2007; Brooymans 2011), but the problem is largely ignored by politicians and the public.

In the remainder of this article, I briefly outline some of the major water quality problems in Canada, progress that has been made in solving them since the mid-20th century, and problems that loom in the foreseeable future.

Eutrophication

In the mid-20th century, there was growing concern about the increases in algal blooms that were appearing in fresh and coastal waters of many countries. It was the focus of much of the above-mentioned IJC (1969) study in the St Lawrence Great Lakes, where widespread algal blooms were increasing in lakes Erie and Ontario, as well as coastal areas of the other Great Lakes. Eutrophication became the focus of much of the early work of the two new Canadian laboratories, CCIW and FWI, as well as the Dorset Field Station.

Eutrophication had been the subject of a 1967 symposium sponsored by the US National Academy of Sciences (NAS 1969). No consensus was reached on how to control the problem. A prominent Swiss limnologist, RA Vollenweider, attended the meeting. He was recruited by FWI to head its Great Lakes branch in Burlington, Ontario. Vollenweider had just finished a comprehensive review of the problem for the OECD, which concluded that increased inputs of phosphorus and nitrogen to lakes was the primary cause of the eutrophication problem. His unpublished tome (Vollenweider 1968) became the basis for attempts to control eutrophication in Europe and North America. Vollenweider later received the Tyler Prize for Environmental Achievement for this work.

The nutrient bases of Vollenweider's models were explored in whole lake experiments in northwestern Ontario at the Experimental Lakes Area (ELA), another part of the FWI research program on eutrophication. In a first experiment begun in 1969, Lake 227 was fertilized with phosphorus and nitrogen but not carbon, to test the theory promoted by the soap and detergent industry in the 1960s and early 1970s that carbon inputs must also be controlled to successfully curb eutrophication (Canadian Research and Development 1970). Their conclusion was based on the results of short-term laboratory experiments. At the time of fertilization, Lake 227 had the lowest concentration of dissolved inorganic carbon ever measured in freshwater. The lake quickly produced a large algal bloom once fertilized with phosphorus and nitrogen. The algae's shortage of carbon was found to be supplied from the atmosphere, quickly leading to the abandonment of the carbon theory. The experiment also exposed how unreliable poorly-scaled small scale experiments could be at predicting sound management policies for whole ecosystems (Schindler *et al*. 1972).

Based on Vollenweider's study, the IJC had proposed that controlling only one element, phosphorus, could control or reverse the eutrophication problem. This was reflected in the 1972 Water Quality Agreement between the two countries. Others believed that nitrogen must also be controlled, which posed a much more expensive problem. In an experiment to test these two theories, Lake 226 at the ELA was split in half with a heavy nylon curtain. Nitrogen and carbon were added to both halves, but phosphorus was only added to one half. Only the side receiving phosphorus produced an algal bloom (Schindler 1974). The strikingly visible difference between the two basins resulted in phosphorus input being reduced in Canada, the USA and many European countries. In the Great Lakes, amendments to the IJC-sponsored water quality agreement in 1983 required even more stringent control of phosphorus http://www.ijc.org/en/activitiesX/consultations/glwqa/guide_3.php .

Significantly, these early agreements ignored growing evidence that non-point sources like agricultural runoff were contributing significantly to the phosphorus input to the lakes, even though they were already important in lakes Erie and Ontario. The federal Pollution from Land Use Reference Group (PLUARG) studied this problem for several years in the 1970s. Their 157 page final report: http://agrienvarchive.ca/download/PLUARG_pollution_great_lakes_land_use.pdf in 1980 spelled out the problem in some detail, pointing out that water quality objectives for lakes Erie and Ontario could not be achieved without considerable reduction in non-point sources. However, following the earlier policies to control point sources, eutrophication fell from political fashion and funds for research and monitoring were cut back by both Canada and the USA. As a result, although all of the Great Lakes have achieved the water quality objectives for phosphorus that were set in the 1970s (Dove and Chapra 2015), algal blooms still plague areas of lakes Erie and Ontario with the highest phosphorus input from land use (Michalak *et al*. 2013).

Schindler (1977) summarized results of the whole lake experiments with nutrients at ELA, noting that algal blooms eventually became proportional to phosphorus concentrations in all lakes, regardless of the amount of nitrogen or carbon added. He hypothesized that in-lake mechanisms were responsible for enhancing inputs of carbon and nitrogen from the atmosphere, supplying enough of these two elements to keep algal blooms proportional to phosphorus loading. This conclusion went unchallenged until the new millennium, when the controversy over whether nitrogen inputs to lakes also need to be controlled resurfaced (Lewis and Wurtsbaugh 2008). Nutrient additions to small, short term bottle and mesocosm experiments continue to used as evidence that it is necessary to decrease nitrogen inputs in lakes to control eutrophication. However, such experiments ignore the long-term (years) responses of the biogeochemical cycles of lakes to correct deficiencies in nitrogen (Schindler 2012; Schindler *et al*. 2008; Higgins *et al*. 2017). As Vitousek *et al*. (2010) pointed out, much of the evidence used to promote nitrogen control is based on experiments that show only proximate (short term) nutrient limitation, whereas decreasing eutrophication requires reductions in ultimate (long-term) nutrient limitation, which in the case of lakes, is phosphorus.

In an extreme experimental test, in 1989 nitrogen fertilizer ceased to be added to Lake 227, while phosphorus addition continued. The lake has remained eutrophic for the ensuing 29 years. Despite the predictions of critics (Scott and McCarthy 2010), nitrogen fixation has supplied enough nitrogen to produce algal blooms in proportion to phosphorus, even though proximate nitrogen limitation is observed for about half the summer each year (Paterson *et al*. 2011; Higgins *et al*. 2017). As further proof of the effectiveness of controlling phosphorus, many lakes in North America and Europe have now recovered from eutrophication by reducing phosphorus inputs alone, although in some cases, phosphorus return from sediments has delayed recovery by several years (Schindler *et al*. 2016).

More recently, eutrophication has become a problem in western Canada, largely as the result of non-point sources such as feedlots (Chambers *et al*. 2001). Phosphorus inputs and algal blooms on Lake Winnipeg more than doubled in the 1990s, as the result of intensive use of fertilizers and expansion of the pork industry in the Red River watershed, in both Canada and the USA. To exacerbate transport of nutrients from land to water, the Red River had five floods in 15 years that were at the one in 100 year flood level (Schindler *et al*. 2012). Eutrophication has also been widespread in the western prairies, as the result of lakeshore development in areas where many lakes are eutrophic under pristine conditions, so that even rather small human influence results in hypereutrophy and nuisance algal blooms. The lakes are shallow, and geologically susceptible to recycling of phosphorus from sediments (Orihel *et al*. 2017).

Acid Rain

Although some of the first research on the effects of acid rain was done in Canada (Gorham and Gordon 1960), it was not recognized as a widespread problem here until well after it had been documented in Scandinavia and the USA in the late 1960s. Thorough study of acid rain in Canada did not begin until the mid-1970s, when it became obvious that emissions of sulfur and nitrogen oxides in southern Canada and the northeastern USA were causing precipitation with average pH below 5 to fall in acid-sensitive parts of the Canadian Shield that contained thousands of lakes, and soils poor in the base cations that neutralize acid rain in less sensitive areas (Schindler *et al*. 1981).

Initial research was focused on toxicity of hydrogen ion to sport fish, using short-term bioassays. It was concluded that damage did not begin to occur until lakes had been acidified to pH<5. However, controlled acid additions to small, intensively studied experimental lakes showed that damage to important organisms lower in the food web and to key biogeochemical processes occurred at pH values as high as 6, ten times less acidic than laboratory toxicity tests had indicated (Schindler *et al*. 1985; Rudd *et al*. 1988). Once such damage was recognized, emissions of sulfur oxides in Canada were reduced rapidly. Sources, although large, were few in number, and most industries made voluntary reductions. Recovery in Canadian lakes did not begin to occur until reductions were also made to American sulfur oxide emissions, beginning in 1990. The recovery of lakes has been uneven, because of several factors, including declining base cation concentrations, drought-induced mobilization of SO4 in wetlands, damaged internal alkalinity generation mechanisms, and increasing nitrate or organic anion levels (reviewed by Jeffries *et al*. 2003). Little attention has been paid to monitoring lake recovery in the past two decades.

It was first reasoned that nitrogen oxides would not need to be controlled because the nitrates formed in the atmosphere before deposition would be neutralized by plant uptake once they reached the biosphere. However, examples in Europe showed that with increased deposition of nitrates, forests quickly became saturated, leading to runoff of nitric acid and removal of base cations from soils (Dise *et al*. 2011). Canada still pays little attention to oxides of nitrogen, ranking 16th of 17 countries in per capita emissions: https://www.conference-board.ca/hcp/Details/Environment/urban-nitrogen-dioxide-concentration.aspx?AspxAutoDetectCookieSupport=1 .

Controlled additions of nitric acid to small experimental lakes also indicated that biological uptake and neutralization of nitrogen was low in the absence of phosphorus, causing acidification to occur (Rudd *et al*. 1990). Studies in eastern Canada and other areas with base-poor soils showed that long-term emissions of nitric acid have depleted base cations, particularly calcium, enough to threaten forest regrowth after logging (Watmough *et al*. 2005). Once soils become sufficiently calcium depleted, runoff of the element from watersheds causes calcium depletion in lakes as well, leading to the elimination of Daphnia and other calcium-sensitive crustaceans and molluscs. The *Daphnia* are often replaced by *Holopedium*, an acid-tolerant crustacean which has a large gelatinous carapace that is more difficult for zooplanktivores to ingest. The resulting high abundance of *Holopedium*, has led some to refer to the result as the "jellification" of lakes (Jeziorski *et al*. 2008). Due to weak policies to reduce nitric oxide emissions in Canada, the acidification problem remains, although reduced in intensity.

While additional reductions in acid rain are desirable in eastern Canada, since the 1980s new acid rain concerns have developed in western Canada, where acidifying emissions from Alberta's oil sands industry are carried over acid-sensitive Precambrian Shield in northwestern Saskatchewan (Whitfield and Watmough 2012). Spring acid pulses have also been recorded in some streams in the oil sands region, although the impacts on species and biodiversity are still largely unknown (Alexander *et al.* 2017). The acidification problem is expected to increase as oil sands mining continues to expand. One large contributor to acidifying emissions is the high emission of nitrogen oxides from large trucks used for hauling bitumen.

Toxic Mine Drainage and Emissions

Mining has been one of Canada's traditional industries, and related pollution has caused regional problems in many areas of the country, the result of lax regulation. Over 10,000 abandoned mines were already on file at the turn of the new millenium (Mackasey 2000). These range from coal to base metal, oil sands, diamond and uranium mines. Weak regulations and unscrupulous developers have often left restoration of abandoned mining sites incomplete, leaving leakage of toxins and other problems for future generations of taxpayers to look after. Many of the mines have cleanup costs that are so prohibitive that instead of reclamation, they have been relegated to "perpetual care," where government departments prevent leakage of toxins and otherwise maintain the integrity of sites without correcting the problem. In 2002, the reported annual cost of such care was $20,000,000 for the Northwest Territories alone (Auditor General of Canada 2002). The cost of reclaiming abandoned mines of the North was estimated to be over $700,000,000.

The most notorious recent reclamation problem is the Giant Mine, which extracted gold from underground and open pit mines only 5 km north of Yellowknife, NWT. Between 1948 and 2004, when the mine was in operation, it produced over 220,000 kg of gold. In response to public concerns about releases of toxic arsenic dust to the atmosphere, in 1951 the mine started to blow arsenic trioxide dust into underground shafts that had been mined, reasoning that permafrost would keep the arsenic permanently in place. When the mine closed, over 237,000 tonnes of arsenic trioxide had been stored in this way. However, during the same period, climate has warmed at least 3 degrees in the area, and subsidence of permafrost is causing the stored arsenic to be mobilized as water is flooding into the mine. Current plans include the perpetual use of freezing technology similar to that used for ice rinks to keep the arsenic trioxide frozen in place. The remediation cost to taxpayers was estimated to approach 1 billion dollars in 2013 https://www.cbc.ca/news/canada/north/yellowknife-s-giant-mine-cleanup-costs-to-double-1.1313262 .

The Colomac Mine was an open pit gold mine 222 km north of Yellowknife. It operated for only four years between 1990 and 1997, and was never profitable. A 76 ha tailings lagoon contained by an earthen dike is contaminated with cyanide, toxic metals and ammonium, which if the dike is breached, would spill into the Indin River, the drinking water supply for downstream Dene communities. Remediation was estimated to cost $70 million in 2002 (Auditor General of Canada 2002). Remediation is reportedly complete, done in partnership between the federal government and Indigenous communities https://www.canada.ca/en/environment-climate-change/services/federal-contaminated-sites/success-stories.html#colomac . Monitoring continues at the site, but no actual costs or assessment of success have been released.

Among the most acutely affected mining sites is the vast oil sands area of northeastern Alberta, where over 4800 km^2 can be surface mined for bitumen. Tailings ponds alone had a total area of 220 km^2 in 2017, containing 1.2×10^{12} liters of toxic tailings behind earthen dikes as high as 90 m. While current rules state that tailings ponds must be ready to reclaim within 10 years after mining ceases, the rules are not enforced. There are fears that reclamation of the oil sands will be too costly, and that companies will simply walk away, leaving the burden on Canadian taxpayers. In 2015, only 1.9 billion dollars in securities had been guaranteed by oil sands companies, but recent revelations under the Freedom of Information Act indicate that the true cost of reclamation is estimated to be $260 billion https://www.thestar.com/news/investigations/2018/11/01/what-would-it-cost-to-clean-up-albertas-oilpatch-260-billion-a-top-official-warns.html . Only 0.6% of this sum has been set aside by the industry, suggesting that reclamation will largely be funded by the public, if it is done at all.

Water from the oil sands tailings ponds is acutely toxic to a wide variety of organisms. Tarry floating bitumen sludge is lethal to birds and animals entering the ponds, and high concentrations of naphthenic acids, polycyclic aromatic hydrocarbons, toxic trace metals and other pollutants are known, in addition to salinity that is far higher than federal or Alberta guidelines.

There is concern that seepage from the tailings ponds could contaminate the water of the nearby Athabasca River. A recent study (Frank *et al*. 2014) used a "fingerprinting" technique based on similarities in suites of organic compounds to prove that contaminants from the tailings ponds are reaching the river. Estimated seepage is 6.5 million liters per day. The resulting concentrations of contaminants in the river are small because they are diluted by an average of 780 m-3s-1 of water from upstream of the oil sands, leading industry spokespeople to assure the public that all is well. Airborne emissions from tailings ponds are also believed to be a significant regional source of semi-volatile organic pollutants (Parajulee and Wania 2015).

The scenario where a breach in a tailings pond dike is caused by an engineering flaw or natural disaster is never discussed, although such failures have produced expensive and ecologically devastating results in tailings ponds elsewhere (Blight and Fourie 2005), even though amounts of tailings released were much smaller than could occur in the oil sands. A dike breach in a large oil sands tailings pond would be particularly destructive if it occurred in winter, so that releases were under ice, as they could be carried into Lake Athabasca and the Slave River, eventually reaching Great Slave Lake and the Mackenzie RIver.

On October 31, 2013, a tailings pond dike was breached at the Obed Mountain Coal Mine, discharging into the Athabasca River 1100 km upstream from its mouth, releasing 670,000,000 liters of coal slurry into the Athabasca River. Ice was forming on the river at the time, and ice-cover prevented effective monitoring of the progress of the spill as it was carried downstream, or of its toxicity to aquatic life. The spill, which included arsenic, toxic metals, and PAHs, was traced the entire length of the river, into Lake Athabasca (Cooke *et al*, 2016). The company was fined $4.5 million dollars by federal and provincial governments.

In a similar, but unrelated incident, on August 3 and 4 2014, the tailings pond dike at Mount Polley copper and gold mine in British Columbia breached, sending 21 billion liters of water and tailings into watercourses leading to Quesnel Lake, an important sockeye salmon nursery. The dam was found to be poorly constructed, and a major crack had been reported in 2010. Some attribute the disaster to cutbacks in the British Columbia government's frequency of mine inspections a few years earlier. The investigation is still ongoing, and to date no charges have been laid. Meanwhile, recent reports of a healthy salmon return indicate that the effects of the spill may have been insignificant https://www.wltribune.com/news/sockeye-salmon-return-in-droves-to-quesnellake-watershed/ . Unless regulations are tightened, a disastrous tailings pond release is highly likely in Canada, especially in the oil sands, where dikes and tailings ponds are much larger and more toxic than those in the above examples.

Mercury

Few pollutants have caused as great a problem in Canadian waters as mercury. Foremost among infamous mercury problems is the case of the Wabigoon River and the Indigenous communities of Grassy Narrows and Whitedog in northern Ontario. In 1962, Dryden Chemical Company began operating a chlor-alkali process to produce sodium hydroxide and chlorine for bleaching paper during production by the nearby Dryden Pulp and Paper Company. Both companies were owned by the British multinational, Reed International.

The effluent from the chlor-alkali plant was discharged directly into the Wabigoon-English River system downstream of Lake Wabigoon. In 1970, extensive mercury contamination was discovered in the river system, leading to closure of the commercial fishery, and destroying the livelihoods of Grassy Narrows and nearby Whitedog, two First Nations over 100 km downstream that relied on fish for subsistence and income from guiding sport fishermen. In March, 1970, the Ontario provincial government ordered Dryden Chemical Company to cease dumping mercury into the river system. It was estimated that over 9,000 kg of mercury had been dumped by the company into the Wabigoon-English river system. The company stopped using mercury cells in its chlor-alkali process in October 1975 and closed a year later.

By the time the problem was discovered, the river system and its fauna had been severely contaminated. Predatory fish contained over 10 ppm of mercury, almost all of it in the toxic methylmercury form. Early investigators of the problem recommended mitigation (Rudd and Turner 1983, Parks and Hamilton 1987), but authorities believed that the river would clean up itself over time. Over 5 decades, mercury in fish has declined to about 1/3 of initial values, but concentrations are still too high in fish for human consumption (2-4 ppm in predatory species), and mercury in both fish and bottom sediments are several times higher than in nearby reference lakes. Moreover, concentrations in both fish and sediments have reached a plateau that has changed little in the past two decades (Rudd *et al*. 2017).

Rudd *et al*. (2017) found that there were still potential sources of mercury at the original site of the chlor-alkali plant, as well as nearby waste disposal sites, and there are current plans to remediate the area. But sediments in the river and lakes downstream of the pulp mill are still highly contaminated with mercury which is recycled each year, and remediation plans have not been finalized.

As a result of eating contaminated fish, by the late 1960s people from Grassy Narrows and Whitedog were found to have symptoms of Minimata Disease. Mercury concentrations were often over 100 ppb in the blood of people from the First Nations, and values over 200 ppb were recorded in some cases. Neurological symptoms and other disorders related to mercury poisoning were observed that were similar to those observed following mercury exposure at Minimata Bay, Japan. Symptoms were still widespread when the community was examined in 2010 (Takaoka *et al*. 2013). In 2018, an epidemiology report showed that the general health of all ages in the community was poorer than in other indigenous communities, and in rural communities at large https://www.cbc.ca/news/canada/thunder-bay/grassy-narrows-health-report-release-1.4675091. The report has still not been publicly released. As a result of the accumulating evidnece, in 2017 the province of Ontario allocated funds for remediation of the Wabigoon River system, but it is still in the planning phase.

Major mercury poisoning problems for Indigenous People in Canada also follow construction of hydroelectric reservoirs (Calder *et al*. 2016). Studies in Manitoba, Ontario and Quebec have all shown that soils and vegetation inundated when reservoirs are flooded release mercury and enhance methylation by bacteria (Bodaly *et al*. 1984; Kelly *et al*. 1997; Schetagne *et al*. 2013). As in the case of Grassy Narrows, methyl mercury is biomagnified in food chains to reach concentrations in fish that require consumption restrictions if human health is not to be jeopardized.

Mercury in fish typically remains high for 10-30 years after a reservoir is flooded (Rosenberg *et al*. 1995; Munthe *et al*. 2007). Fish are therefore lost as a resource to subsistence users for at least two generations, a clear violation of treaty rights as well as human rights.

Even airborne mercury concentrations have increased enough to cause problems at some remote locations. Mercury is released by high temperature combustion, because it is very volatile. After emission, it can be carried in the atmosphere for long distances before being re-deposited, contaminating lakes in remote areas (Chételat *et al*. 2015). Lakes in such regions often contain predatory species that are long-lived but slow growing, ideal conditions for biomagnifying mercury to high values. For example, Kidd *et al*. (1995) found that long food chains in northern lakes often biomagnified mercury concentrations to values in lake trout that required consumption advisories. Similar results have been found throughout the Canadian arctic during the Canadian arctic contaminants program (Muir and DeWitt 2010; Chételat *et al*. 2015).

While the global fallout of atmospheric mercury is known to have increased by about 3- fold since the industrial revolution (Fitzgerald *et al*. 2005), recent studies have also implicated regional sources. Kelly *et al*. (2010) found elevated mercury concentrations (as well as concentrations of many other contaminants) in snow within a 50 km radius of the center of oil sands upgrading. Radmanowich (2012) found slightly higher concentrations of mercury in water and fish in the Athabasca River downstream from the same sources. Hebert *et al*. (2013) found that farther downstream on the Athabasca River, the eggs of fish-eating birds have increasing concentrations of mercury in eggs over the past 30 years. The Indigenous communities that rely on fish or birds are being affected by the resulting consumption advisories. Unfortunately, Canada's current plan for controlling emissions of greenhouse gases http://publications.gc.ca/site/eng/9.825953/publication.html includes building the equivalent of 100 large hydroelectric reservoirs before 2040, largely on northern rivers where they would contaminate fish and other aquatic animals with mercury, violating human rights and the terms of Canada's numbered treaties, which are supposed to protect the rights of Indigenous People and guarantee their ability to subsist on their traditional lands (Schindler 2018).

Climate warming can exacerbate mercury pollution. In general, forests and wetlands sequester mercury that enters from the atmosphere, preventing almost all of it from entering downstream waters. However, when forests burn, they release much of the mercury stored in soils and vegetation, causing elevated concentrations in downstream waters (Kelly *et al*. 2006). Forest fires in Canada have already increased greatly in area and intensity, so that more mercury will enter downstream water bodies. Swanson *et al*. (2006) also found that the invasion of native fish communities by alien rainbow smelt *Osmerus mordax* caused mercury to increase in predatory fish, due to alteration of the food chain.

Invasive Species

One of the most pernicious of freshwater problems in Canada has been the introduction of "biological pollutants" by the accidental or deliberate introduction of species from other continents. Again, the Great Lakes are the best documented example, with over 180 non-native and invasive species known to be introduced, the most of any ecosystem in the world (Pagnucco *et al*. 2015). Unfortunately, the damage caused by invasive species often goes beyond the ecological. They can threaten human health and hurt the Great Lakes economy by damaging critical industries such as fisheries, agriculture, and tourism. Reviewing this topic would take many pages, but I will give a few examples to illustrate the importance to the Great Lakes and humans in the watershed.

The first of many problem invaders was the sea lamprey *Petromyzon marinus*, which is native to the Atlantic Ocean. It was observed in Lake Ontario as early as 1835, but Niagara Falls prevented it from entering other Great Lakes until it entered via the newly completed Welland Canal sometime in the 19th century. Lampreys spread slowly through the other Great Lakes, reaching even Lake Superior by 1938. In the 1940s, lamprey populations exploded, devastating the lucrative lake trout, lake whitefish and cisco fisheries which once yielded 7 million kg of fish per year. Within a few years, fisheries were reduced to about 2% of pre-lamprey values. Expensive lamprey control programs have been in place for several decades, but have not eliminated the species http://www.glfc.org/sea-lamprey.php.

According to NOAA, "Species such as the zebra mussel, quagga mussel, round goby, sea lamprey, and alewife reproduce and spread, ultimately degrading habitat, out-competing native species, and short-circuiting food webs. Non-native plants such as purple loosestrife and Eurasian watermilfoil have also harmed the Great Lakes ecosystem.

Zebra mussels and quagga mussels *Dreissena polymorpha* and *D. bugensis* are believed to have been introduced in the late 1980's by ballast water from transoceanic ships carrying veligers (larvae), juveniles or adult mussels. Zebra and quagga mussels are capable of heavily colonizing both hard and soft surfaces, including, docks, boats, break walls and beaches. Colonies of these species are also responsible for clogging intake structures in power stations and water treatment plants, where removal is costly and time consuming. Zebra mussels have continued to invade other waters, including small lakes in Canada and the USA, and in 2014, Lake Winnipeg. They can live several days out of water, and are probably transported between lakes by small boats, where they attach to hulls, motors and anchors. Many areas have introduced compulsory cleaning stations, where boats entering the area must be cleaned and inspected before entering, in an attempt to slow the spread of zebra mussels.

Invading mussels provide another example of how water quality can be affected by factors other than chemicals. The invasive mussels filter water much more rapidly than native species, clearing the water and excreting nutrients near the bottom of the lake. This has caused a proliferation of attached algae, such as *Cladophora*, in nearshore areas, in a so-called benthic shunt". The algal mats are not effectively consumed by herbivores, instead senescing and blowing ashore where they cause nuisance windrows and taste and odor problems (Hecky *et al*. 2004).

Many of the other invaders have harmed the Great Lakes aquatic community, which bears little resemblance to its pristine condition.

Canada's Drinking Water

Most large cities in Canada have excellent drinking water, with modern treatment plants designed by water quality specialists, and supported by state of the art electronic monitoring and control systems that are upgraded frequently. Source water can be a problem, particularly in the western prairies, where major rivers are used for both water supplies and waste disposal. As a result, there have been some rather classic cases of waterborne disease.

As one example, the City of Edmonton began experiencing increasing reports of flu-like symptoms in late 1982, when about 700,000 people were served by two drinking water treatment plants. The outbreak continued for several months, with the city first denying any responsibility. Eventually, the outbreak was diagnosed as giardiasis, the result of contamination of water supplies with the protozoan *Giardia lamblia,* which is resistant to chlorination. Over 800 cases of giardiasis were confirmed, and it was estimated that the total number of people infected was probably an order of magnitude larger. It was found that the water intake of one of the city's water treatment plants was downstream of storm drainages that combined sewage and stormwater during storm events (Hrudey and Hrudey 2004), As a result, water treatment and water disposal in the city were completely overhauled, including UV treatment to kill protozoans.

In contrast, many small communities have limited expertise and resources, relying on infrastructure that is decades old and in bad repair, and poorly trained personnel. For example, Walkerton, Ontario suffered an outbreak of *E. coli* infection in May of 2000, just after a large rainstorm had caused flooding in the area. Seven people died, and over 2000 were ill. Investigations revealed that one of the groundwater wells that were used as water sources was contaminated by runoff from a nearby feedlot during the flooding. A chlorinator was not working, and plant operators were neglecting monitoring safeguards and deliberately fudging data. The community had a boil water order in place for several months, and the incident was the subject of a judicial inquiry http://www.archives.gov.on.ca/en/e_records/walkerton/index.html.

In March, 2001, flu-like symptoms became common in residents of North Battleford, Saskatchewan, a town of 14000. The town's water intake actually lay downstream of the effluent from its water treatment plant. Eventually, the problem was diagnosed as cryptosporidiosis, the result of contamination of water supplies by *Cryptosporidium parvum,* which like *Giardia* is resistant to chlorination. Three people died and several thousand were ill. It too was the subject of a judicial inquiry http://www.publications.gov.sk.ca/freelaw/Publications_Centre/Justice/NorthBattlefordWater/NorthBattlefordWaterInquiry.pdf.

Eventually, it was discovered that feedlots in the upper reaches of the North Saskatchewan River were the probably source of *Cryptosporidium* oocytes for both Edmonton and North Battleford (Hrudey and Hrudey 2004). Numerous other towns and cities draw their water from the river, and are at similar risk. Given that the highest concentrations of large feedlots and highest applications of manure to cropland are in Alberta, rivers in that province appears to be particularly vulnerable to contamination https://www150.statcan.gc.ca/n1/pub/16-002-x/2008004/c-g/manure-fumier/map-carte001-eng.htm.

The drinking water problem is particularly acute in the southern prairies, where source water is scarce and often of poor quality. Early settlers had great difficulty in coping with the lack of potable water in southern prairie regions. In 1960, the Prairie Farm Rehabilitation Administration (PFRA) began to recommend that prairie farmers construct their own "dugouts" to catch runoff water at snowmelt that could be used as water supplies http://www.pfra.ca/doc/Dugouts/Miscellaneous/DugoutsForFarmWaterSupplies_1985.pdf. Many dugouts are still in use, but many have been plagued by contaminants, algal blooms and toxin, taste and odor problems. In the vicinity of major cities, many rural communities are simply piping water from the large modern water plants, but this is not possible for communities far from such modern facilities. Typically, over 1000 boil water advisories are in place in Canada, with some unchanged for a year or even several years http://www.watertoday.ca/map-graphic.asp.

Worst of all are the drinking water problems of indigenous communities, which lie under federal rather than provincial purview, usually with very low operating budgets. In 2018, 91 First Nations have long-term drinking water advisories in place. The federal government has recently promised to eliminate the advisories by 2021, but this seems unlikely with over 1000 First Nations having water treatment plants, many of them needing replacement or upgrading. The Parliamentary Budget Office has estimated that the goal will cost $3.2 billion.

Several problems, some of them unique, hinder the eradication of drinking water problems in First Nations. Many have poor water sources, with high turbidity, high dissolved solids or high nutrient concentrations, or high arsenic. Standard approaches to disinfecting waters with high turbidity or dissolved solids involve adding large amounts of chlorine. Many indigenous communities do not like the resulting taste, and it is widely known that the combination of high chlorine and high dissolved solids produces trihalomethanes and other carcinogens. Although the increased incidence of cancers is very low, people generally avoid using the water.

Another problem is a shortage of qualified water treatment plant operators. Federally sponsored trainers are few in number, and the turnover in plant operators is high, because wages are low for a job with such high responsibility.

Many indigenous communities are spread out over broad areas, with houses some times a kilometer or more apart. Installing and maintaining a distribution system is expensive, and in many cases cisterns or barrels are used to store water instead, inviting secondary contamination.

There have been a few small success stories that should serve as models for what could be done. The Safe Drinking Water Foundation is a small non-profit organization that was formed to promote education about drinking water and to help solve the drinking water problems of prairie First Nations. As their first case, SDWF's sole engineer, Hans Peterson was invited to Yellowquill First Nation, northwest of Yorkton, Saskatchewan in 1999. Yellowquill had a boil water advisory in place since 1985. Neither a conventional water treatment plant nor a reverse osmosis (RO) plant had been successful. Reverse osmosis membranes clogged within hours, requiring unacceptably frequent flushing. The problem was dissolved organic carbon of 25mg L^{-1}, which also caused the water to be dark brown in color.

Peterson reasoned that the dissolved organic matter probably contained large refractory molecules that were difficult to break down, quickly clogging the RO membranes. He added a long biological pre-filter to the water intake. He also used state of the art reverse osmosis membranes. The result was successful, and in 2004, the water treatment plant was officially opened. http://ammsa.com/publications/saskatchewan-sage/clean-water-flowing-yellow-quill-taps

Local operators were trained to run the plant and it has been serving the community since that time. Peterson's IBROM (Integrated Biological and Reverse Osmosis Membrane) plant has now been duplicated at several other First Nations, where it has dealt successfully with a wide variety of source water problems, including toxic cyanobacterial blooms and high arsenic https://www.safedrinkingwaterteam.org/ibrom/. A small Saskatchewan company, Sapphire Water, now produces its own SIBROM plants commercially https://www.sapphire-water.ca/.

IBROM plants have a number of features that are appreciated by First Nations. They do not require addition of large amounts of costly chemicals. After treatment, water is trickled through a mineral filter to restore calcium and magnesium, making the water less corrosive, and a very small amount of chlorine to prevent secondary contamination. The plants occupy little space, and require little maintenance. Plant operators and a few outside experts have formed the Safe Drinking Water Team (see above website) to help solve water problems at First Nations and in other small communities. The largest plant in operation is at Saddle Lake, Alberta, where it supplies drinking water to over 6000 people of the provinces second largest First Nation. At least 21 IBROM plants are now in operation. The IBROM process is described by Peterson *et al.* (2007).

Many of western Canada's cities are located on rivers, where they were originally founded as transportation hubs, because most of the early travel used the rivers as highways. They both draw their water and discharge their sewage into the same rivers. Modern personal care products, including pharmaceuticals, birth control hormones, and cosmetics are of concern, because they do not degrade as rapidly as sewage, and some contain nanomaterials which have not been thoroughly assessed. Although concentrations are small, they are still of concern as endocrine disruptors or for causing selection for drug resistant microbiological communities.
Feedlots draining to the rivers also add pharmaceuticals and endocrine disruptors.

In one spectacular test, Kidd *et al*. (2007) added a small amount (5-6 ngL^{-1}) of the synthetic estrogen in birth control pills (17a-ethynyloestradiol; EE2) to a small lake at the ELA for three summers. There were rapid changes in the gonadal tissues of both males and females of the fathead minnow *Pimephales promelas* leading to reproductive failure and a collapse of the fish population. Other fish species were less sensitive, and insects, zooplankton and algae were unaffected. Indeed, some invertebrate populations increased, which was attributed to the decrease in predation pressure when fathead minnows declined. Effects on the fatheads persisted for two years after addition of the estrogen ceased, but the population has since recovered to pre-treatment levels (Kidd *et al*. 2014). Evidence of endocrine disruptors has been often reported downstream of sewage effluents (Falconer 2006).

Agriculture and forestry are also known to release chemicals that are endocrine disruptors, and feminized fish have been found in areas where effluents from feedlots and pulp mills discharge into rivers.

A wide variety of pharmaceuticals and personal care products are found in Canadian drinking water, especially where major rivers are water supplies for several cities. Antibiotics, endocrine disruptors, micro particles of plastic, cosmetic chemicals and a variety of miscellaneous chemicals are flushed into waters with sewage, and conventional treatment does not remove them. As such chemicals and their effects are recognized, reverse osmosis and a variety of advanced drinking water treatments are increasingly being deployed. This trend seems likely to continue (Ebele *et al*. 2017). It can be expected to raise the cost of drinking water treatment for large cities considerably as chlorination plants are upgraded or replaced.

Organochlorines and other Semi-Volatile Organic Compounds

Among the most bizarre troublesome pollutants are a series of organic pollutants that persist in the environment, biomagnify in food chains, and volatilize at some environmental temperatures and condense at slightly lower temperatures. Such semi-volatile compounds include many PCBs, numerous pesticides such as DDT, toxaphene, dieldrin and many others, Dioxins and furans are among such compounds that have caused problems in Canada, because until they were regulated in the late 1990s, they were discharged by pulp and paper mills which used chlorine-based bleaching processes. They were biomagnified in food chains to concentrations that required consumption advisories (Muir *et al*. 1992). After regulation, concentrations declined slowly, but most consumption advisories are no longer needed.

Many of the original persistent organic pollutants (or POPs) were chlorinated compounds, but more recently, many brominated and fluorinated compounds have shown similar properties. Although they were first regarded as a curiosity of long range atmospheric transport, it was soon discovered that they biomagnified to high levels in arctic food chains, as the result of long food chains of long-lived organisms that seasonally stored large quantities of lipids, and most of the contaminants are lipophilic (Muir *et al*. (1988). After the discovery that many of the bioaccumulated toxins were reaching detrimental concentrations in indigenous people of the north, a circumpolar effort was begun to identify, track and reduce such compounds, the Arctic Monitoring and Assessment Program (AMAP results were reviewed by Muir and DeWitt 2010). Wania and Mackay (1995) were able to explain how such compounds appeared in the arctic, even though most were emitted thousands of kilometers to the south. Most have semi-volatile behaviour at normal seasonal temperatures, by which chemicals emitted from industries and soils at southerly latitudes would gradually make their way north, because they would condense under cooler temperatures, moving much as dew on the grass.

The same semi-volatile properties allow the chemicals to increase in concentration with elevation, where they accumulate in snowpacks and glaciers (Blais *et al*. 1998; Donald *et al*. 1999). As climate warming causes glaciers to melt, some older pesticides that were sequestered in glaciers in decades past are again being mobilized to enter alpine streams and lakes (Donald *et al*. 1999, Blais *et al*. 2001). Fortunately, use of many of the worst pesticides was discontinued before concentrations in ice became high enough to pose a threat to organisms in alpine food chains, although alpine food chains investigated to date are also much shorter than arctic ones, reducing the potential to biomagnify in top predators (Campbell *et al*. 2000; Demers *et al*. 2007).

Summary

Given the proliferation of water quality problems in Canada, it is clear that the large investment made in research in the 1960s was an excellent investment. Many water quality problems have been identified, and some reduced or eliminated. Remaining problems are largely the result of weak and inconsistent water policies among federal and provincial agencies. Despite the failures of past water policies as described above, many industries are arguing for a "steamlining" of regulatory processes, which would generally weaken water policies. Such weak water policies are being resisted by NGOs such as the Council of Canadians https://canadians.org/water-policy. Given the impending threats to future water policy, it is essential that Canada rejuvenates and maintains a strong program of water research to underpin sound water policies.

References

Alexander, A., Chambers, P., and Jeffries, D. (2017). Episodic acidification of 5 rivers in Canada's oil sands during snowmelt: A 25-year record. Sci. Tot. Environ. 599–600, pp. 739–749.

Auditor General of Canada (2002) Abandoned mines of the North. Chapter 3 in: 2002 October Report of the Commissioner of the Environment and Sustainable Development.

http://www.oag-bvg.gc.ca/internet/English/parl_cesd_200210_03_e_12409.html.

Bakker, K. (ed.). (2007). Eau Canada: The Future of Canadas Water. Vancouver, University of British Columbia Press. 417 pp. ISBN-13: 978-0-48-1339-6

Bakker, K. and Cook, C. (2011). Water Governance in Canada: Innovation and Fragmentation. International Journal of Water Resources Development, 27(2), pp. 275-289. DOI: 10.1080/07900627.2011.564969

Blais, J. M., Schindler, D. W., Muir, D. C. G., Kimpe, L. E. , Donald, D. B., and Rosenberg, B. (1998). Accumulation of persistent organochlorine compounds in mountains of western Canada. Nature 395(6702), pp. 585-588.

Blais, J.M., Schindler, D.W., Muir, D.C.G., Sharp, M., Donald, D., Lafreniere, M., Braekevelt, E., Comba, M. and Backus, S. (2001). Glaciers are a dominant source of persistent organochlorines to a subalpine lake in Banff National Park, Canada. Ambio 30, pp. 410-415. DOI: 10.1579/0044-7447-30.7.410

Blight, G.E. and Fourie, A. B. (2005). Catastrophe revisited – disastrous flow failures of mine and municipal solid waste. Geotechnical and Geological Engineering 23, pp. 219–248. DOI: 10.1007/s10706-004-7067-y

Bodaly, R. A, Hecky, R. E. and Fudge, R. J. P. (1984). Increases in Fish Mercury Levels in Lakes Flooded by the Churchill River Diversion, Northern Manitoba. Canadian Journal of Fisheries and Aquatic Sciences 41(4), pp. 682-691, https://doi.org/10.1139/f84-079

Booth, L. and Quinn, F. (1995). Twenty five years of the Canada Water Act. Canadian Water Resources Journal, 20:2, pp. 65-90, DOI: 10.4296/cwrj2002065.

Boyd, D. (2003). Unnatural law: Rethinking Canadian Environmental Law and Policy. Vancouver, UBC Press. 488 pp.

Brooymans, H. (2011). Water in Canada: A Resource in Crisis. Edmonton, Lone Pine Publishers. 232 pp. ISBN 978-1-926736-04-4.

Calder, R. and 5 others. (2016). Future Impacts of Hydroelectric Power Development on Methylmercury Exposures of Canadian Indigenous Communities. Environ. Sci. Technol. 50 (23), pp. 13115-13122. DOI: 10.1021/acs.est.6b04447 .

Campbell, L. M., Schindler, D.W., Muir, D. C., Donald, D. B., and Kidd, K. A. (2000). Organochlorine transfer in the food web of subalpine Bow Lake, Banff National Park. Can. J. Fish. Aquat. Sci. 57(6), pp. 1258-1269.

Canadian Research and Development. (1970). We Hung Phosphates

without a Fair Trial; Toronto, Maclean Hunter Publishers.

Chambers P.A. and 7 others. (2001). Nutrients and their impact on the Canadian environment. Environment Canada. 241 pp. http://publications.gc.ca/pub?id=9.648087&sl=0 .

Chetelat, J. and 21 others. (2015). Mercury in freshwater ecosystems of the Canadian Arctic: Recent advances on its cycling and fate. Science of the Total Environment 509–510, pp. 41–66

Cooke, C. and 4 others. (2016). Initial environmental impacts of the Obed Mountain coal mine process water spill into the Athabasca River (Alberta, Canada). Sci. Tot. Environ, 557–558, pp. 502-509.

Demers, M.J., Kelly, E.N., Blais, J.M., Pick, F.R., St. Louis, V.L. and Schindler, D.W. (2007). Accumulation of persistent organic pollutants in trout from lakes spanning a 1600 meter elevation gradient in the Canadian Rocky Mountains. Environ. Sci.Technol. 41, pp. 2723-2729. DOI: 10.1021/es062428p

Dise, N. B., Ashmore, M., Belyazid, S., Bleeker, A., Bobbink, R., De Vries, W. (2011). Nitrogen as a threat to European terrestrial biodiversity. In: The European Nitrogen Assessment. Sources, effects and policy perspective; Cambridge, Cambridge University Press.

Donald D., and 7 others. (1999). Delayed deposition of organochlorine pesticides at a temperate glacier. Environ. Sci. Technol. 33, pp. 1794-1798

Dove, S. C. and Chapra, S. (2015). Long-term trends of nutrients and trophic response variables for the Great Lakes. Limnol. Oceanogr. 60, pp. 696–721. doi:10.1002/lno.10055

Ebele, A.J., Abdallah, A-E. and StuartHarrad, M. (2017). Pharmaceuticals and personal care products (PPCPs) in the freshwater aquatic environment. Emerging Contaminants 3(1), pp. 1-16. https://doi.org/10.1016

Falconer, I.R. (2006). Are endocrine disrupting compounds a health risk in drinking water? Int J Environ Res Public Health. 3(2), pp. 180-4.

Fitzgerald, W. F. and 5 others. (2005). Modern and Historic Atmospheric Mercury Fluxes in Northern Alaska: Global Sources and Arctic Depletion. Environ. Sci. Technol. 39 (2), pp. 557-568.

Frank, R.A., and 10 others. (2014). Profiling Oil Sands Mixtures from Industrial Developments and Natural Groundwaters for Source Identification. Environ. Sci. Technol.

48 (5), pp. 2660–2670. DOI: 10.1021/es500131k

Gorham, E., Gordon, A.G. (1960). The influence of smelter fumes upon the chemical composition of lakes near Sudbury, Ontario, and upon the surrounding vegetation. Canadian Journal of Botany 38, pp. 477-497.

Hayes, F. R. (1973). The Chaining of Prometheus: Evolution of a Power Structure for Canadian Science. Toronto. University of Toronto Press. 238 pp.

Hebert, C.E. and 7 others. (2013). Mercury trends in colonial waterbird eggs downstream of the oil sands region of Alberta, Canada. Environ. Sci. Technol. 47(20), pp. 11785-92. doi: 10.1021/es402542w

Hecky, R. and 6 others. (2004). The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes. Can. J. Fish. Aquat. Sci. 61, pp. 1285–1293.

Higgins, S.N., Paterson, M.J., Hecky, R.E., Schindler, D.W., Venkiteswaren, J.J., and Findlay, D. L. (2017). Biological nitrogen fixation prevents the response of a eutrophic lake to reduced loading of nitrogen: Evidence from a 46-year whole-lake experiment. Ecosystems. 21 (6), pp. 1088–1100. https://doi.org/10.1007/s10021-017-0204-2

Hrudey, S. and E. Hrudey. (2004) Safe Drinking Water: Lessons from Recent Outbreaks in Affluent Nations (IWA Publishing Alliance House: London, U.K.)

International Joint Commission. (1969). Pollution of Lake Erie, Lake Ontario and the lnternational Sectlon of the St. Lawrence River. A Report to the IJC by the International Lake Erie Water Pollution Board and the International Lake Ontario-St. Lawrence River Water Pollution Board. Three volumes.

Jeffries, D.S. and 8 others. (2003) Assessing the recovery of lakes in southeastern Canada from the effects of acid rain. Ambio 32, pp. 176-182.

Jeziorski, A., Yan, N.D., Paterson, A.M., DeSellas, A.M., Turner, M.A., Jeffries, D.S., Keller, B., Weeber, R.C., McNicol, D.K., Palmer, M.E., McIver, K., Arseneau, K., Ginn, B.K., Cumming, B.F., and Smol, J.P. (2008). The widespread threat of calcium decline in fresh waters. Science 322, pp. 1374-1377.

Jones, D. (1987). Empire of Dust: Settling and Abandoning the Prairie Dry Belt. Lincoln. University of Nebraska Press. 334pp. ISBN-10: 0888641206.

Kelly, C. A. and 13 others. (1997). Increases in fluxes of greenhouse gases and methyl mercury following flooding of an experimental reservoir. Environ. Sci. Technol. 31, pp. 1334–44.

Kelly, E. N. and 4 others. (2006). Forest fire increases mercury accumulation by fishes via food web restructuring and increased mercury inputs. Proc. Nat. Acad. Sci. USA 103, pp. 19380-19385.

Kelly, E. N., Short, J. W., Schindler, D. W., Hodson, P. V., Ma, M., Kwan, A. and Fortin, B.L. (2009). Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries. Proc. Nat. Acad. Sci. USA 106, pp. 22346-22351.

Kelly, E. N.; Schindler, D. W.; Hodson, P. V.; Short, J. W.; Radmanovich, R.; and Nielsen, . C. (2010). Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries. Proc. Nat. Acad. Sci. USA 107, pp. 16178–16183.

Kidd, K. A., Hesslein, R. H., Fudge, R. J. P. and Hallard, K. A. (1995). The influence of trophic level as measured by δ15N on mercury concentrations in freshwater organisms. Water, Air, Soil Pollut. 80, pp. 1011-1015.

Kidd, K. A., Blanchfield, P. J., Mills, K. H., Palace, V. P., Evans, R. E., Lazorchak, J. M., and Flick, R. W. (2007). Collapse of a fish population after exposure to a synthetic estrogen. Proc. Nat. Acad. Sci. USA 104, pp. 8897-8901.

Kidd, K. A., Paterson, M. J., Rennie, M. D., Podemski, C. L., Findlay, D. L., Blanchfield, P. J., and Liber, K. (2014). Direct and indirect responses of a freshwater food web to a potent synthetic oestrogen. Phil. Trans. R. Soc. B 369, 20130578. http://dx.doi.org/10.1098/rstb.2013.0578

Lewis, W. M. Jr. and Wurtsbaugh, W. A. (2008).Control of lacustrine phytoplankton by nutrients: Erosion of the phosphorus paradigm. Int. Rev. Hydrobiol. 93, pp. 446–465

Mackasay, W. O. (2000). Abandoned mines in Canada. Prepared for Mining Watch Canada.11p. https://miningwatch.ca/sites/default/files/mackasey_abandoned_mines.pdf

Michalak, A. M., Anderson, E. J., Beletsky, D., Boland, S., Bosch, N. S., Bridgeman, T. B., Chaffin, J. D., Cho, K., Confesor, R., Daloglu, I.; *et al.* (2013) .Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. Proc. Natl. Acad. Sci. U. S. A. 110, pp. 6243–6244.

Muir, D.C.G., Fairchild, W.L. and Whittle, D.M. (1992). Predicting bioaccumulation of chlorinated dioxins and furans in fish near Canadian bleached kraft mills. Water Quality Research Journal (1992) 27 (3): 487-508. https://doi.org/10.2166/wqrj.1992.033

Muir, D., and DeWitt, C. (2010). Trends of legacy and new persistent organic pollutants in the circumpolar arctic: overview, conclusions, and recommendations. Sci. Tot. Environ. 408(15), pp. 3044-51. doi: 10.1016/j.scitotenv.2009.11.032.

Munthe, J, Bodaly, R. A., Branfireun, B. A., Driscoll, C. T., Gilmour, C. C., Harris, R., Horvat, M., Lucotte, M., and Malm, O. (2007). Recovery of mercury-contaminated fisheries. Ambio 36, pp. 33-44.

National Academy of Sciences USA. (1969). Eutrophication: Causes, Consequences, Correctives. Washington, D.C. National Academy Press.

Orihel, D. M. and 6 others. (2017). Internal phosphorus loading in Canadian fresh waters: a critical review and data analysis. Can. J. Fish. Aquat. Sci. 74, pp. 2005–2029 (2017) dx.doi.org/10.1139/cjfas-2016-0500

Pagnucco, K. and 5 others. (2015). The future of species invasions in the Great Lakes-St. Lawrence River basin. J. Great Lakes Res. 41(Supplement 1), pp. 96-107

Parajulee, A., and Wania, F. (2015). Evaluating officially reported polycyclic aromatic hydrocarbon emissions in the Athabasca oil sands region with a multimedia fate model. Proc. Nat. Acad. Sci. USA. 111 (9), pp. 3344-3349; https://doi.org/10.1073/pnas.1319780111

Parks, J. W. and Hamilton, A. L. (1987). Accelerating the recovery of a mercury contaminated river system. Hydrobiologia 149, pp. 159-188.

Paterson, M. J., Schindler, D. W., Hecky, R. E., Findlay, D. L., and Rondeau, K. J. (2011). Comment: Lake 227 shows clearly that controlling inputs of nitrogen will not reduce or prevent eutrophication of lakes. Limnol. Oceanogr. 56, pp. 1545-1547.

Pearse, P., Bertrand, F. and MacLaren, J. (1986). Currents of Change: Final Report, Inquiry on Federal Water Policy, Canada,Environment: Science and Policy for Sustainable Development, 28:10, pp. 25-27, Ottawa. DOI: 10.1080/00139157.1986.9928838 .

Pearse, P., and Quinn, F. (1996). Recent developments in federal water policy: One step forward, two steps back. Canadian Water Resources Journal. 21(4), pp. 329-340, DOI: 10.4296/cwrj2104329

Peterson, H. and 3 others. (2007). Development of Effective Drinking Water Treatment Processes for Small Communities with Extremely Poor Quality Water on the Canadian Prairie. Soc. Can. Env. Biol. 64(1), pp. 28-35.

Quinn. F. (1985). The Evolution of Federal Water Policy. Canadian Water Resources Journal 10(4), pp. 21-33. DOI: 10.4296/cwrj1004021

Radmanowich, R. (2012). Mercury in the lower Athabasca River and its watershed. M.Sc. thesis, Edmonton. University of Alberta. 123 pp.

Rosenberg, D.M., Bodaly, R.A. and Usher, P.J. (1995). Environmental and social impacts of large scale hydroelectric development: who is listening? Global Environmental Change 5 (2), pp. 127-148.

Rudd, J. W. M., Kelly, C. A., Schindler, D. W. and Turner, M. A. (1988). Disruption of the nitrogen cycle in acidified lakes. Science (Wash., DC) 240, pp. 1515-1517.

Rudd, J. W. M., Kelly, C. A., Schindler, D. W. and Turner, M. A. (1990). A comparison of the acidification efficiencies of nitric and sulfuric acids by two whole-lake addition experiments. Limnol. Oceanogr. 35, pp. 663-679.

Rudd, J., Harris, R., Kelly, C., Sellers, P., and Townsend, B. (2017). Proposal to Clean-Up (Remediate) Mercury Pollution in the English-Wabigoon River. 10.13140/RG.2.2.28734.08004.

Rudd, J.W.M., and Turner, M. A. (1983). The English-Wabigoon River system: II. Suppression of mercury and selenium bioaccumulation by suspended and bottom sediments. Can. J. Fish. Aquat. Sci. 40, pp. 2218-2227.

Schetagne, R, Therrien, J, and Lalumiere, R. (2003). Environmental monitoring at the La Grande complex. Evolution of fish mercury levels. Summary report 1978-2000. Direction Barrages et Environnement, Hydro-Québec Production and Groupe conseil GENIVAR Inc., 185 pp. and Appendices.

Schindler, D.W. (1974). Eutrophication and recovery in experimental lakes: Implications for lake management. Science (Wash., DC) 184, pp. 897-899.

Schindler, D. W. (1977). Evolution of phosphorus limitation in lakes. Science 195, pp. 260–262.

Schindler, D.W. (2012). The dilemma of controlling cultural eutrophication of lakes. Proc. R. Soc. B. 279, pp. 4322–4333.

Schindler, D.W. (2013). Geoscience of Climate and Energy 12.

Water Quality Issues in the Oil Sands Region of the Lower Athabasca River, Alberta. Geosciences Canada 40(3), http://dx.doi.org/10.12789/geocanj.2013.40.012

Schindler, D.W. (2018). Will Canada's Future be Dammed? Site C could be the tip of the iceberg. Ch 2 in Holm, W. (ed.). Damming the Peace: The Hidden Costs of the Site C Dam. Toronto. James Lorimer and Company.

Schindler, D.W., Brunskill, G. J., Emerson, S., Broecker, W. S., and Peng, T-H. (1972). Atmospheric carbon dioxide: Its role in maintaining phytoplankton standing crops. Science 177(4055), pp.1192-1194. https://doi.org/10.1126/science.177.4055.1192.

Schindler, D. W. and 12 Others. (1981). Atmosphere-Biosphere Interactions: Toward a Better Understanding of the Ecological Consequences of Fossil Fuel Burning. Washington, D. C. National Academy Press. 263 pp.

Schindler, D. W., Mills, K. H., Malley, D. F., Findlay, D. L., Shearer, J. A., Davies, I. J., Turner, M. A., Linsey, G. A., and Cruikshank, D. R. (1985). Long-term ecosystem stress: the effects of years of experimental acidification on a small lake. Science 228, pp.1395-1401.

Schindler, D. W., Hecky, R. E., Findlay, D. L., Stainton, M. P., Parker, B. R., Paterson, M. J., Beaty, K. G., Lyng, M., and Kasian, S. E. (2008). Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proceedings of the National Academy of Sciences USA. 105, pp. 11254-11258.

Schindler, D.W., Hecky, R.E., and McCullough, G. K. (2012). The rapid eutrophication of Lake Winnipeg: Greening under global change. J. Gt. Lakes Res. 38, p 6-13. https://doi.org/10.1016/j.jglr.2012.04.003

Schindler, D. W., Carpenter, S. R., Chapra, S. C., Hecky, R. E., and Orihel, D. M. (2016). Reducing phosphorus to control eutrophication is a success. Environ. Sci. Technol. 50(22), pp. 12421-12428.

Scott, J. T., and McCarthy, M. J. (2010). Nitrogen fixation may not balance the nitrogen pool in lakes over timescales relevant to eutrophication management. Limnol. Oceanogr. 55, pp. 1265–1270.

Sprague, J. (2007). Great Wet North? Canada's Myth of Water Abundance. Ch 2 in Bakker, K (ed.) Eau Canada: The Future of Canada's Water. Vancouver, UBC Press. 415 pp.

Swanson, H.K., T.A. Johnston, D.W. Schindler, R.A. Bodaly and D.M. Whittle. (2006). Mercury bioaccumulation in forage fish communities invaded by rainbow smelt (*Osmerus mordax*). Environ. Sci. Technol. 40, pp. 1439-1446.

Takaoka, S. and 6 others. (2014) Signs and symptoms of methylmercury contamination in a First Nations community in Northwestern Ontario, Canada. Sci. Tot. Environ. 468-469, pp. 950-957. doi: 10.1016/j.scitotenv.2013.09.015.

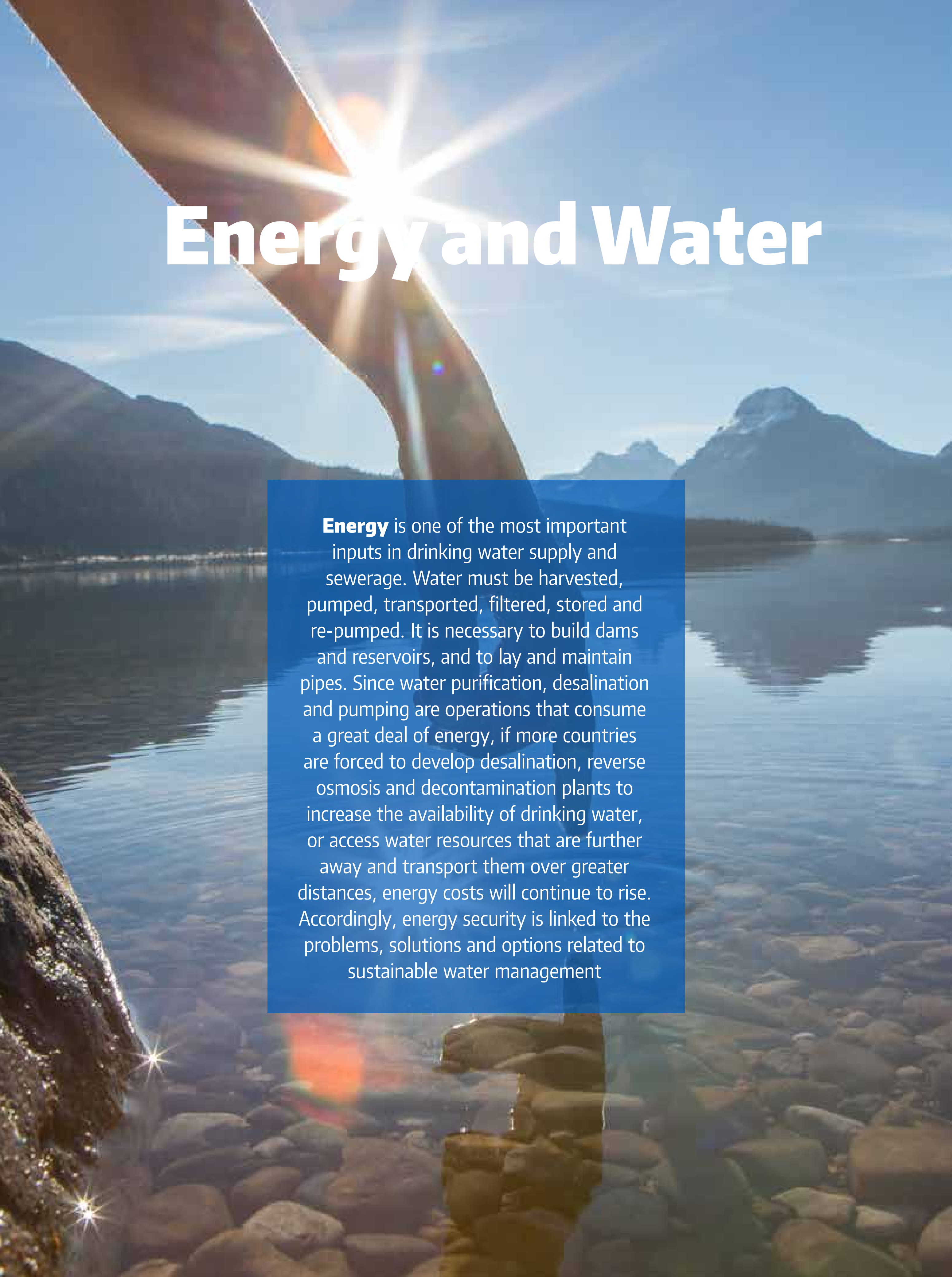
Vitousek, P., Porder, S., Houlton, B., and Chadwick, O. (2010). Terrestrial phosphorus limitation: mechanisms, implications, and nitrogen–phosphorus interactions. Ecological Applications 20, pp. 5-15.

Vollenweider,R. (1968). Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Paris, France. OECD Tech. Rep. DAS/CS/68.27.

Wania, F. and Mackay, D. (1995). A global distribution model for persistent organic chemicals. Science of the Total Environment 160, pp. 211-232.

Watmough, S., and 14 others. (2005). Sulphate, Nitrogen and Base Cation Budgets at 21 Forested Catchments in Canada, the United States and Europe. Environ. Monit. Assess. 50 (22), pp. 12421-12428. DOI: 10.1007/s10661-005-4336

Whitfield, C. and Watmough, S. (2012). A regional approach for mineral soil weathering estimation and critical load assessment in boreal Saskatchewan, Canada. Sci. Tot. Environ. 437, pp. 165-72.



Energy and Water

Energy is one of the most important inputs in drinking water supply and sewerage. Water must be harvested, pumped, transported, filtered, stored and re-pumped. It is necessary to build dams and reservoirs, and to lay and maintain pipes. Since water purification, desalination and pumping are operations that consume a great deal of energy, if more countries are forced to develop desalination, reverse osmosis and decontamination plants to increase the availability of drinking water, or access water resources that are further away and transport them over greater distances, energy costs will continue to rise. Accordingly, energy security is linked to the problems, solutions and options related to sustainable water management

Water Quality and Alternative Energy Nexus in the Americas

Kwame Emmanuel and Anthony Clayton

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Introduction

Access to adequate supplies of clean water is critically important to all human aspirations and goals, including sustainable development, and is now defined as a basic human right. The proper treatment, recovery, reuse and disposal of wastewater are also critically important, as failure in this regard has a number of damaging consequences; the discharge of untreated waste can contaminate ground and surface water, which has serious implications for the potable water supply and ecosystem integrity. Sustainable Development Goal (SDG) 6 states that safe water and sanitation are essential to human health, environmental sustainability and economic prosperity. There have been great achievements in this area, bringing clean water to millions of people, but some of these achievements are now threatened by a combination of population growth and climate change, which is putting water supplies in some regions at unprecedented risk.

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So significant further progress in this area is now essential. If the development of more efficient systems for water supply and utilization does not keep pace with population growth, then water supplies per capita are likely to fall. Similarly, if water supply systems do not adjust to the changing weather patterns associated with climate change, then many parts of the world are likely to be increasingly water-stressed in future. Without significant progress in these areas, therefore, progress towards the other SDGs will become increasingly difficult, if not impossible.

Energy is one of the most critical inputs in the provision of potable water and sanitation. Water must be harvested, pumped, transported, filtered, stored and pumped again. Dams and reservoirs must be built, pipes laid and maintained. Water purification, desalination and pumping are very energy-intensive operations, so if more countries have to develop desalinization, reverse osmosis and decontamination plants to increase the availability of potable water, or to access water resources from further away and transport them over greater distances, the energy cost will continue to rise. So energy security and the goals of SDG 7 - access to affordable, reliable, sustainable and modern energy for all – are linked to the problems, solutions and choices involved in sustainable water management. If a country makes a policy decision to deliver piped water to all consumers, the energy cost will be significantly higher (because of the need to pump water to consumers who may be uphill from the reservoirs) than if the country makes a policy decision to develop rainwater harvesting and local springs. An energy-intensive water system is also less resilient than a system that emphasizes local resources; if the energy system fails, the water system will fail too.

The energy sector also faces a number of critical challenges, including dependency on unstable oil-exporting regimes, fluctuating oil prices, high environmental costs and profoundly serious implications for climate change. An energy-intensive water supply system therefore connects two diverse sets of challenges, which significantly increases the probability of disruption.

The Inter-American Network of Academies of Sciences (IANAS) is therefore exploring the development of a collaborative approach in the Americas to address energy and water problems in conjunction. As policy decisions for energy and water have a number of mutual cross-over implications, a conjoint approach to find solutions to both energy and water supply problems simultaneously is more likely to result in indefinitely viable arrangements that will operate under a wider set of circumstances. This is therefore a multi-dimensional optimization problem, where it is necessary to develop solutions that work in different dimensions at the same time. This also allows proposed solutions to be stress-tested under more realistic scenarios, such as, for example, what will happen to the water supply if the power grid fails?

IANAS is therefore mapping out the transition pathways from the current status quo to a more sustainable future for the water and energy nexus.

The remainder of this chapter summarizes the submissions of regional experts from across the Americas on a number of aspects of this nexus, including the use of alternative energy to treat saline, brackish and contaminated freshwater, and wastewater management in the Americas.

The goal was to determine the depth and range of expertise in the Americas on the energy and water nexus. This involved looking at a number of examples of emerging good practice, including the use of low-carbon alternative energy sources in managing and treating water. The focus was on tracking the development of technologies from research to commercial development, with particular regard to practical or close-to-market solutions.

Water Quality

Water for primary use has to meet stringent microbiological and chemical quality standards in order to prevent waterborne diseases and health risks from e.g. toxic chemicals. The final water product must be chemically and microbiologically safe for human consumption, and fit for other purposes, such as industrial use. For domestic consumption, water should also be free from unpleasant tastes and odours and, in some cases, improved for human health purposes, including fluoridisation or other mineralization. With regard to wastewater, the purpose of treatment is to transform the primary waste product into a form that is clean enough to either be disposed of in the natural environment without harmful effects, or to be used for secondary purposes such as irrigation or groundwater replenishment. The goal of wastewater treatment is to eliminate pathogens and remove organic and inorganic constituents and, in some cases, to reduce aesthetic pollution such as agents that would discolour the water. This is achieved by putting the water through various physical, chemical and biological processes.

The Americas

The Americas comprise two continents and a very diverse group of countries. It is the most water-abundant region in the world, with South America alone having nearly 31% of the world's total freshwater resources. The region, however, is significantly challenged by threats to water quality, impacting negatively on the volume of potable water which can actually be provided to its population. The issues include saline intrusion of coastal aquifers caused by over-extraction as in the case of Jamaica and Barbados, which will be exacerbated by sea level rise; poor land use practices and watershed degradation resulting in siltation of raw water sources; arsenic contamination of groundwater in countries such as Argentina, Ecuador and Mexico; high levels of the Escherichia coli bacterium, for example in Nicaragua; and high colloidal iron content and contamination by agricultural and industrial sectors in Ecuador. In the case of the Dominican Republic, one of the most serious problems is the contamination of aquifers and water sources by agricultural discharge, for example, from livestock rearing (e.g., pigs and cows) and slaughterhouses. There are also issues with micro-plastics in wastewater and water sources in Panama, and glyphosate pollution in Colombia. In Mexico, widespread distrust of piped water quality has resulted in the country being the highest *per capita* consumer of bottled water globally, which means that millions of plastic bottles are discarded in Mexico each year (Flores-Díaz et al 2018). These issues, all of which stem from management failings or technical gaps, will make it difficult for many countries in the region to meet the SDG 6 targets, which include universal access to safe water and improved water quality by reducing pollution.

So there are a number of factors that characterize the water quality dilemma in the region. The case of the small Caribbean small island of Grenada, as summarized by Mitchell et al (2018), illustrates some of the challenges. The factors there include:

- A lack of financing for the maintenance and expansion of treatment facilities;
- The absence of zoning regulations, which negatively impact watershed management and water quality;
- Infrequent monitoring and analysis of water quality, due to the lack of legal, technical and financial resources;
- No secondary or tertiary treatment of wastewater, as well as defective disposal infrastructure;
- Limited community involvement in water quality management; and
- An inadequate institutional framework that is incapable of Integrated Water Resource Management (IWRM).

Many of these and similar problems can be seen in other countries across the region.

Other factors influencing water quality in the Americas include:

- A combination of population and economic growth driving up water and energy demand and increasing waste generation and pollution, which create problems for water quality management;
- Rapid and poorly planned urbanization, with many informal settlements, which negatively affects watershed management;
- A very large disparity in water and sanitation coverage between rich and poor, as in countries like Argentina;
- Weak or non-existent enforcement of water quality standards, and a complete lack of required standards for a number of contaminants; and
- A common pattern of investing in water supply infrastructure but neglecting to invest in wastewater management.
- Geological conditions also pose significant challenges for water management in some countries. For example, water managers in

Mexico have to contend with arsenic and fluoride contamination as a result of naturally-occurring geochemical processes, while arsenic is a waste product of mining activities in Ecuador.

This complex array of challenges highlights the need for a comprehensive and integrated approach to water quality management, including better management and enforcement, and the development of cleaner technological solutions.

Alternative Energy

There is a bi-directional relationship between water and energy issues. Water is used in almost all forms of energy production, while energy is a fundamental component of potable water supply and wastewater treatment. The supply of clean water is extremely energy intensive from well abstraction to treatment (including desalination) to pumping and conveyance to the consumer. In many of the Caribbean nations, the water utilities are by far the largest single customer of the power companies. This relies almost entirely on a conventional oil-based energy supply system, however, which then contributes to climate change with potentially disastrous consequences for the island nations.

In response, the use of alternative non-fossil energy (including renewable and nuclear) has become a vital mitigating strategy as it reduces the emission of greenhouse gasses to the atmosphere while providing the energy necessary to support economic and population growth, as well as improved welfare and social development.

The main objective of SDG 7 is to ensure access to affordable, reliable, sustainable and modern energy for all. The 2030 targets therefore include substantially increasing the share of renewable energy in the energy supply mix, and enhancing international cooperation to support research and investment in cleaner energy. Globally, the development of renewable energy has surpassed projections in recent years, and the use of the technology is likely to show above-trend growth for decades to come (IANAS-IAP 2016), eventually displacing high-carbon sources. In the region, countries such as Chile, Mexico, Argentina, Cuba and Venezuela have successfully integrated renewables into their energy portfolio. Venezuela is an interesting case, as the country has some of the largest oil reserves in the world, but relies more on hydropower, with the Caroni River and its tributary, Paragua River, providing 72% of the electricity for the country (Rivas et al., 2018). Venezuela is currently experiencing serious disruption in its energy sector, but that is a problem of governance, not the availability of resources.

Energy and Water Treatment

Case studies from nine countries in the region that are now using renewable energy for water treatment are presented here; one in North America five in South America, one in Central America and three in the Caribbean. The countries are Argentina, Columbia, Ecuador, Nicaragua, Peru, Venezuela, St Lucia, Barbados, Jamaica and a special collaboration from Mexico.

Argentina

Franco (n.d.) describes the use of solar stills to produce freshwater without electrical or mechanical energy. The technology, which simulates a greenhouse, comprises two primary components: a tank or collector and the cover. The tank is where the impure water to be treated is kept. Fixed above it, at an angle, is a transparent cover, which can be made of either plastic or glass. The cover has two functions: temperature magnification and condensate collection. The treatment process is triggered by solar radiation passing through the cover resulting in the evaporation of water. Condensation then occurs beneath the cover and droplets of freshwater are transported via gutters to a storage facility.

The Institute of Research on Unconventional Energy (INENCO) at the National University of Salta has developed modular and transportable solar stills, which can be assembled in a few hours. These solar stills have been installed in a number of communities in the province of Salta to treat water contaminated with arsenic, produce distilled water and for desalination. Franco (n.d.) concludes that the technology is suitable for sparsely populated and isolated areas with limited access to energy and potable freshwater sources.

Colombia

Rincón-Martínez and Durán-Hernández (n.d.) reported that wind-powered desalination has been installed on the arid Guajira Peninsula where climate change is now compounding the water scarcity crisis. The aero-desalinator, invented by engineer Juan Carlos Borrero, is a device that connects a wind-turbine to well abstraction infrastructure. The technology extracts saline water from wells and transports it to a series of filters and membranes with copper and silver ions for the removal of pathogens. A reverse osmosis process is used to produce potable water. Advantages of the system include reduced operating cost, as the price per gallon is 20 to 30 percent lower than diesel or solar alternatives, and no external power source and chemical treatment required. Currently there are five aero-desalinators operating in the Guajira region and there is a Government contract with Juan Carlos Borrero to establish forty more. Rincón-Martínez and Durán-Hernández (n.d.) also cited the work of engineering students at the National University of Colombia who developed a solar desalination prototype made of recyclable materials.[1] The prototype generates half a litre of water an hour using seven kilowatts of energy harvested from solar exposure in La Guajira. The objective of this exercise was to solve the problem of water scarcity in this region. The apparatus has two primary components: the focus (or energy concentrator) and the parabola and the process is based on the principles of refractive optics and concave reflection to heat the saline water. After evaporation and separation of the salt and other undesirable constituents, the vapor is cooled in the condenser and droplets of freshwater collected. The indigenous community in La Guajira can now replicate the model using easily accessible materials and become directly responsible for managing their water supply.

Ecuador

Sáenz et al (n.d.) explored the use of Solar Water Disinfection (SODIS) as part of a community-based research project in the village of La Concordia. SODIS is a low cost process for treating drinking water using ultraviolet rays and heat from the sun to eliminate pathogens. The method is not 100% efficient in eliminating pathogens, especially in highly turbid water, but studies have shown its efficacy in reducing the prevalence of illnesses such as diarrhea. During the project, a microbiological analysis was conducted before and after exposure to sunlight and the results confirmed the effectiveness of the SODIS method in water treatment. SODIS is also considered a viable disaster management option for disinfection and has an advantage over chlorination and boiling, as chlorination alters taste and boiling requires energy. SODIS is therefore considered a sustainable, inexpensive treatment method which does not require electric power.

A workshop conducted by the Swiss Federal Institute for Environmental Science and Technology in 2001 in Quito, also demonstrated the effectiveness of the SODIS method to disinfect piped water from the Amaguana community and non-piped water from the San Pedro river (Sáenz et al n.d.). After plastic bottles filled with the two samples of water had been exposed to sunlight, the water was analyzed to determine the presence of fecal coliforms. The first set of four bottles with piped water that were exposed to sunlight reported 51 FCU/100 ml before exposure and 0 FCU/100 ml after. The second set of bottles containing non-piped water reported 284 FCU before exposure to sunlight and 0 FCU after exposure, with the exception of one bottle that reported 1 FCU.

Nicaragua

Sandoval (n.d.) reported on the use of a photovoltaic system to purify brackish water for the cleaning of bivalve molluscs intended for human consumption. In this case, the water purification apparatus converts solar energy to electrical energy to power a UV lamp, which eliminates bacteria in brackish water.

The Institute for Training, Research and Environmental Development (CIDEA/UCA) purchased the equipment because of water quality concerns and the high cost associated with connecting to the power grid. The apparatus was installed in the community of Aserradores on the Pacific coast where the main livelihood is fishing and mangrove cockle collection. Approximately three million units of mangrove cockle are harvested each year from es-

1. http://agenciadenoticias.unal.edu.co/detalle/article/desalinizador-solar-purifica-agua-en-la-guajira.html

tuaries making it the most consumed mollusc in the country. Unfortunately, the safety of the delicacy has been compromised by the water quality where the cockles are located. A 2007 study by CIDEA revealed estuaries in western Nicaragua contained *Escherichia.coli* bacteria above permissible levels.

Shellfish purification systems have been widely developed in other countries but limited research has been done on the decontamination of the mangrove cockle, *Anadara spp* (*Anadara tuberculosa* and *Anadara similis*). The process adopted involves three stages:

1. Filtration of the brackish water to remove the suspended solids which can interfere with the UV light treatment in stage two;
2. Exposure of the water to UV light to eliminate the bacteria; and
3. Submersion of the cockles in treated water for 48 hours for cleaning.

The system used by CIDEA has proven to be effective and could now be adopted more extensively to ensure the safety of mangrove cockle industry.

Peru

Rodriguez (n.d.) noted that there has been research programs at the National Engineering University, the University of Lima and the National University of Tumbes on the use of renewable energy to improve water quality. Several patents have been awarded. The main object of the research was to develop water purification systems that are efficient, robust and easy to use and maintain. There was a particular focus on the need to supply clean water to isolated, rural populations with limited access to energy, chemical inputs and technical personnel.

Technologies were categorized as follows:

1. Optical systems to increase the efficiency of solar energy: These include desalination systems, which involve evaporation and steam condensation to minimize salt content, as well as solar disinfection systems to treat water in rural areas.
2. Non-optical systems: These include activated carbon and titanium oxide systems for disinfection in disaster areas where access to safe water is limited. In the case of titanium oxide, when placed in the sun for a few hours, it disinfects water more efficiently than solar irradiation alone.
3. Solar electrification systems: These systems provide energy via solar panels for decontamination processes that require a limited amount of electrical energy.

Venezuela

The Academy of Physical, Mathematical and Natural Sciences and the National Academy of Engineering and Habitat (n.d.) summarized the Venezuelan experience of using renewable energy to provide potable water in primarily remote, rural areas. Although having some of the world's largest oil reserves, Venezuela's energy mix comprises approximately 70% hydroelectric energy with the main installations such as the Guri, Caruachi and Macagua plants located in Bolivar state in the southern part of the country. Notwithstanding the extensive use of clean energy, there have been very few publications on its use for water purification.

In 2005, the Government initiated the 'Sowing Light' program, which involved the use of photovoltaic installations and other alternative energy solutions such as wind energy in isolated rural communities. The program included the installation of water purification and desalination systems as well as pumping facilities for crop irrigation using surface and underground sources.

Another program implemented by the Government, entitled 'Planting Electricity', involved micro-electrification, pumping and treatment to supply drinking water to indigenous communities in isolated, border areas. The Government also installed solar powered infrastructure for water treatment on the river island, Fajardo, and is looking into incorporating wind technology.

Venezuelan universities have also investigated renewable energy options for water treatment in rural areas. For example, the Simón Bolívar University (USB) developed a desalination plant prototype using multiple-effect humidification and also conducted research on low temperature thermal solar energy systems.

Another energy source for potable water supply identified in the Venezuelan case is position energy, which is commonly used in the design of aqueducts. This is considered a renewable energy form, which is rarely recognized. This utilization of gravity has resulted in less fossil fuel consumption and carbon dioxide emissions and significant savings in operating costs.

Caribbean

The use of alternative energy to improve water quality is a relatively new concept in the Caribbean according to Andre Quesnel, Technical Director of Ecohesion, a sustainable water infrastructure company based in Barbados. There are therefore many opportunities for business as well as research and development in the Caribbean.

A St. Lucian fisherman and self-taught inventor, Karlis Noel, designed and manufactured a mobile, solar-powered, desalination unit that neutralizes the brine waste product, the first of its kind globally. The self-sufficient system now benefits the Laborie village where the inventor is from, and the technology has also been exported to the small Pacific island of the Republic of Nauru, which is now very badly affected by saline intrusion into its groundwater supply.

Another example of alternative energy for water purification is the solar water distillation system developed by the Florida-based company Sun Fresh Water in collaboration with The Centre for Advanced Engineering Design and Development at the City University of New York. The company recently secured two patents for its novel optimal concentration distillation prototype, which will be marketed primarily in the Caribbean. The scalable unit is a portable, low-maintainance and inexpensive solution for potable water production and is particularly suitable for remote areas. The heat transfer system was piloted in Florida and it was found to be more energy efficient than Reverse Osmosis. Planned improvements include the incorporation of nanotechnology, which is projected to enhance freshwater production to greater than 14 litres per square metre per day . The next step for Sun Fresh Water will be to secure funding to optimize, manufacture and distribute a commercial unit. The company also intends to establish a water farm comprising thousands of units in a Caribbean community as part of a case study to be conducted by the Global Water Partnership on the efficacy of technology.

There is also the case of Freshwater Ionics in Barbados, a desalination plant owner and operator, which has installed solar capacity at its reverse osmosis facility but has entered into a 'buy-all, sell-all' arrangement (indirect electrification) with the country's electricity utility, Barbados Light and Power.

In addition, there are plans to incorporate solar electrification at the Mona water treatment and distribution facility in Kingston, Jamaica. The National Water Commission is looking into erecting panels over the Mona reservoir in order to generate enough energy to power the facility as well as sell to the grid. The inclusion of renewables is now recognized by the Jamaican Government as an important step in establishing a sustainable business model for water management.

Energy and Wastewater Treatment

Wastewater pollution is a serious threat to sustainable water management. Generally, only a small percentage of the volume of wastewater generated is collected, and an even smaller percentage is treated. In the Dominican Republic, for example, only 38% of the wastewater collected is treated (Tio 2017). This situation underscores the finding that institutions responsible for water and sanitation tend to invest more resources in water supply than in wastewater treatment.

Wastewater treatment facilities that can now be considered as exemplars of the new energy-water nexus include bio-digesters and other forms of biological systems. These systems either produce renewable energy or use sunlight for the processing of wastewater and do not require electrification, which means they are particularly energy efficient. Bio-digesters are now being used in the Dominican Republic and Ecuador in waste management and energy production. They utilize micro-organisms to digest and break down organic waste in an anaerobic environment. The end products are biogas, a form of renewable energy, and a nutrient rich derivative, which can be used as fertilizer.

McFarren (n.d.) summarized the Dominican Republic experience, which involves the treatment of pig slurry and cattle dung. McFarren noted that in Monción, in the Sánchez Ramírez Province, there is a small digester that was installed to produce methane gas from 40 head of cattle. After five years in operation, it now provides enough energy to prepare 66 meals per day at the Las Carmelitas Con-

Box 1. Treatment Using the Photo-Fenton Process for Industrial Effluent in Morelos, Mexico

Antonio E Jiménez and Claudio A. Estrada*

In the state of Morelos, Mexico, water resources face serious pollution problems due to effluents, first from the industrial, agricultural, rural and municipal sectors and, second, due to the lack of drainage in much of the state. The latter forces much of the municipal and rural sector to discharge its wastewater directly into the ravines and rivers in the region. Consequently, nowadays over 70% of the surface waters of Morelos contain some degree of contamination.

In Mexico, treatment plants process approximately 45% of the municipal wastewater produced. Likewise, the level of water treatment from the industry is 35%, which provides a great opportunity to recover a large percentage of water. These statistics show how far the country lags behind in wastewater treatment systems and legislation, since most of these waters converge, without any treatment, directly into rivers and ravines. These figures represent a great opportunity for the development, innovation and use of more efficient systems for the treatment of their wastewater installed in an appropriate place in each industry, capable of degrading recalcitrant pollutants before the effluent is channeled and discharged into receiving bodies of water, mainly rivers, which is how this is usually done.

Given that industry is the sector that most pollutes water, Mexican regulations on wastewater discharges stipulate that a Chemical Oxygen Demand (COD) of more than 200 mg/L is classified as heavily polluted water. The state of Morelos has industries whose wastewater has extremely high levels of contamination, with a COD level of over 2,000 mg/L.

In the IER-UNAM (www.ier.unam.mx/), advanced oxidation processes for the treatment of wastewater using concentrated solar energy have been studied. Early studies made it possible to reduce sodium dodecylbenzene sulfonate in aqueous solution using a parabolic solar concentrator with titanium dioxide as a catalyst. Up to 94% of the contaminant was removed [1]. For several years, various studies of photocatalytic degradation with solar concentration were undertaken [2, 3, 4].

An alternative methodology for wastewater treatment has recently been developed through the photo-FENTON process, using photocatalytic reactors integrated with Parabolic Compound Cylinder solar concentrators (CPC) and geometric concentration ratios of 1 sol. This has made it possible to degrade effluents from the textile and pharmaceutical industry to levels of pollutant removal of over 80% in terms of COD and Total Organic Carbon COT, which is an extremely encouraging result. Work is being done to optimize experimental parameters that increase the level of degradation processes. A scaling study is proposed to be presented to the industries involved, so that a photocatalytic degradation plant can be installed on the premises of each company before they discharge their effluent into water-receiving bodies.

1. Jiménez A.E., Estrada C.A., Cota A.D. & Román A. Photocatalytic Degradation of DBSNa Using Solar Energy. *Solar Energy Materials & Solar Cells* 60 (2000) 85-95
2. Bandala Erick R. & Estrada Claudio. Comparison of Solar Collection Geometries for Application to Photocatalytic Degradation of Organic Contaminants. *Journal of Solar Energy Engineering*, February 2007, Vol. 129, 22-26
3. Velázquez Martínez S., Pineda-Arellano C.A., Salgado-Tránsito I., Silva-Martínez S., Jiménez González A.E. Modified sol-gel/hydrothermal method for the synthesis of microsized TiO2 and iron-doped TiO2, its characterization and solar photocatalytic activity for an azo dye degradation. *Journal of Photochemistry and Photobiology A: Chemistry* 359 (2018), 93-101. https://doi.org/10.1016/j.jphotochem.2018.04.002.
4. Pineda Arellano C.A., Jiménez González A., Silva Martínez S., Salgado-Tránsito I., Pérez Franco C. (2013). Enhanced mineralization of atrazine by means of photodegradation processes using solar energy at pilot plant scale. *Journal of Photochemistry and Photobiology A: Chemistry,* Volume 272, 21-27.

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Table 1. A summary of water technology using renewable energy in the Americas

Country	Technology	Stage	Proponent
Argentina	Solar stills	Commercial	University
Colombia	Aero-desalinator (wind-powered)	Commercial	Engineer
	Solar desalination (small scale)	Research	University
Ecuador	Solar water disinfection	Research	University / Research Institute
Nicaragua	Photovoltaic system to purify brackish water (shellfish purification system)	Commercial	University
Peru	Optical systems: desalination, solar disinfection Non-optical systems: Activated carbon and Titanium oxide systems Solar electrification systems: solar panels	Commercial (Patents)	University
Venezuela	Photovoltaic and wind energy installations for water purification systems	Commercial	Government
	Desalination (multiple-effect humidification)	Research	University
	Low temperature thermal solar energy systems	Research	University
	Aqueducts using position energy	Commercial	Water Authority
Caribbean	Solar-powered Desalination (St. Lucia and Barbados)	Commercial	Inventor (St. Lucía) Private Sector (Barbados)
	Solar Water Distillation	Transitioning from Research to Commercial	Private Sector and University Collaboration

vent. The biodigester also fuels a small cheese and sweet production facility and has the potential to run a 4,000Kw power plant.

Ecuador had 38 bio-digesters in operation in 2013, treating wastewater from livestock and generating energy, as outlined by Sáenz et al (n.d.). A study conducted during the processing of pig waste on a commercial farm in Rumiñahui Canton, Pichincha province, revealed that a biodigester with a liquid volume of 9 cubic metres generated approximately 3 cubic metres of biogas per day, with a methane content of 52%.

Other forms of wastewater management systems in the region include horizontal dry wetlands, which use biological processes to purify wastewater as part of primary treatment. This system has been implemented in the Dominican Republic in the Domingo Maíz Community and replicated in Jarabacoa and in Vallejuelo, San Juan Province (described by McFarren (n.d.). Aquatic plants are used to provide oxygen to the system through the roots and also absorb non-organic materials such as heavy metals and agro-chemicals. The technology works by gravity (so no conventional energy is required) and the plants harness energy from the sun, making it a natural, low-maintenance and energy efficient facility. The Dominican Republic also employs other energy efficient, natural systems as summarized by Tio (2017). These include anaerobic lagoons and facultative ponds. Tio (2017) notes that further research is required to achieve better use of natural conditions in wastewater treatment.

Findings and Conclusions

Unlike fossil fuels, renewable energy sources such as the sun and wind are effectively inexhaustible, and therefore can be utilized as the basis for an indefinite energy strategy. Renewable energy also has the very important benefit of producing negligible greenhouse gas emissions in operation, and thereby mitigating the impact of climate change, which now appears to be an existential threat to much of human civilization and the natural environment. An approach that integrates alternative energy with water treatment technologies strengthens the adaptive capacity of the region by providing potable water where resources are contaminated or now limited due to climate-related impacts such as drought and saline intrusion.

Electric power from solar, wind or hydro-technology are now relatively mature technologies, but there are other options that do not require electricity to operate; including photo-catalytic reactors (e.g., activated carbon and titanium oxide systems) and optical systems. Position energy, associated with gravity-based systems such as aqueducts, is also a form of renewable energy, but its potential has not been explored. Biogas, which can be generated from wastewater treatment using with bio-digesters, can make an important contribution, particularly in agricultural areas.

The cases reviewed in this book have highlighted the increasing cost-effectiveness of these cleaner solutions, sometimes because no external power is required, and sometimes because no chemical inputs are needed. There are particularly important applications of alternative energy in conjunction with water treatment facilities in remote, sparsely populated areas where there is limited access to clean water or a reliable electricity supply. The technology is also very useful in disaster areas, where centralized power and water distribution grids have been damaged and cannot provide electricity and clean water to people in the affected areas. The Nicaraguan case also demonstrated the applicability of the energy-water nexus in ensuring food safety in the fisheries sector. In Colombia, the social benefits were clear, with indigenous communities in remote areas being able to replicate the solar desalination model using recyclable and easily accessible materials and therefore taking direct responsibility for their water supply.

This situational analysis of work across the Americas has shown that the majority of interventions to integrate alternative energy into water quality solutions mainly focus on water treatment, with limited applications in the wastewater management field. This finding is in line with the overall finding that there is a greater propensity to invest in water supply systems than in wastewater management.

A number of universities and research institutions have championed technology development and research in their countries, and across the region. Some universities (in Peru, for example, have secured patents for their designs and have partnered with the private sector to develop and roll-out solutions for the energy-water sector. In Venezuela, government policy has been the main driver of the adoption of renewable energy in the water sector. In the Caribbean, individual ingenuity and private sector innovation are the main drivers, and the region is now in the early stage of the development of a sophisticated, commercially-driven business model.

Recommendations

The management of water requires a combination of preventative and end-of-pipe solutions, integrated in a comprehensive policy approach aimed at meeting water quality targets. The main recommendations for water management include:

- Developing regulations for non-point sources of pollution (such as agro-chemicals);
- Establishing an independent water quality monitoring and research program, a comprehensive set of robust standards and the institutional capacity required to deliver improvements and enforce standards;
- Implementation of zoning policies and integrated watershed management;
- Incorporating eco-centric and precautionary principles in water quality management, especially as it relates to the use of toxic substances.

With regard to the energy – water nexus, the main recommendations include:

- Research and development collaboration at the regional level: This can be facilitated by IANAS in partnership with the Global Water Partnership (GWP), Caribbean Water and Wastewater Association (CWWA) and other water and energy institutions in the region.
- Financing for nexus initiatives: Financing has to be made available in order to develop and manufacture the technology needed to solve the problems in the region. In the case of the successful St. Lucian inventor, the Global Environmental Fund (GEF) provided small grant assistance to conduct the feasibility study as well

as to develop the technology, and it has now reached the point where it has been exported to solve water problems in another small island developing nation. This financial support, which could take the form of a dedicated window in the development banks offering low-interest credit, or shareholdings, should be extended to both researchers and the private sector, particularly where the financing is required to bring a prototype to market.

- Government incentives for integrating water and energy technologies: The policy environment needs to be developed to encourage more sustainable approaches to ensuring water security. This could include financial incentives for clean technology and polluter-pays disincentives for old, inefficient technologies still used in energy supply and water treatment.
- Wastewater management: Water supply requires investment, but measures to improve efficiency and reduce leaks and theft are equally important, and commensurate investment must be focused on wastewater treatment. This comprehensive approach will deliver both the water and the energy efficiency gains required to achieve the Sustainable Development Goals.

References

Academia de Ciencias Físicas, Matemáticas y Naturales de Venezuela y Academia Nacional de la Ingeniería y el Hábitat (s/f). *Aldeas inteligentes, energías sostenibles y uso del agua.* (Documento inédito). Venezuela.

Flores-Díaz, Adriana C. *et al.* (2018). *Calidad del agua en México.* (Documento inédito). México: Academia Mexicana de Ciencias.

Franco, J. (s/f). *Una experiencia de desalinización del agua mediante energía solar en el norte de Argentina.* (Documento inédito). Argentina: Universidad Nacional de Salta.

González Rivas, E.J. *et al.* (2018). *Calidad del agua en Venezuela.* (Documento inédito). Venezuela

IANAS-IAP (2016). *Guía hacia un futuro energético sustentable para las Américas.* Mexico: IANAS. https://www.ianas.org/docs/books/eb01.pdf

McFarren, Tim (s/f). *Experiencias de tecnologías utilizadas en la República Dominicana para mitigar los efectos del agua contaminada mediante la tecnología apropiada.* (Documento inédito). República Dominicana.

Mitchell, Kerry, Martin S. Forde, y Allan Neptune (2018). *Water Quality in the Americas – Grenada.* (Documento inédito). St. George's, Grenada: St. George's University

Rincón-Martínez, José M. y Diana M. Durán-Hernández (s/f). *Energía renovable y desarrollo de la calidad del agua en Colombia.* (Documento inédito). Colombia.

Rodriguez, Juan (s/f). *Experiencias y prácticas efectivas en el uso de energías alternativas para mejorar la calidad del agua: el caso de Perú.* (Documento inédito). Lima, Perú: Center for the Development of Advanced Materials and Nanotechnology, Universidad Nacional de Ingeniería, Av. Tupac Amaru 210, Rimac, Lima, Perú.

Sáenz, Melio, Felipe Cisneros y Ricardo Izurieta (s/f). *Calidad del agua y energía en las Américas: un caso de estudio de Ecuador.* (Documento inédito). Cuenca, Ecuador: Universidad de Cuenca

Sandoval, Erick (s/f). *Uso de un sistema fotovoltaico para purificar el agua salobre utilizada para limpiar los moluscos bivalvos destinados al consumo humano en el municipio de Aserradores-Chinandega, Nicaragua.* (Documento inédito). Managua, Nicaragua: Universidad Centroamericana.

Tió, Roberto C. (2017). *Estatus de plantas de tratamiento de aguas residuales (PTAR) en la República Dominicana.* (Documento inédito). República Dominicana.

Chile

Chile is a land of contrasts regarding water resources, with annual runoff varing from 500 to 7,000 m^3/inhab as one moves from the arid North to the wet South. Chile has achieved high levels of sanitation and access to drinking water for the region and has also made considerable progress in the knowledge and protection of water quality. However, the pressures of urban, mining, agricultural and industrial development, coupled with various hydrological and geochemical conditions, pose significant challenges for water quality towards meeting the 2030 Agenda for sustainable development, in dimensions that go beyond sanitation and access to drinking water.

Cochrane Lake in the Patagonia region, Chile © iStock

Water Quality in Chile: Progress, Challenges and Perspectives

Pablo Pastén, Alejandra Vega, Paula Guerra, Jaime Pizarro and Katherine Lizama

Abstract

Although a great deal of progress has been made in the knowledge and protection of water quality in Chile, various hydrological and geochemical conditions, coupled with urban, agricultural, industrial and mining pressures, make Chile an interesting case, creating multiple challenges for complying with the 2030 Agenda in dimensions beyond sewerage and access to drinking water.

1. Introduction

Between 1990 and 2015, Chile showed a positive evolution in the indicators of access to drinking water and sanitation associated with the United Nations Millennium Development Goals (MDG) (2001). This positive evolution in drinking water treatment provided benefits for both health and the environment, and socioeconomic development. The country now has the commitment to advance the Sustainable Development Goals (SDG) agreed in the 2030 Agenda (ONU, 2015). SDG 6 proposes goals and indicators directly related to water quality. However, whether directly or indirectly, water quality plays a key role in other goals and indicators associated with the SDGs, beyond access to drinking water, sanitation and hygiene. Water quality is therefore also linked to water resource management, the resilience of communities and cities, agricultural, mining and industrial development, the viability of ecosystems, and equity and environmental justice (e.g. Evans & Kantrowitz, 2002; VanDerslice, 2011).

This chapter seeks to describe the main spatial and temporal trends in water quality in Chile, highlight some of the advances in the knowledge of the processes that control water quality and identify challenges for the future. Special emphasis is placed on thematic and problematic characteristics of the country such as the mineral enrichments that have given rise to extensive mining activity in the past and present.

This chapter begins by presenting the objectives and goals related to water quality, in both the MDGs and the SDGs, and their evolution and baseline for Chile. It then describes the water quality monitoring and information networks existing in Chile. It subsequently describes water quality in Chile, identifying the spatial and temporal macrotrends of key water quality parameters for surface and groundwater. Afterwards, it explain distinctive aspects of water quality for selected regions and watersheds, highlighting key issues for Chile and emphasizing the main scientific advances regarding the occurrence, distribution, dynamics and control of pollutants. Aspects of governance and regulations framing the control

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and protection of water quality are then briefly addressed. Lastly, the main conclusions and challenges are summarized, emphasizing the need for scientific and technological development, together with the development of public policies for the improvement and protection of water quality.

Readers can find additional information on hydrography, hydrology and urban water in Chile in the two earlier volumes of this series published by IANAS.[1]

2. Water quality in Chile in relation to the MDGs and SDGs

Performance for MDG targets and indicators

The main goals and indicators associated with water quality contained in the MDGs are presented in **Table 1**, including their variation for Chile between 1990 and 2015. Water quality in the MDGs is mainly related to MDG 7, particularly Target 7C and Indicators 7.8 and 7.9. Accordingly, aspects of water quality in the MDGs focus on access to drinking water and sanitation.

Water quality and SDG goals and indicators

Water quality is a fundamental aspect for several SDGs, beginning with SDG 6, where the availability of water for all depends on the quality in relation to its use. Direct indicators of water quality are associated with Goals 6.3 and 6.6. For the latter, indicators 6.3.2 (proportion of waterbodies with good environmental water quality) and 6.6.1 (change in the size of ecosystems related to water over time) are specifically considered. The list of indicators for the SDG 6 targets is available at UN Water (2017a) y and will be discussed for Chile later on.

Tables 2a and **2b** show the evolution of the drinking water and wastewater indicators for Chile, comparing values with those for the region. These tables confirm that Chile has seen a positive evolution of drinking water and sanitation indicators, and achieved an outstanding performance in the context of Latin America and the Caribbean.

1. www.ianas.org/docs/books/Diagnostico_Agua.html, p. 169 and www.ianas.org/docs/books/Desafios_ Agua.html, p. 152.

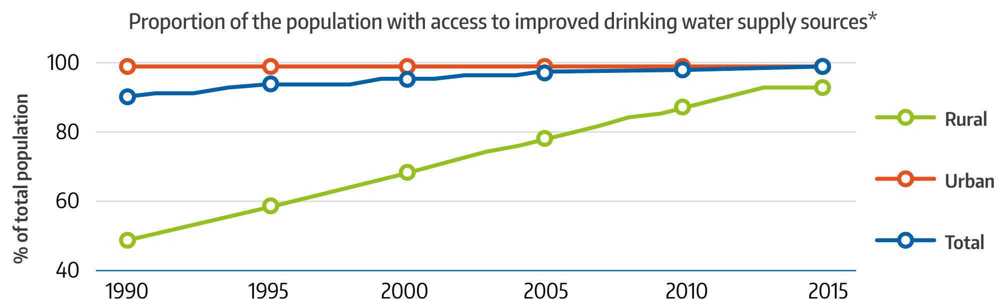
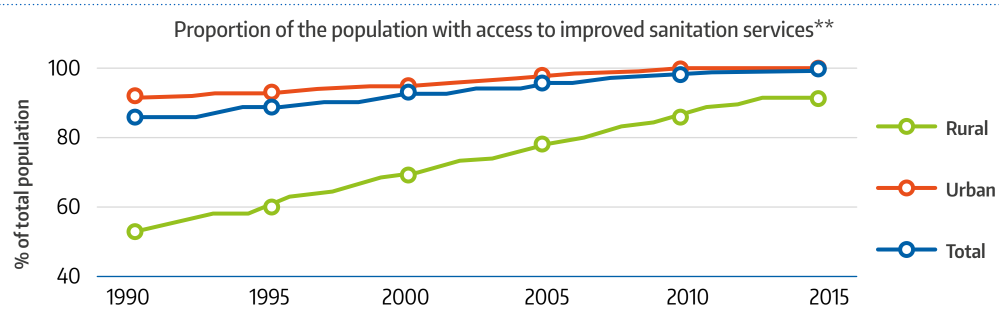
The systematic implementation of interceptors, wastewater pipes, and sewage treatment and disposal plants favorably impacted public health indicators. The implementation of this public policy, which in this case, was undertaken under the system of concessions to private individuals, is associated with an increase in the amount of hectares watered with water suitable for agriculture, the availability of water suitable for complying with international food security stands for agricultural export products, more favorable conditions for tourism and the possibility of recovering energy in anaerobic digestion systems (United Nations, 2017).

However, sanitation statistics include disposal through underwater outfalls. In November 2014, it was found that nearly 30% of municipal wastewater was disposed of through underwater outfalls, in 33 systems using this alternative, resulting in nearly 250,000,000 m^3 per year of wastewater being dumped into the ocean (SISS, 2014) without secondary treatment. Thus, good performance in Target 7C of the MDGs occurs partly at the cost of the transfer of wastewater to marine ecosystems.

Although it has been suggested that well-designed underwater outfall systems can be safe (Roberts *et al*., 2010), there is overwhelming evidence that underwater outfalls alter coastal systems (Gibbs and Miskiewicz, 1995; Roth *et al*., 2016). In addition, the final disposal of sewage in the sea prevents its reuse, a fundamental aspect for arid and semi-arid regions in northern and central Chile.

In regard to potable water, the percentage of compliance with values of parameters established in the drinking water quality standard (NCh409Of.2005) and its sampling until 2016 was 99.2% in the urban sector with a positive evolution over time (Ministerio del Medio Ambiente, 2017b). Noncompliance with parameters such as chloride, nitrate, total suspended solids, sulfate and arsenic is mainly concentrated in drinking water systems in northern Chile (e.g. Copiapó, Alto Hospicio, Caldera, Tierra Amarilla and Chañaral), an aspect that is addressed through the change of sources and technologies in the development plans of the sanitary companies, under the supervision of the Department of Sanitary Services (SISS). Notwithstanding the foregoing, there should be a periodic review of the parameters and values regulated in relation to the evidence of risks to human health. For example,

Table 1. MDG. Identification of objectives related to water quality and their goals and indicators for 1990 and 2015

<table>
<tr><th colspan="3">Indicators associated with Target 7C and their values for Chile from 1990 to 2015</th></tr>
<tr><td rowspan="2">Goal 7C: To halve the percentage of people without sustainable access to drinking water and basic sanitation services by 2015</td><td>Indicator 7.8: Access to improved sources of drinking water supply</td><td>
</td></tr>
<tr><td>Indicator 7.9: Access to improved sanitation services</td><td>
</td></tr>
</table>

Source: Compiled by the authors based on MDG Indicators, consulted at http://mdgs.un.org/unsd/mdg/Data.aspx on June 4, 2018. *Improved sources of drinking water supply correspond to a facility which, due to its design, is protected from external contamination, particularly contamination of fecal origin. Bottled water users are only considered to have adequate access when they have an improved secondary supply source. Wells, unprotected springs, water from tanker trucks and bottled water, water taken directly from rivers, ponds, streams, lakes, reservoirs or irrigation canals are not included. **Improved sanitation service is defined as a facility that hygienically prevents contact between excrement and humans, animals and insects. It includes toilets and latrines connected to sewerage, septic tanks, latrines with a platform of any material that covers the pit except for the discharge opening. Unimproved services include public or shared facilities, bathrooms with direct discharge into open drainage or ditches, latrines without platforms, bucket latrines, hanging toilets or latrines, and defecation in the open air, fields or water bodies.

boron is not included in the primary drinking water quality standard, but in the North Macrozone (see **Figure 1**), there are water sources with high boron values, well above the 2.4 mg L^{-1}. recommended by the WHO.

Table 3 presents baselines and goals for several of the SDG 6 indicators, presented in the Diagnosis and Implementation of the 2030 Agenda Report and the Sustainable Development Goals in Chile (Gobierno de Chile, 2017), associated with the work of the National Council for the Implementation of the 2030 Agenda.[2] At the national level, the figures indicate a high percentage of potable water and sanitation provision in 2015. However, national figures do not fully reflect the efforts that are yet to be made in rural areas where 12.7% of the population lived in 2015 (Instituto Nacional de Estadísticas, 2015), as shown in **Tables 1, 2.a** and **2.b.**

The supply of drinking water in rural areas is organized through Rural Potable Water (APR) systems, outside the system of concessions of sanitation companies that focuses on urban areas. These are the organizations (committees, cooperatives) that obtain operating permits from the Ministry of Health, to which the regulations concerning concessionaires

2. The following participate in the National Council for the Implementation of the 2030 Agenda for Sustainable Development: the Ministry of Economy, Development and Tourism, the Ministry of Social Development and the Ministry of the Environment, which is chaired by the Ministry of Foreign Affairs. *"Their main functions are: To advise the president on the implementation and monitoring of the 2030 Agenda, and coordinate the Implementation and Follow-up of the Agenda and the SDGs at the national and regional level"* (Exteriores, M.d.R., 2016).

Table 2.a: SDG. Evolution of the main performance variables of Indicator 6.1 of SDG 6 related to water quality

		Chile		Latin America and the Caribbean		North America and Europe	
		2000	2015	2000	2015	2000	2015
	Population (millions)	15,170	17,948	526,890	634,387	1,040,132	1,096,280
	% Urban	86	90	75	80	73	76
% population with availability of drinking water							
National	At least basic	95	100	90	96	99	99
	Limited	-	-	1	1	0	0
	Unimproved	5	0	6	2	1	1
	Surface water	0	0	3	1	0	0
	Annual change rate in basic	0.32		0.38		0.02	
Rural	At least basic	72	100	71	86	96	97
	Limited	-	-	2	2	1	0
	Unimproved	28	0	16	6	3	2
	Surface water	0	0	10	6	0	0
	Annual change rate in basic	1.84		0.97		0.05	
Urban	At least basic	99	100	97	99	99	99
	Limited	-	-	0	0	0	0
	Unimproved	1	0	3	1	0	0
	Surface water	0	0	0	0	0	0
	Annual rate of change in basic	0.07		0.14		0	
% population using improved water supplies							
National	Managed safely	92	98	61	65	89	94
	Accessible in the home	92	99	82	93	91	94
	Available when needed	94	99	72	74	-	98
	Free of contamination	95	98	61	65	96	98
	Channeled	94	100	83	91	94	95
	Unchanneled	2	0	8	6	5	4
Rural	Safely managed	-	-	-	-	-	-
	Accessible in the home	53	95	53	79	78	90
	Available when needed	67	93	56	61	-	-
	Free of contamination	-	-	-	-	-	-
	Channeled	62	100	54	72	82	89
	Unchanneled	10	0	19	16	15	8
Urbano	Safely managed	98	98	77	77	-	96
	Accessible in the home	98	100	91	91	96	96
	Available when needed	99	99	77	77	99	99
	Free of contamination	99	98	92	93	-	100
	Channeled	99	100	93	96	98	98
	Unchanneled	0	0	4	3	2	2

Source: adapted from WHO and UNICEF (2017a; 2017b). **Safely managed:** Drinking water from an improved source that is located in dwellings, available when needed and free of fecal or prioritary chemical contamination. **Basic:** Drinking water from an improved source for which collection time does not exceed 30 minutes per round including queuing. **Limited:** Drinking water from an improved source for which collection time exceeds 30 minutes per round including queuing. **Unimproved:** Drinking water from an unprotected well or spring. **Surface water:** Drinking water taken directly from a river, dam, lake, pond, stream, canal or irrigation canal.

do not apply (the SISS is not involved in their operation), although they must comply with technical standards, such as the drinking water quality norm. Law 20,998 of 2017 regulating rural health service management internalizes the technical advice of the APR in the Ministry of Public Works. In recent years, the Ministry of Public Works has made significant investments in the APR system, especially in locations in northern Chile with high levels of As. However, broad, systematic monitoring has yet to be carried out not only of compliance with water quality parameters, but also of the cost-effectiveness of the solutions adopted.

First steps in baselines and goals for water quality indicator

For Indicator 6.3.2 of the SDGs, a baseline of 67% of good-quality water bodies and a target of 80% were established for 2030 (**Table 3**). It should be noted that only six systems were considered, for which a norm exists, including two river sections (Maipo in Cambimbao and Biobío at the outlet), two aquifers (Cachapoal and Tinguiririca) and two lakes (Villarrica and Llanquihue). Sub-indicator 6.6.1.c has more details related to Indicator 6.3.2, although a reconversion should be considered to reflect the fact that indicator 6.6. refers to a percentage of change over time, while Indicator 6.3.2 refers to a percentage of good-quality water bodies (UN Water, 2017b; UN Water, 2017c). Considering the fact that methodologies and guidelines for calculating the indicators were only recently established, it is encouraging that there are already estimates for six bodies of water, the necessary establishment of new secondary water quality standards will allow the calculation of indicators for other waterbodies of interest

Table 2.b: Evolution of main performance variables of Indicator 6.2 of SDG 6 related to water quality

		Chile		Latin America and the Caribbean		North America and Europe	
		2000	2015	2000	2015	2000	2015
Sanitation (% population)							
National	At least basic	92	100	75	86	96	97
	Limited	0	0	4	5	1	1
	Unimproved	6	0	11	6	4	2
	Open-air defecation	2	0	10	3	0	0
	Annual rate of change in basic	0.54		0.7		0.1	
	Annual rate of change of open-air defecation	-0.15		-0.44		0.00	
Rural	At least basic	67	99	47	68	89	94
	Limited	0	0	3	5	1	1
	Unimproved	29	0	20	15	10	5
	Open air defecation	3	1	29	11	0	0
	Annual rate of change in basic	2.12		1.41		0.32	
	Annual rate of change of open-air defecation	-0.16		-1.21		-0.01	
Urban	At least basic	96	100	84	90	98	98
	Limited	0	0	4	5	1	1
	Unimproved	2	0	8	4	1	1
	Open air defecation	2	0	3	1	0	0
	Annual rate of change in basic	0.28		0.38		0.01	
	Annual rate of change of open-air defecation	-0.15		-0.15		0.00	

% population using improved sanitation systems							
National	Safely managed	27	85	10	22	74	78
	In-situ disposal	6	5	-	-	-	-
	Emptied and treated off site	0	0	-	-	-	-
	Wastewater treatment	21	80	10	22	74	78
	Latrines and others	5	1	11	9	6	5
	Septic tank	7	9	17	17	10	10
	Connection to sewerage	80	90	47	60	79	82
Rural	Safely managed	-	-	-	-	42	47
	In-situ disposal	-	-	-	-	-	-
	Emptied and treated off site	-	-	-	-	-	-
	Wastewater treatment	3	20	2	5	42	47
	Latrines and others	28	13	20	22	16	14
	Septic tank	28	63	18	32	28	29
	Connection to sewerage	11	22	9	14	45	50
Urban	Safely managed	47	81	12	27	86	87
	In-situ disposal	2	1	-	-	-	-
	Emptied and treated off site	0	0	-	-	-	-
	Wastewater treatment	45	80	12	27	86	87
	Latrines and others	1	0	8	5	3	3
	Septic tank	3	2	16	13	4	4
	Connection to sewerage	91	98	60	72	91	92

Source: adapted from WHO and UNICEF (2017a; 2017b). **Safely managed:** Use of improved facilities that are not shared with other households and where excreta are properly disposed on site or transported to off-site treatment systems. **Basic:** Use of facilities that are not shared with other households. **Limited:** Improved facilities shared by two or more households. **Unimproved:** Use of latrines without a platform, hanging latrines or bucket latrines. **Open air defecation:** Disposal of human feces in fields, forests, bushes, open bodies of water, beaches and other spaces or with solid waste.

throughout the country. According to the *Atlas del Agua 2016* (Dirección General de Aguas, 2016), Chile has 101 hydrographic basins, 1,251 rivers, 12,784 lakes and lagoons and 24,114 glaciers, with a total of 829 fully-functioning water quality monitoring stations (**Figure 1**). The recent adoption of secondary water quality standards and surveillance plans for priority basins in Chile will be an important input for increasing coverage of the water quality indicators for SDG 6.

Towards a more comprehensive calculation of pressures and interactions of water quality

The MDGs and SDGs also consider aspects of sustainability indirectly related to water quality. Chile has promoted initiatives oriented towards coordinating efforts and reports on sustainability aspects which include the state of aquatic environments, pressures and biodiversity conservation efforts, such as the National Biodiversity Strategy (Comisión Nacional de Medio Ambiente, 2003)[3] and the Green Growth Strategy (Ministerio del Medio Ambiente, 2013). A more comprehensive approach to environmental accounts is considered in the National Environmental Accounts Plan (Ministerio del Medio Ambiente, 2016). This plan establishes the institutional and operational implementation of the Integrated System of Environmental, Ecosystem and Economic Accounts (SICAEE). The SICAEE "*responds to the need to advance integrated systems of statistical production, in order to respond to the*

3. The Council of Ministers for Sustainability (CMS) recently approved the National Biodiversity Strategy for the period 2017-2030 (Ministerio del Medio Ambiente, 2018).

growing national and international demands for coherent and consistent environmental information, integrated into economic and social information" and thus "*respond to the environmental measurements in the United Nations statistical program (ODS) and the commitment to international organisms such as the OECD, European Union, United Nations and CBD*". In regard to pressure on water quality under a DPSIR approach (*Driving forces-Pressure-State-Impact-Response*) (European Environment Agency, 1999), the Pollutant Emission and Transfer Register (RETC) is currently operating (Ministerio del Medio Ambiente, 2017a), integrated into the National System of Environmental Information for compiling environmental accounts. The RETC "*is a database designed to: capture, collect, systematize, conserve, analyze and disseminate information on emissions into the air and water, waste and transfers of contaminants that are potentially harmful to health and the environment, produced in industrial or non-industrial activities*". The RETC provides information on the location and magnitude of emissions into surface and groundwater by productive activity. The Third Report on the Status of the Environment (Ministerio del Medio Ambiente, 2017b) notes that in 2015, the activities reported to the RETC which created the most emissions into surface water bodies were the elimination of residues and wastewater, sanitation and similar activities (56.6%), copper extraction (16.5%) and aquiculture and related services (14.7%), whereas those that created the most emissions into groundwater were beverage production (48.7%), the production, processing and conservation of meat, fruit, pulses, vegetables, oils and fat (27%) and livestock raising (13.3%).

3. Water quality monitoring network

General Directorate of Water (DGA) Monitoring network

The DGA is the state agency under the authority of the Ministry of Public Works which operates the inland water quality network, including surface (rivers, lakes) and groundwater. The distribution of 829 water quality stations, together with a sum-

Table 3: 2030 Baselines and targets for SDG 6 indicators

Goal	Indicator	2015 Base	2030 Goal	Notes[a]
6.1	6.1.1 Proportion of the population with safely managed drinking water supply services (%)	97.95	100	Tier I; MI; National value[b]
6.2	6.2.1 Proportion of the population that uses safely managed sanitation services, including a hand washing facility with soap and water.	96.53	100	Tier I; MI; National value
6.3	6.3.1 Proportion of safely treated wastewater (%)	99.89	99.98	Tier II; MI; National value
	6.3.2 Proportion of good quality water bodies	67	80	Tier III; MI; See Note c and Indicator 6.6.1c
6.4	6.4.1 Change in the efficiency of water use over time	N/I	NA	-
	Municipal	66.42		Tier III; MN
	Energy	5.22		Tier III; MN
	Industrial	0.83		Tier III; MN
	6.4.2 Stress level due to water scarcity: extraction of fresh water as a proportion of available freshwater resources.	1.47	NA	Tier II; MN; Year 2014, National value
	Municipal	0.19		Tier II; MN
	Energía	1.25		Tier II; MN
	Industrial	0.03		Tier II; MN
	Agricultural	3.25		Tier II; MN

6.5	6.5.1 Degree of application of integrated water resource management (0-100)	13.5	30	Tier II; MI
	6.5.2 Proportion of area of transboundary basins with an operating arrangement for cooperation in the field of water.	N/I	NA	Tier II; MI undefined
6.6	6.6.1 Change in the extent of water-related ecosystems over time	See note d	0	Tier III; MI; See Note c
	6.6.1.a Change in the spatial extent of the aquatic ecosystem (km^2)	N/I		
	Lake Villarrica-South Coastline	176	NA	Tier III; See Note e
	Lake Llanquihue-Octay Port	870.5		
	6.6.1.b Change in the amount of water in the aquatic ecosystem	N/I		
	Lake Villarrica-South Coastline (km^3)	21		
	Lake Llanquihue-Octay Port (km^3)	152.9		
	Maipo River in Cabimbao (m^3/s)	111.55	NA	Tier III; See Note e
	Biobío river at outlet (m^3/s)	954		
	Cachapoal Aquifer (SHAC[f]) Pelequén-Malloa-San Vicente de Tagua Tagua	N/I		
	Tinguiririca Aquifer (SHAC[f]) Tinguiririca Superior	N/I		
	6.6.1.c Change in water quality	N/I		
	Lake Villarrica-South Coastline (%)	70		
	Lake Llanquihue-Octay Port (%)	97		
	Maipo River in Cabimbao (%)	90	NA	Tier III; Corresponds to Indicator 6.3.2. See Note e
	Biobío river at outlet (%)	47		
	Cachapoal Aquifer (SHAC[f]) Pelequén-Malloa-San Vicente de Tagua Tagua	100		
	Tinguiririca Aquifer (SHAC[f]) Tinguiririca Superior (%)	81		

Source: adapted from Gobierno de Chile, 2017. Notes: a) Corresponds to the classification of the International Statistical Commission of SDG Indicators. Tier I: Conceptually clear indicator, established methodology and available standards and data produced regularly by the countries; Tier II: Conceptually clear indicator, established methodology and available standards but data not produced regularly by the countries; Tier III: Indicator for which there is no established methodology and standards or methodology/standards are being developed/tested. b) Includes the categories "Public Network" and "Well"; Excludes "River, slope, lake or estuary", "Tanker truck" and "Other source". c) Lake Villarrica (south coast station); Lake Llanquihue (Puerto Octay station); Maipo river (Maipo station in Cabimbao); Biobío river (North outlet station); the Cachapoal Aquifer (SHAC Pelequén-Malloa-San Vicente de TaguaTagua) and the Tinguiririca Aquifer (SHAC Tinguiririca Superior) are reported. d) Values incorporated in each sub-indicator. e) Data are only available for specific water bodies. National indicator pending. f) SHAC: hydrogeological system of common use. N/I: No information. NA: Goal not defined.

mary of the demographic and hydrological characteristics of the four macrozones of Chile (North, Central, South and Southern) is shown in **Figure 1.** Approximately 61% of the basins have water quality monitoring stations, roughly 85% of which monitor surface waters while the remaining 15% monitor groundwater[4] (Dirección General de Aguas, 2014). A monitoring network exists to evaluate the trophic condition of 20 lakes and lagoons, three of which are located in the Central Macrozone and 17 in the Southern Macrozone (Dirección General de Aguas, 2016). The distribution criterion of the stations considers areas of water scarcity, high population density and areas of anthropic pressure. It is designed to have stations that make it possible to identify the "natural state" and stations that make it possible to identify the effect of pressure on water quality. However, in practice it is difficult to determine what the natural state is for dissolved salts and metals in many Andean basins, given that natural enrichment and mining operations ocurr in the headwaters of these basins.

Sampling takes place four times a year (one per season) for surface water since 2017, and three or four times in previous years. For groundwater,

4. This statistic does not consider stations in the minimal lake network.

sampling is carried out twice a year, in autumn and spring (Gobierno de Chile, 2017). There is a very small proportion of hydrometric stations that have multiparameter sensors which continuously deliver information through the satellite platform. Water quality sampling is carried out by DGA staff, and the analyses are performed by the DGA staff central laboratory, which has ISO 17,025 accreditation.[5] Once the results of the analyses are available, they are entered into the BNA database (National Water Bank) and made available to the public through the CIRH (Water Resources Information Center) platform.

The parameters measured by the DGA in the field are temperature, pH, electrical conductivity and dissolved oxygen, whereas the parameters measured in the laboratory include a wide range of metals, anions, nutrients and an aggregated organic parameter (chemical oxygen demand) (Dirección General de Aguas, 2014). The Environmental Laboratory of the DGA currently measures 60% of the regulated parameters and plans to measure 80% of the parameters contained in secondary water quality standards by 2022. The centralization of the analyses and the availability of resources prevent the analysis of other parameters that require more expeditious analysis, such as BOD5. The list considers the basic parameters proposed by UN Water (2017b), whereas other relevant parameters on the list of progressive monitoring parameters are not included. Considering the pressures on water quality that could be relevant in some basins, the monitoring of the DGA reported by Dirección General de Aguas (2014) does not consider parameters such as alkalinity, turbidity, suspended solids, hydrocarbon, pesticides, volatile organic compounds, emerging contaminants or microbiological parameters. However, as a result of the progressive implementation of the secondary environmental quality standards, these parameters will be part of the surveillance plans according to the needs identified in regulated water bodies, consistent with the concept of progressive monitoring parameter.

5. ISO/IEC 17025 - Testing and calibration laboratories, "enables laboratories to prove that they operate competently and generate valid results, thus promoting confidence in their work nationally and around the world", https://www.iso.org

Other sources of water quality information from public institutions

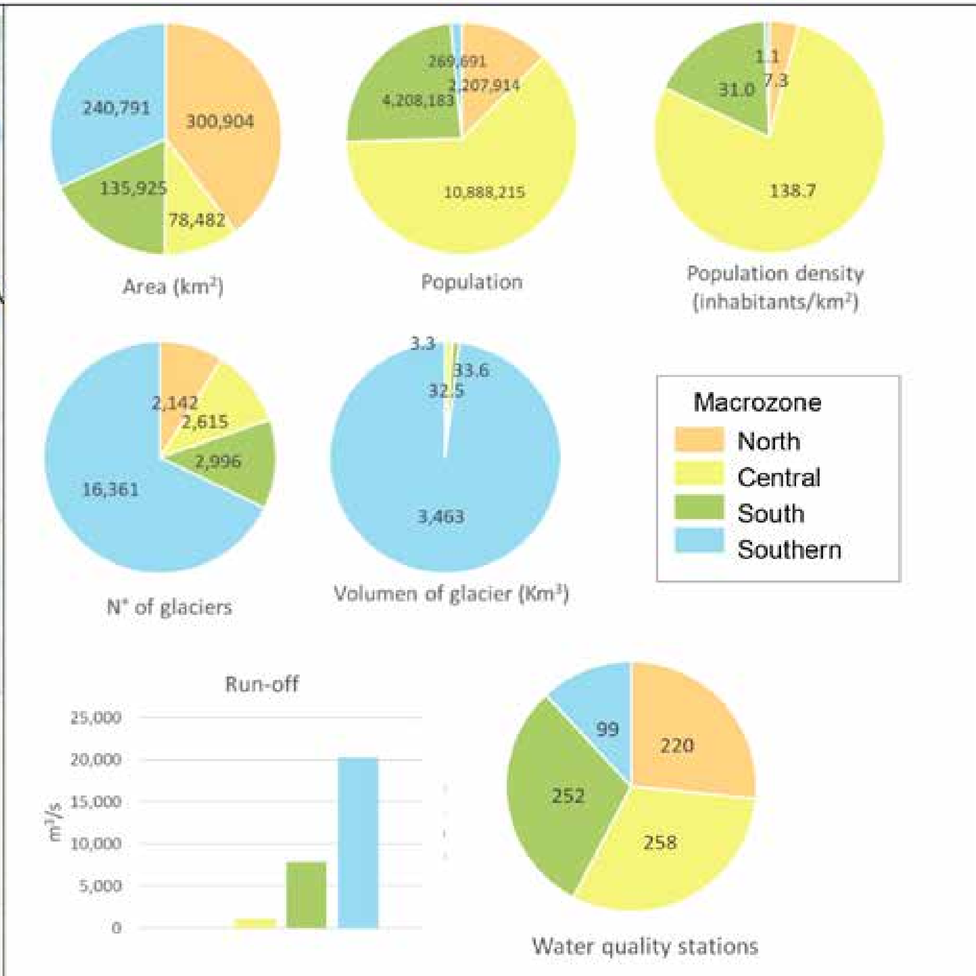
a. **Surveillance plans associated with secondary environmental quality standards (NSCA) of waters.** NSCAs seek the protection or conservation of the environment. To this end, they determine surveillance areas where systematic monitoring of specific parameters is carried out on a control network and also define a complementary observation network to evaluate the performance of the NSCAs. The oversight plans associated with the NSCAs are designed by the Superintendency of the Environment (SMA). They are implemented by the DGA and form part of the water quality database. If reports determine that the standard is not met, a saturated zone is declared and a decontamination plan established, whereas if a parameter complies and falls below the established limit, yet exceeds 80% of this value, the area is declared a latent area and a prevention plan is established. The NSCAs of the following basins are currently in effect: Serrano (2010), Llanquihue (2010), Maipo (2014), Villarrica (2013) and Biobío (2015), while Aconcagua, Mataquito, Elqui, Rapel, Huasco and Valdivia are under development.[6]

b. **Environmental Impact Assessment System (SEIA) of the Environmental Assessment Service (SEA).** A wide range of new investment projects or their modifications must undergo an environmental impact analysis.[7] Those that may have potential impacts on water quality require the establishment of a baseline of potentially impacted systems in the situation without a project and a monitoring plan during implementation and operation. This information is publicly available in the electronic file of the evaluation of each project in the SEIA and through the files of the SMA, responsible for monitoring the Environmental Qualifi-

6. The NSCA of the Valdivia river basin was in effect from December 2014 to September 2016, but was canceled after a claim was filed with the Environmental Court. Its drafting was resumed and in December 2017 it was undergoing a process of public consultation.

7. Law 19,300 of General Bases of the Environment and its associated regulations determine which projects must undergo an environmental impact assessment.

Figure 1. Distribution of the DGA water quality monitoring network and general description of the four macrozones defined by the DGA



Water quality monitoring stations: 829
101 basins across 756,102 km^2, with 1,251 rivers, 12,748 lakes and lagoons, 24,114 glaciers
Rainfall (mm/year); National: 1,525, North: 87, Central: 943, South: 2,420, Southern: 2,963. Uneven distribution of resource across country
Average run-off: 29,245 m^3/s
Average run-off per capita: 51,218 m^3/inhabitant/year

North Macrozone	Central Macrozone	South Macrozone	Southern Macrozone
12: Lluta 21: Loa 30: Endorreica* 34: Copiapó 38: Huasco 41: Los Choros* 43: Elqui 45: Limarí 47: Choapa	51: Petorca* 52: Ligua* 54: Aconcagua 57: Maipo 60: Rapel 71: Mataquito 73: Maule	81: Itata 83: Biobío 91: Imperial 94: Toltén 101: Valdivia 103: Bueno*	113: Aysén 122: Coastal between Seno Andrew and R. Hollemberg and eastern ilsands 125: Coastal between Lag. Blanca and Magallanes

Source: compiled by the authors based on the *Atlas of Water* (DGA, 2016) and the 2017 census. Available at: https://www.censo2017.cl/
Note: Selected watersheds in Figure 2 are listed and highlighted in the map. Additional watersheds presented in tables 4 and 5 are marked with an asterisk.

cation Resolutions (RCA) defined at the end of the evaluation in the SEIA.

c. **SISS.** It supervises the sanitary service concessions that operate in urban areas, controlling compliance with drinking water quality standards and the discharge of treated wastewater. It also monitors compliance with regulations for the discharge of liquid waste into surface and marine waters.

4. Macrotrends in water quality parameters in Chile

The study by Vega *et al* (2018) undertakes an analysis of trends in water quality parameters and the following sections use it as the basis for discussion. Since this study has integrated data from stations in different tributaries per basin since the 1980s, as well as data from different years, it does not necessarily reflect current quality, as can be seen in the parameters positively impacted by improvements in sanitation.

Surface water: rivers and estuaries

Figure 2 presents a graphic summary of the quality of surface water in the rivers and estuaries of selected basins using the DGA water quality database and the methodology of Vega *et al.*, (2018).

pH values generally vary between 6.5 and 8.5, with two basins in the North Macrozone with exceptionally low values, which have been associated with acid drainage present in the basins of the Lluta River (Guerra *et al.*, 2016a; Guerra *et al.*, 2016b; Leiva *et al.*, 2014) and the Elqui river (Espejo *et al.*, 2012; Flores *et al.*, 2017; Oyarzun *et al.*, 2013; Oyarzun *et al.*, 2012; Ribeiro *et al.*, 2014).

The electrical conductivity in general shows a trend from high values in the North Macrozone to exceptionally low values in the South and Southern Macrozones. In the North Macrozone, there are values of 15 mS cm^{-1}, for example, in the Salado river in the Loa river basin, which receives water from the El Tatio geothermal field, an important source of As and boron (Dadea *et al.*, 2001; Romero *et al.*, 2003).

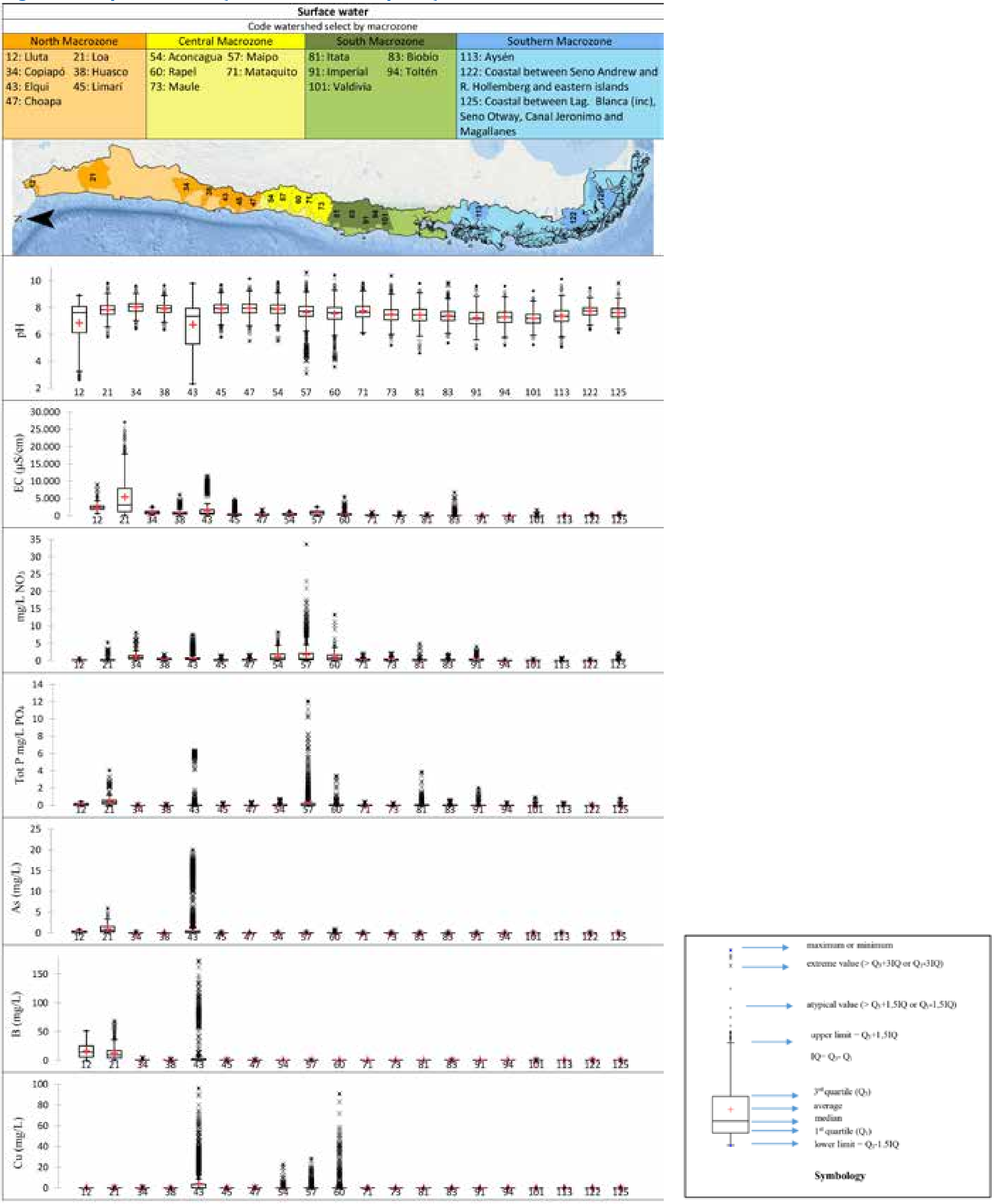
The Lluta river basin also has high values of electrical conductivity, As and boron. Although Andean mineral enrichments continue towards the Central Macrozone, the contributions of dissolved salts and metals are diluted by more favorable hydrological conditions, as in the basins of the Aconcagua and (Gaete *et al.*, 2007), Maipo-Mapocho rivers, fed by the Yerba Loca estuary (Montecinos *et al.*, 2016; Pasten *et al.*, 2015; Segura *et al.*, 2006), Rapel (Pizarro *et al.*, 2003) and Mataquito (Tapia *et al.*, 2009). In general, the high concentration of dissolved salts in northern basins is due to a combination of high evaporation with hydrothermal vents, acid drainage and the outcrop of brackish groundwater. Later, the case of arsenic in the basins of the Lluta, Loa and Elqui rivers is presented and discussed in more detail, as cases of enrichment by metals and metalloids from natural contributions and sources associated with mining. Towards the south, the geological framework changes, saline tributaries decrease and pluvial and nival runoff increases, creating currents with lower concentrations of dissolved salts.

The average concentrations of nitrate are high for three basins in the Central Macrozone (Aconcagua, Maipo and Rapel), and three basins in the North Macrozone (Copiapó, Huasco and Elqui). In a smaller range, three basins in the South Macrozone (Itata, Biobío and Imperial) have enrichment with respect to other basins further south (Toltén and Valdivia). Enrichment by nitrate in water is associated with diffuse pollution in urban areas and agroindustrial practices and livestock (e.g., Fernandez *et al.*, 2017; Fuentes *et al.*, 2014; Ribbe *et al.*, 2008).

The concentrations of COD[8] show high values in two basins, when compared with the rest of the country. In the Central Macrozone, the BOD shows high values in the River Maipo Basin, due to the record discharges of untreated or minimally treated wastewaters, mainly into the Mapocho River, prior to the sanitation plan of the 1990s. (Pflieger, 2008). The dramatic change caused by this plan has permitted previously unthinkable initiatives, such as the Mapocho 42K Project, which brings the Mapocho river channel closer to the urban population. This consists of a system of integrated parks with a cycle-path on the banks of the river (Iturriaga *et al.*, 2013).

8. Chemical Oxygen Demand. Aggregate measure of concentration of organic compounds, whose degradation creates dissolved oxygen consumption, which is expressed as oxygen demand (mg O2 L^{-1}). The value of the COD can be seen as an oxygen "debt".

Figure 2. Graphic summary of surface water quality in selected watersheds



Source: Compiled by the authors on the basis of data from the DGA.

Surface water: lakes, lagoons and reservoirs

The results of the DGA for 20 lakes show that there are three lakes with mesotrophy and two with hyperatrophy, while all the rest are oligotrophic (General Water Directorate, 2016).

There is overwhelming evidence that there is enrichment of metals and metalloids in a number of lakes and reservoirs in Chile (e.g., Contreras *et al*., 2015; Galleguillos *et al*., 2008; Pizarro *et al*., 2003; Pizarro *et al*., 2009). The analysis of sediment columns in lakes and reservoirs can provide a historical record of sources of contamination, as well as evidence of the transfer of pollutants between sediments and the water column in rural and urban environments (e.g., Hansen, 2012; Thapalia *et al*., 2010; Yang & Rose, 2003). In particular, it is important to recognize the links between the flows of metals from sediment to the water column (e.g. oxide-reduction gradients that can reductively dissolve iron oxides or oxidative sulfides) with the cycles of nutrients, organic matter, hydrological conditions and waste discharge (e.g., Tapia & Audry, 2013; Vega *et al.,* 2017).

Groundwater

Electrical conductivity follows a downward trend from north to south, as do boron and chloride. The arid basins of the north are characterized by the presence of environments with high evaporation, functioning as a salt concentrating mechanism which, together with the evapotranspiration generated by agriculture, is associated with high conductivities (e.g. Lluta, San José, Loa, Copiapó, Huasco). It has been established that aquifer waters in desert areas such as the Pampa del Tamarugal (near Iquique) obey regional circulation patterns that bring water from the northeast to the southwest, passing through saline environments, while low salinity waters may emerge due to fault zones (Magaritz *et al*., 1990).

As has levels of approximately 10 μg L^{-1} in the groundwater[9] of the North and Central Macrozones (aquifers in the north zone of Santiago). This has forced a number of sanitation companies and APR to implement As removal systems through adsorption, coagulation with ferric chloride followed by filtration and inverse osmosis (e.g., Aracena & Muñoz, 2017; SISS, 2013).

9. Limit for As in drinking water recommended by WHO and maximum limit established by NCh409 /1.Of. 2005.

Nitrate and dissolved salts in the North Macrozone come from a combination of geological formations and arid hydrological environments, whereas in the Central and South Macrozones, it would be locally associated with urban pollution and diffuse agricultural pollution (Arumi *et al*., 2005; Donoso *et al*., 1999; Fernandez *et al*., 2017; Fuentes *et al*., 2014; Yevenes *et al*., 2016). The high concentrations of sulfate, chloride, nitrate and/or As in the North and Central Macrozones raise a challenge of sustainability in the production of drinking water in cities in northern Chile (e.g. Arica, Iquique, Copiapó, among others), where it is necessary to invest in technologies that demand the use of energy and reagents to achieve the limits established in the drinking water quality standard.

5. Pollution and decontamination processes at a regional scale

Metals in basins of the North and Central Macrozones of Chile

Basins in central and northern Chile are permanently exposed to the natural and anthropogenic pollution of their waters. An example of the former is the high level of As, which has affected populations since ancient times, as borne out by the analysis of the mummified remains of the Chinchorro culture (7000-2000 years BCE) (Bundschuh *et al*., 2012). One example of the latter is the intense mining activity in the north, which creates wealth and national progress, yet at the same time is a factor of concern for potential contamination due to accidental and diffuse discharges in surface waters and aquifers. This produces an impact on the health of the inhabitants, and the deterioration of aquatic and terrestrial ecosystems, as well as metal-rich waste.

An analysis of the water quality of water rivers in the north and center of Chile (Pizarro *et al*., 2010b), shows that in the Elqui river, the average concentration of As of recent decades is 1.705 μg L^{-1}, which is much higher than the level established

Table 4. Historical average of concentrations in 12 rivers in the North and Central zones of Chile. DGA data, for 21 years (1987-2008)

Basins	As (μg L^{-1})	Cu (μg L^{-1})	Cr (μg L^{-1})	Hg (μg L^{-1})	Cd (μg L^{-1})	Mo (μg L^{-1})	Pb (μg L^{-1})	SO_4^{2-} (mg L^{-1})
Endorheic	**814**	**2,440**	28	**9**	**26**	**60**	ND	236.3
Copiapó	**483.6**	77	60	**148**	**77**	**60**	148	**483.6**
Huasco	10	123	31	**6**	**93**	**60**	292	**360.2**
Los Choros	**175.6**	ND	60	**817**	ND	**60**	817	175.7
Elqui	**1,705**	**6,082**	26	**3**	**28**	**70**	147	**445.7**
Limarí	6	41	30	**3**	**35**	**60**	60	77.1
Choapa	14	78	25	**4**	**43**	**138**	63	110.6
Petorca	**182**	43	54	**3**	ND	**63**	ND	52.8
Ligua	54.4	ND	68	ND	ND	**68**	ND	54.4
Aconcagua	**132**	**789**	25	**87**	ND	**175**	80	115,1
Maipo	12	**1,293**	55	**9**	**35**	**463**	167	215.6
Rapel	**119.3**	45	**215**	**281**	**45**	**215**	281	119.3
NCh1333.Of78	100	200	100	1	10	10	5.000	250

Source: Adapted from Pizarro *et al.*, 2010b. NA: not available; in bold, amount in excess of NCh1333.Of78 for irrigation. The presented values correspond to those reported in the source. Using the methodology employed to calculate the values in Figure 2, the resulting characteristic concentrations are lower (for example, in Copiapó the obtained average values are 0,02 and <0,01 mg L-1 for As and Hg respectively).

Table 5. Average annual concentration of NO_3^- -N and PO_4^{3-}-P of nine rivers in the Central and South zones of Chile. DGA data, for 23 years

Rivers	Rapel	Mataquito	Maule	Itata	Biobío	Imperial	Toltén	Valdivia	Bueno
NO_3^--N (mg L^{-1})	1.57	0.55	0.49	0.35	0.21	0.4	0.11	0.31	0.18
PO_4^{3-}-P (mg L^{-1})	0.23	0.29	0.24	0.41	0.15	0.23	0.23	0.1	0.12

Source: adapted from Pizarro *et al.*, 2010b).

by the Chilean Standard for water quality requirements for irrigation (NCh1333.Of78). This high value is attributed to the development of gold mining in the basin, which has seen intense activity since the 1980s. This study shows another six rivers with average concentrations of As higher than those recommended by this standard: endorheic basins> Copiapó> Petorca> Los Choros> Aconcagua> Rapel. The concentrations of certain metals also exceed this standard (**Table 4**).

The water shortage in the North and Central areas and the decrease in rainfall due to climate change tends to aggravate the availability of water in both quality and quantity, affecting the activities that take place in the basin. These conditions raise the need to implement water monitoring programs that consider the quantification of emerging pollutants, the improvement of the frequency of sampling, the intensification of studies on the effect of heavy metal contamination on the food chain and the biodiversity of local flora and fauna.

Nutrients and eutrophication in basins in the Central and South Macrozones of Chile

The concentration of nitrogen (N) and phosphorus (P) has increased six and ninefold, respectively, from the time prior to industrialization, in the world's main rivers (Boyer *et al.*, 2006; Dumont *et al.*, 2005; Meybeck, 1982; Smith *et al.*, 2003; Smith, 2002). Rivers in the Central and South zones of Chile are no exception to this trend. The increasing contribution of N and P affects water quality and increases the process of eutrophication. Depending on the basin, these nutrients come from forestry, agricultural, wine and livestock activities, which have increased greatly in recent decades. These rivers are important as regards the availability of water for the area, with flows controlled by annual precipitation and the melting of snow and glaciers during the spring-summer period.

The record concentrations of N and P of certain basins are shown in **Table 5**. The use of statistical models showed that the concentration of N and P has increased in six (BioBío, Bueno, Imperial, Maule, Rapel and Valdivia) and two (Rapel and Maule) of the basins analyzed, respectively (Pizarro *et al*., 2010a). The average concentration of N in the Rapel river is the highest due to the intense activity of agri-food and agricultural industries, and the marked increase in tourism in the area and population density. However, the greatest increase has been recorded in the Biobío, Bueno, and Valdivia rivers, whose levels of concentration failed to show an increase in the first years in the study, yet experienced a major variation in the last 10 years analyzed. The concentration of P only shows an increase in the last decade in the Rapel and Maule rivers, while the Biobío, Itata and Valdivia rivers have a certain stability in the concentration of P. However, in the Itata River, there is an increase that could be explained by the forest development achieved in the basin during the decade from 1990 to 2000. The evolution of these nutrients should be observed, which could make it possible to detect the effects of population growth and the impact caused by agro-industrial, livestock, forestry and tourism activities in the area studied.

Water quality behavior must also be considered in the lakes in this area, water bodies that are intimately related to rivers, either because the latter are tributaries or constitute their natural discharge forming rivers that flow into the sea. Lakes witness activities in the basin and provide information on the biogeochemical changes caused by natural or anthropogenic disturbances, and the effluent water they form is the means of transport that influences the final destination of the results of these changes. Lakes in the area are monomictic and oligotrophic with low levels of chlorophyll and high transparency (Soto, 2002; Soto & Campos, 1995).

The concentration of N and P in the past two decades, in lakes whose basins have not undergone significant changes in land use and with a tendency to maintain native forest, has shown very slight variations, whereas in those where the basin has been intervened in more as a result of the increase in forest, tourist and/or agricultural activities, these nutrients tend to increase (Pizarro *et al*., 2016), which could accelerate the process of eutrophication lakes naturally undergo.

Lastly, the variation in the concentration of nutrients in the rivers does not show substantial differences from the concentration of the latter in the world's main rivers. It is impossible to rule out the fact that, if the increase in water continues, rivers could acquire the status of contaminated systems in the near future. Special attention should be paid to the management and planning of activities in the lake basins which, although currently considered oligotrophic systems, in the event of a rapid expansion of agriculture, livestock breeding and intensive tourism, these waters could be provided with excess nutrients that accelerate the degradation process, which is currently relatively controlled. These studies could serve as a reference for future monitoring programs and pollution mitigation projects at the basin level.

6. Pollution and decontamination processes at local scale: the case of As in three Andean basins

As is a toxic element mobilized through water, soil and air both anthropically and naturally. Its main origin is geological deposits rich in elements of economic interest, whose exploitation has accelerated the availability of As. Moreover, the hydrothermal natural sources associated with volcanic activity constitute significant contributors of As. The dynamics of As in three basins located in arid or semi-arid zones of the north: the Lluta, Loa and Elqui rivers (**Figure 1**) will be presented below. These cases serve to measure the complexity and challenges in understanding the speciation of pollutants, especially metals and metalloids, which is a determining factor in their fractionation between solid and dissolved phases, which in turn determines their bioavailability.

Lluta river basin

The basin originates in the Tacora Volcano (~5,500 masl), from which hydrothermal sources rich in metals, metalloids and salts emanate (Capaccioni *et al.*, 2011). To one side of the volcano stands the Tacora Sulfur company, abandoned since the 1960s, where deposits of tailings and rocks exposed to water and air produce an acid drainage stream known as the Sulfur River (Leiva *et al.*, 2014).

This tributary, with pH <2 and concentrations of As > 2 mg L^{-1}, is the main source of water pollution in the basin. The Lluta river basin is a clear example of the diversity and complexity of biological, geochemical, hydrological and hydrodynamic processes that control the fate and transport of pollutants. Four hundred meters from the source of the Azufre River there is a wetland where biogeochemical processes occur that modify the speciation of As (Leiva *et al.*, 2014); for example, extremophilic bacteria oxidize As from arsenite to arsenate, a less toxic species that is more prone to being sorbed onto iron oxyhydroxides, present in the wetland as orange sludge (Leiva *et al.*, 2014). As a result of these local processes, dissolved As almost entirely disappears within a few meters. Understanding these processes is essential to identifying the determinants of water quality, providing a fundamental control point to improve or protect the resource.

At the confluence of the river Azufre and the Caracarani river (pH 8.6) a series of geochemical, hydrological and hydrodynamic interactions occur that promote the formation of iron and aluminum oxyhydroxides, modifying the dissolved and solid fractionation of As (Abarca et al., 2017; Guerra et al., 2016a; Guerra et al., 2016b).

These precipitates tend to settle in the riverbed, reducing the concentration of As and metals in the water: 100 m downstream of the confluence, total As decreases by half. Concentrations of As of between 90 and 900 mg kg^{-1} have been measured in deposits in the Caracarani river bed, much higher than the base range in sediments (5-10 mg kg^{-1}) (Smedley & Kinniburgh, 2002). This example shows that natural attenuation processes exist in river systems, where sediment sampling can reflect whether the bed is a repository or source of pollutants.

This process of attenuation at the confluence can be modified by the presence of other elements and local and temporary changes in the flow rate. Studies on the same site show that: (1) the presence of organic matter (present in natural systems as humic substances) increases the size of oxi-hydroxide precipitates, thereby increasing the settling velocity and improving the removal of As (Arce *et al.*, 2017), (2) hourly variations in the flow due to freeze-thaw cycles cause variations in dissolved As (Guerra *et al.*, 2016b). When the Azufre River thaws, suspended solids dissolve (**Figures 3a** and **3b**), while hours later, the increase in the Caracarani river flow dilutes the salts and provides OH- ions for the precipitation of the mineral phases of iron, (3) the heterogeneous mixture that occurs in the vicinity of the confluence (**Figure 3c**) generates local points that favor the precipitation of iron phases and retention of As due to the pH and iron concentrations (Guerra *et al.*, 2016a), and (4) the particle size also increases or decreases depending on how particles migrate from one chemical environment to another, thereby determining whether As remains suspended in the aqueous phase or settles on the river bed, depending on the particle size achieved. The conceptual model of these processes is shown in **Figure 3d**, which is discussed in detail later.

Hydraulic infrastructure can also impact the destination of these pollutants. Models have predicted that the accumulation of sediments rich in As in anaerobic environments can lead to the release of reduced species of As, as could happen in the Chironta reservoir (Contreras *et al.*, 2015), currently under construction in the Lluta River (confluence of the Caracarani river with the Colpitas river). However, the presence of sulfur in anoxic environments may contribute to the immobilization of arsenite on sulfide phases such as mackinawite (FeS) (Contreras *et al.*, 2015).

In addition to highlighting the importance of understanding local processes in critical nodes of the system, the case of the Lluta River shows the hydrological and hydrodynamic interactions, with specific consequences for the interaction between hydraulic infrastructure works and water quality.

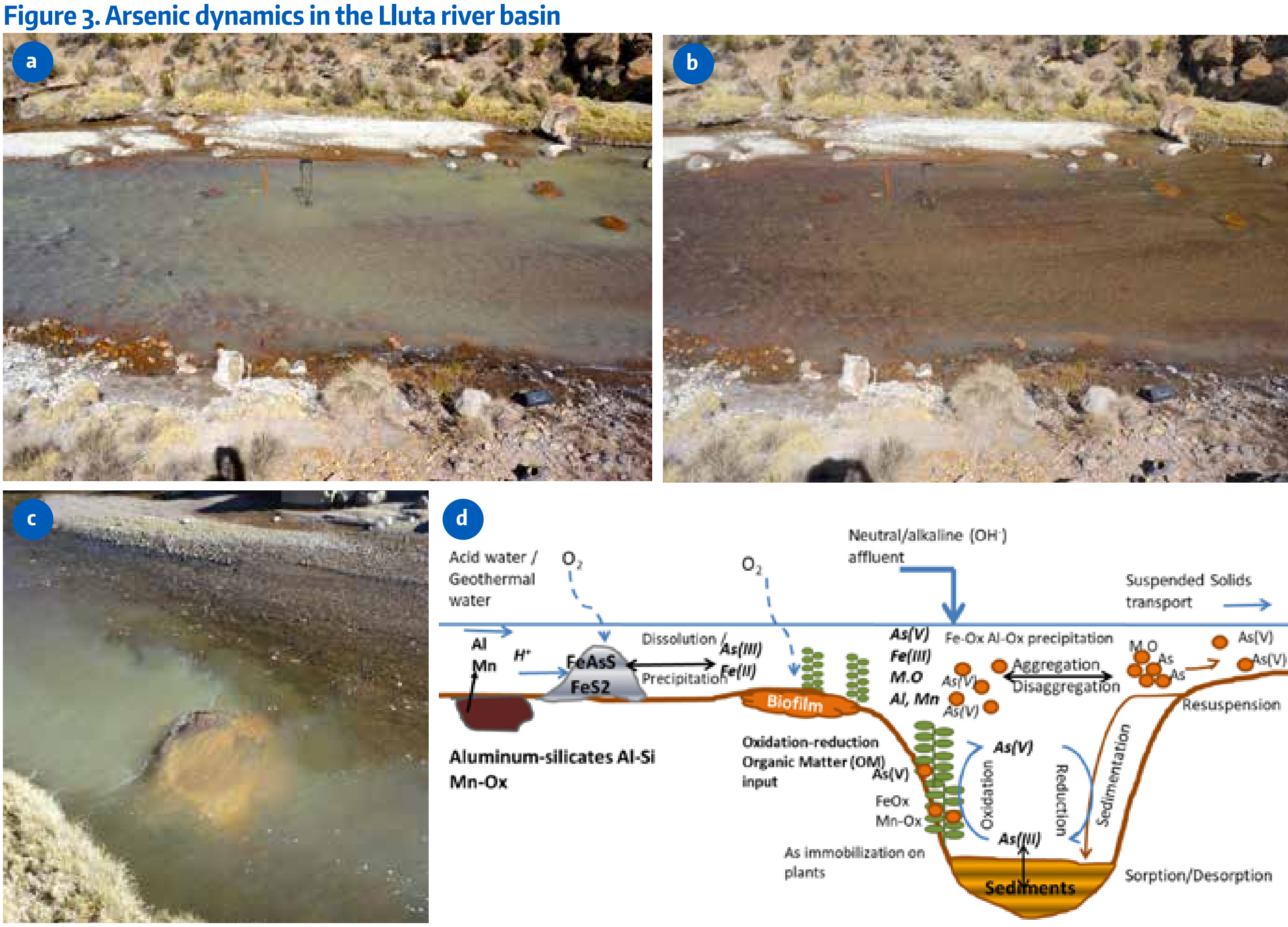
Loa river basin

The Loa River flows through the Atacama Desert, the driest place on earth, and is the only permanent surface water tributary in the Antofagasta Region. Its main tributaries are the Salado, San Pedro and San Salvador rivers. Its water has restricted use due to its poor quality (high salinity and high concentrations of Boron and As), particularly in the vicinity of Antofagasta, a situation intensified by the low availability of water resources and the aridity of the region.

The presence of As in the basin is mainly due to two factors: (1) The basin is located in the porphyry copper belt, where the Chuquicamata, El Abra and Radomiro Tomic deposits contribute to the flow of As due to the meteorization of the deposits and the presence of mining tailings (Pell *et al.*, 2013), and (2) the Salado river tributary rises in the geothermal springs of El Tatio, which has As concentrations of over 20 mg L^{-1} (Landrum *et al.*, 2009). As in the case of the Lluta River, there are a series of biogeochemical processes that control the speciation of As in El Tatio. One of these is the immobilization of As both as a result of the presence of iron oxi-hydroxides and because of the precipitation of minerals similar to loellingite ($FeAs_2$) (Alsina *et al.*, 2014).

The confluence of the Salado River with the Loa River in the upper part of the basin also causes a decrease in As, mainly due to dilution effects (Romero et al., 2003). However, from the upper part to the mouth of the river, its concentration remains within a limited range of 1-2 mg L^{-1}, which is attributed to conditions that do not favor the adsorption of arsenate and the lack of tributaries that contribute to the dilution of As, in addition to the high evaporation rates (Orellana, 1985; Romero *et al.*, 2003).

Figure 3. Arsenic dynamics in the Lluta river basin



(a) and (b) Change in the concentration of suspended particles due to the thawing of the Azufre River (a) shows the particles before thawing upstream; (b) shows how particles dissolve when the river Sulfur, an acid tributary, thaws; (c) incomplete mixing causes the formation of different particles, which are heterogeneously distributed; (d) conceptual diagram of As regulatory processes. As is released by natural processes (e.g. hydrothermal vents) or the oxidation of mining waste (e.g. sulfides) and can be subsequently immobilized/mobilized by various physical and chemical processes.
Source: a, b and c, authors' own photos; d, compiled by the authors.

Moreover, the San Salvador River flows into the Loa River in the middle part of the basin, also contributing As to the system (Romero *et al.*, 2003). Plants and algae are important for the formation of As repositories (Orellana, 1985; Romero *et al.*, 2003). The latter can accumulate As, achieving concentrations of between 182 and 11,000 mg kg^{-1} of As in the case of the hyperaccumulating species *Chladophora* sp.(Pell *et al.*, 2013). They can also contribute to the accumulation of As in sediments, as in the Quillagua oasis, rich in aquatic plants and organic matter, which has a high enrichment of As in sediments compared to Tranque Sloman, which lacks macrophytes and has low organic matter content (Bugueño *et al.*, 2014).

High concentrations of As in the basin have caused serious health problems in the population (Ferreccio & Sancha, 2006; Smith *et al.*, 2011). This has required the installation of treatment plants such as the Cerro Topater Plant. This seawater desalination plant has been essential to supplying the region with good quality drinking water in sufficient quantity and free of As for human consumption, assuming the increase in the cost of water when using this type of technology.

Elqui river basin

The Elqui river basin, in the Coquimbo Region, is a geochemically complex system where the composition of water and sediments is dominated by hydrothermal activity and the legacy of the El Indio mining area, a chemically reactive zone that produces acid drainage with high concentrations of pollutants (e.g. As > 1 mg L^{-1}) (Oyarzun *et al.*, 2013). Tailings erosion in the Talcuna mining area is another source of reactive sediments with high concentrations of pollutants (up to 340 mg kg^{-1} of As), which occasionally enter the drainage network during periods of flooding.

As in the examples presented above, along the basin there are processes that contribute to the reduction of dissolved metals and As levels, mainly due to the dilution of the flow originating in the El Indio area with other tributaries such as the La Laguna, Incaguaz, Estero Estrecho and Claro rivers, which are good quality tributaries (Flores *et al.*, 2017).

For example, when the Turbio River meets the Claro River (creating the Elqui River), concentrations of As are in the range of 0.01-0.1 mg L^{-1} of As, with a pH of approximately 8 (Espejo *et al.*, 2012; Flores *et al.*, 2017; Oyarzun *et al.*, 2013).

Conceptual model for the fate and transport of As in Andean environments

Arsenic in Andean systems comes mainly from acid waters produced by the exposure of mining deposits and fractured tailings to water and oxygen, as well as from geothermal waters. The examples presented above show the existence of a series of processes that contribute to the attenuation or enrichment of the concentration of As throughout them, including the physical processes of sedimentation-resuspension and chemical reactions of oxide-reduction, precipitation-dissolution of mineral phases and adsorption-desorption, which can also be affected by hydrological and hydrodynamic conditions, the presence of other chemical components and biota, as synthesized in the conceptual diagram in **Figure 3d**.

This conceptual model clearly demonstrates the complexity of pollutant dynamics in river systems, meaning that control and sampling methodologies should consider more variables and, in some cases, pay special attention to spatial and temporal extension, in order to adequately capture what happens in each site and be able to establish the most appropriate control measures. This model also constitutes the basis for the production of models which, in the future, will make it possible to evaluate the impact of hydraulic works, alteration in hydrological patterns, and the effect of other contaminants that may enter the system (e.g. nutrients), thus highlighting the connections between infrastructure works, socioeconomic activities and water quality.

7. Water quality management and challenges

Institutional and regulatory aspects

Several state institutions have important competencies and areas of action for water quality management. There are eight institutions directly involved (environmental institutions indicated above in addition to DGA and SISS), and other institutions responsible for water management issues in various contexts such as the Health Authority of the Health Ministry, among others. Environmental institutionality was defined on the basis of Law 20.417 of 2010 (Ministerio del Medio Ambiente, 2015). Institutions such as the DGA and SISS perform specific roles such as the quantification of the quality and quantity of water resources and the management of the sanitary concession system, respectively.

The Ministry of the Environment (MMA) defines and implements political and regulatory guidelines, including aspects of conservation and sustainable development, under the guidelines of the Council of Ministers for Sustainability (CMS), which proposes policies to the president. One of its functions is to handle standard drafts, including secondary water quality standards. The SEA is responsible for administering the SEIA, a system designed to prevent environmental deterioration by public and private projects. The evaluation of the projects and administrative acts of the SEIA are publicly available, constituting an important source of environmental information. Projects that undertake Environmental Impact Studies (EIA), which are approved by the SEIA, produce an RCA that describes the approved project and lists the approved conditions for its operation. Appeals against the requirements established in an EIA are seen by the Committee of Ministers. The SMA is responsible for the control and sanction of environmental breaches, for example, ensuring that the terms established in the RCA are met. Lastly, the Environmental Courts under the Supreme Court are responsible for resolving environmental disputes. For example, the Third Environmental Court recently decreed the annulment of the Secondary Norm for Water Quality in the Valdivia river, in response to an appeal submitted by entities which considered themselves affected by this norm (Tercer Tribunal Ambiental de Chile, 2017). This forced the resumption of the process of issuing the norm, beginning with the point that was challenged.

The most relevant regulations for water quality consider primary, secondary and emission standards. Primary quality standards include water quality standards for drinking water, irrigation, mineral water and recreation with direct contact. Secondary standards are much more recent (as of 2010), and only include environmental quality standards for the waters of two lakes and the basin of three rivers, with another six under development. It is obviously a major challenge to establish secondary environmental quality standards for water, considering that the DGA has approximately 100 basins in its cadastre. Emission standards include limits on the discharge of waste into surface water, sewage networks and groundwater. It should be noted that there is a specific emission standard for the Carén estuary – into which El Teniente from the state-owned mining company Codelco dumps liquid effluents - allowing higher sulfate and molybdenum values than for other parts of the country. Although the constitutionality of this rule has been extensively questioned, the Constitutional Court threw out the appeal filed against it.

Major challenges for water quality management

The following is a summary of the challenges which it seems necessary to address to advance the goals of the 2030 Agenda, from the perspective of the authors. From the perspective of a systemic approach, some of the challenges extend beyond specific water quality issues.

Institutional and regulatory framework for integrated water management

Over the years, water governance in Chile has been plagued by institutional fragmentation, with at least 12 central government institutions participating in the generation of public water policies, the highest number in the region (OECD, 2012). This fragmentation has made it difficult to establish a common objective to advance towards in a coordinated fashion. However, progress has been made in recent years. In 2009, an interministerial committee was established to coordinate the definition of policies for water issues (OECD, 2011) and the Committee of Water Ministers, coordinated by the Ministry of Public Works and comprising the ministries of the Environment, Agriculture, Energy and Mining, was set up. In 2012, the National Water Resource Strategy 2012-2025 was established (Ministerio de Obras Públicas, 2012), with five core ideas: efficient and sustainable management, improving institutionality, addressing scarcity, social equity and informed citizenship. During the next administration, a National Water Policy was defined (Ministerio del Interior y Seguridad Pública-Delegación Presidencial para los Recursos Hídricos, 2015) with four core ideas: the state as a responsible and participatory agent, measures to address the water deficit, a regulatory framework for water resources and strengthening the participation of social organizations. Despite having different nuances, these public policy documents recognize that the multiplicity of institutions with influence over water resource management is an obstacle to efficient water coordination and management, and accordingly they assign a fundamental role to Integrated Water Resource Management Water (IWRM). However, it is now necessary to advance in binding measures that will effectively implement this concept at the institutional and regulatory levels.

A key initiative that would facilitate integrated management is the bill submitted in 2011,[10] modifying the Water Code of 1981. This establishes the system of water rights in Chile, recognized as one of the most pro-market systems in the world (OECD, 2017). IWRM is therefore limited by the pre-eminence of water use rights (WR), which have private property characteristics that are negotiable. This limits the Government's ability to establish a coordinated long-term vision with a common welfare perspective. It also prevents public and private actors from becoming involved in the definition of national water resources and jointly assuming responsibility for the trade-offs implied by IWRM (OECD, 2017). Although the regulations contemplate the existence of user organizations, they are for sections of rivers, and fail to consider the dynamics that occur at the basin level and the relationship between surface and groundwater. The proposals to modify the Water Code seek to reinforce the nature of water as a national good for public use, and include aspects such as: limiting the temporary extension of the WR, limiting the exercise of WR as a function of public interest through their temporary reduction and redistribution, establishing human consumption and sanitation as priority uses in the provision and limitation of WR, forbidding the granting of WR in National Parks and Virgin Region Reserves and restricting in other protected areas, enabling the DGA to temporarily reduce the exercise of WR and demand the installation of measurement systems, among others (Ministerio del Interior y Seguridad Pública-Delegación Presidencial para los Recursos Hídricos, 2015).

10. It includes substitute indications introduced by the Executive Branch in 2014. These were still under discussion in Congress at the time of preparing this document.

Definition of science-based public policies for water quality management

The physical, chemical and biological processes that control water quality in Andean systems and determine the transport, transformation and fate of pollutants in aquatic systems are insufficiently known. This is especially worrying in a context of global change, where there is a growing demand for water resources, an increase in population and a wide range of anthropogenic compounds released into the environment. The pressures that affect water quality in Chile are manifold and distributed throughout a variety of aquatic environments whose functioning is only beginning to be known.

Water quality is a central aspect of major conflicts over water resources and sustainability agendas, in which multiple actors and institutions intervene. The interdependencies that occur in socio-environmental systems require public policy to consider the links between water quality and energy, food, ecosystem services, environmental heritage and environmental justice. The lack of public policies that consider an IWRM can affect sustainable development and increase the tension associated with mining developments, agricultural activity and urban expansion. This tension is currently exemplified in the Andean Cordillera of Central Chile, where the largest known copper reserves in the world are located in the headwaters of the most populated basin (Sistema Maipo-Mapocho), the resources of which are used for drinking water and irrigation.

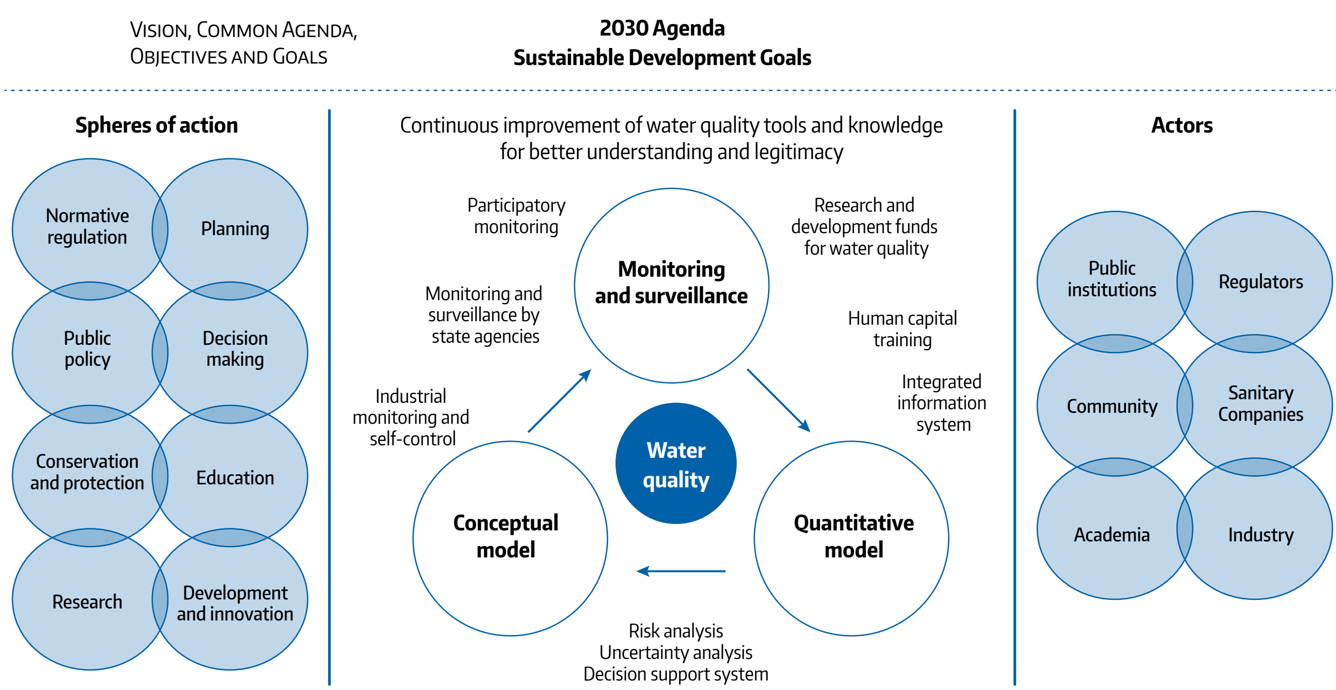
Figure 4 proposes an approach for water quality management, where science plays a fundamental role as support for decision making. The continuous improvement of knowledge and the monitoring of the water quality of Chile's aquatic systems requires the participation of multiple actors to achieve a common vision, such as that presented by the SDGs in the 2030 Agenda. This is also based on continuous feedback between conceptual models, quantitative models and water quality monitoring, which, as a whole, should reflect the common understanding of the functioning of the environment. The development of conceptual and quantitative models is the basis for achieving a transition from the "statistical description" of water quality to a more fundamental and, at the same time, operational understanding of the processes that determine it. The integrated, systemic vision of the processes constitutes one of the bases for building adaptive and resilient systems that adequately manage risks and pressures. The participation of different actors (e.g. citizen participatory monitoring) in the development of conceptual and quantitative models, as well as surveillance networks, also grants greater legitimacy to the results and contributes to the development of a common understanding of the system that should serve as the basis for management.

The national strategy for research, development and innovation (R+D+i) for the sustainability of water resources (Consejo Nacional de Innovación para el Desarrollo, 2016) proposed four strategic lines: (1) R+D+i for the understanding of hydrological processes; (2) R+D+i for integral water resource management ; (3) R+D+i for the understanding of aquatic ecosystems; and (4) technological development for the sustainability of water resources. The development and adequate financing of these strategic lines should establish robust support in the long term.

A more comprehensive water quality monitoring system

Monitoring and oversight of water quality is an essential part of water quality management (**Figure 4**). Monitoring and surveillance should be inserted into an institutional and regulatory framework with clear purposes associated with IWRM, consistent with the vision, objectives and goals associated with the sustainability agenda. There must also be substantial, long-term financing with public-private partnerships for the implementation of R+D+i programs, human capital training and the establishment of integrated information management systems. This must be complemented with the participation of various actors, who will provide viability and legitimacy for a common understanding of water quality, with participatory monitoring programs and self-regulating programs for the industry, in addition to oversight by state institutions (e.g. DGA, SISS, SMA, MMA).

Figure 4. Proposed approach for decision making and public policies designed to improve and protect water quality



Source: compiled by the authors.

The analysis of the characteristics of the quality monitoring network and the pressures on water quality in Chile, together with international practices, makes it possible to identify certain parameters that should be considered in the short and medium term in order for them to be incorporated into monitoring campaigns for water bodies either in the national network operated by the DGA or in the following NSCA surveillance plans:

a. **Total alkalinity.** This parameter quantifies the capacity to resist acidification and is measured by government agencies in developed countries. It is important for Chile because of the latent potential for the generation of acid drainage in the northern and central basins due to the enrichment and mobilization of metal sulfides. Acid drainage is caused by natural processes, as well as current and historical mining activities (e.g. the Lluta and Elqui river basins).
b. **Fractionation between total and dissolved metals.** The toxicity and mobility of metals in water is controlled by their chemical speciation, in other words, the chemical form in which they occur. Dissolved metals (i.e. the fraction that can pass through a membrane of 0.45 µm) are more mobile and bioavailable than those associated with particles. The latter can be deposited in river beds and removed under favorable hydrodynamic conditions, or temporarily accumulated in lakes and reservoirs. Management strategies for metals therefore rely heavily on their fractionation between solid and dissolved phases.
c. **Turbidity.** This is associated with the degree of transparency water loses due to the suspension of inorganic and organic particles and is used to evaluate the state of waterbodies, especially in relation to the capacity to sustain ecosystems or for recreation. Although turbidity may have a natural origin, it may also indicate water quality deterioration processes, such as the discharge of liquid waste, neutralization of acid drainage or growth of photosynthetic algae. It can also indicate soil erosion processes or diffuse pollution effects of urban origin. Although it is measured in the network of 14 lakes, lagoons and reservoirs, its use in surface water flows is recommended.
d. **Nutrients.** Understanding their flows is essential to determining the loading capacities of lotic systems, which will very possibly involve adopting higher standards of nutrient removal for sewage treatment plants. Measuring the different forms of nutrients in surface water flows is necessary to determine the flows towards water bodies, especially towards the lakes in the coastal zones of Chile. The main sources of nutrients to the rivers are typically diffuse agricultural and urban sources, together with the discharge from wastewater treated in plants that do not remove N and P. The growth of photosynthetic algae in natural waters is limited by the availability of nutrients; its increase accelerates eutrophication and the occurrence of periods of anoxia, leading to fish mortality and increased turbidity.
e. **Chemical quality of sediment.** Sediment can be a repository of pollutants in water bodies, especially for metals in northern and central Chile. Sediment has the potential to episodically release accumulated contaminants, triggered by hydrological events (e.g. floods), hydraulic works management (e.g. opening sluices, dredging), or processes that alter the chemistry of sediments (e.g. spills and eutrophication). This is clearly seen in the cases of the Lluta, Loa and Elqui river basins discussed in previous sections, and further south, notably in the Aconcagua, Maipo and Rapel river basins.
f. **Perchlorate.** This pollutant occurs together with nitrate in hyper-arid environments, including desert soils (Calderon et al., 2014; Jackson et al., 2015; Jackson et al., 2010; Lybrand et al., 2016; Parker, 2009; Renner, 2006). and, especially, in caliche and brine from the salt flats of northern Chile that are raw materials for desert fertilizers (Jackson *et al.*, 2015; Parker, 2009). This compound alters the functioning of the thyroid gland when ingested at low concentrations in drinking water (Crump *et al.*, 2000; Tellez *et al.*, 2005).

Since it is highly soluble and not very reactive, it can remain in surface and ground waters enriched by natural and anthropic processes (e.g. diffuse contamination caused by fertilizer use), and is not significantly removed by typical drinking water treatment processes (Srinivasan & Viraraghavan, 2009). As with emerging contaminants, methodologies for its detection and quantification at trace levels are unavailable. In California, USA, a public health objective of 1 ppb was established (California Environmental Protection Agency, 2015). These low concentrations challenge the analytical performance of perchlorate quantification methods.

g. **Emerging contaminants.** There is increasing evidence of the occurrence in waters and/or sediments of chemical substances with potentially negative effects on human health and water systems (Petrie *et al*., 2015). Many emerging pollutants are not considered priority pollutants because they are not included in the monitoring protocols, or analytical techniques are unable to detect trace concentrations, and therefore records of their occurrence in aquatic environments are scarce (Murray *et al*., 2010). Emerging pollutants come from effluents from sewage treatment plants, industrial discharges, urban runoff, rainwater and waste leachate (Wilkinson *et al.*, 2017).

Once they have been discharged to the environment, they are transported and/or undergo chemical transformations, sorption reactions (on particulate matter, plastic microparticles, sediments) and bioaccumulation, and are degraded by photochemical reactions, volatilization or microbial reactions (Wilkinson *et al.,* 2017).

The propagation of genetic material associated with resistance to antibiotics is a particularly urgent issue (Carraro *et al*., 2016; Carvalho & Santos, 2016; Martinez, 2009; Vikesland *et al*., 2017). Not only is it a public and economic health problem, but it also limits the reuse of treated water and digested sludge from sewage treatment plants (e.g. Bondarczuk *et al*., 2016).

Murray *et al*. (2010) organize emerging contaminants that have been widely found in aquatic environments into three categories, for each of which there is evidence of occurrence in Chile: (1) industrial compounds, (2) pesticides, and (3) pharmaceutical compounds and personal care products.

It is therefore necessary for monitoring and surveillance systems to systematically collect information to identify and characterize the occurrence, and manage emerging contaminants, for example, through primary and/or secondary regulations. This involves a triple challenge: (1) collecting evidence that will make it possible to associate occurrence with effect, so that its management is based on risk and national data; (2) have analytical methods that allow measurements to be made with adequate analytical performance and at an achievable cost; and (3) have cost-effective control technologies adapted to the national reality. To address these challenges, the work of universities and research centers within an assertive R + D + i policy plays a key role.

Sustainable technologies for water quality improvement and protection

Conventional activated sludge systems have proved a good alternative for wastewater treatment in cities, since they are capable of treating high flows and pollutant loads in a small space (Kadlec & Knight, 1996), but they are not necessarily the best alternative for rural areas, where they have sometimes been abandoned due to operating, maintenance and financing difficulties. It is therefore necessary to evaluate other, more sustainable options in keeping with local conditions and the availability of personnel required for its operation and maintenance.

One option is natural systems which, unlike conventional systems, are based on the interaction of their natural components (soil, vegetation and micro-organisms), for the removal of pollutants (Crites *et al*., 2014), as a result of which they have lower investment and operating costs. Moreover, natural systems are characterized by using renewable energy sources and, therefore produce fewer greenhouse gas emissions, making them a more sustainable alternative compared to conventional systems with more intensive energy use based on fossil fuels.

Natural systems include built or artificial wetlands that imitate natural ones to treat water and have been widely used in different parts of the world (Kadlec & Wallace, 2009). They are mainly used in secondary and tertiary treatment of domestic wastewater, and are able to remove a variety of pollutants including suspended solids, oxygen demanding material, nutrients, pathogens, metals and metalloids. These systems have been successfully implemented at the household and community level, mainly for sewage and gray water treatment in various parts of Chile. Examples include a system whose effluent will be used to irrigate an ecoplaza in San Pedro de Atacama, in the Atacama Region, and another system that treats gray water from a school in Rungue, in the Metropolitan Region. At the municipal level, there is a pilot system that treats wastewater from 20,000 inhabitants of Hualqui, in the Biobio region (Casas Ledón *et al*., 2017). Local applications have recently been researched at the laboratory level, such as wastewater from the pork industry (Plaza de los Reyes & Vidal, 2015) and waters contaminated with As and metals (Lizama Allende *et al*., 2014). This evidence indicates that it is feasible to use them in Chile. Moreover, further efforts are required to advance its implementation with applications other than wastewater, primarily considering local conditions and target quality.

Constructed wetlands can also achieve other goals, such as the recovery of ecosystems. A good example is the sentinel wetland, slated for construction in the Carlos Anwandter Nature Sanctuary in the Los Ríos Region, as part of the measures to repair environmental damage due to liquid residue discharges from the pulp industry. The main objective of the wetland is to receive the first impact of the waste disposal of this industry, since it will receive tertiary treatment effluent from the treatment plant before it is dumped into the Cruces River. The wetland is already designed and will incorporate representative species from the Cruces River wetland, such as *Typha angustifolia* (cattail) and *Scirpus californicus* (California bulrush).

Other sustainable treatment systems correspond to desalinating membrane technologies that use solar energy (Suárez & Urtubia, 2016) or bioactive membranes to recover bioenergy (hydrogen) from wastewater (Prieto *et al*., 2016). In addition to the high energy requirements of conventional systems and the increasing water demand by industrial activity, the implementation of Secondary Environmental Quality Norms (SEQN) for the protection of rivers and lakes can encourage the search and implementation of environmentally friendly technologies that will improve and protect water sources for different uses.

8. Conclusions

The complex interaction between hydrological, geological, biological and human factors creates extremely heterogeneous hydrochemical characteristics throughout Chile. While the arid and hyper-arid environments of the North Macrozone are characterized by natural enrichment by dissolved salts, metals and metalloids from hydrothermal vents, metallogenic fringes and evaporite environments, to the south, the lower frequency of these sources, in addition to higher rainfall and runoff, generates greater dilution, leading to waters with a low content of dissolved salts and metals in the South and Southern Macrozones.

The geomorphology of the country creates typical runoff from east to west, from the headwaters of the basins in the Andes mountain range to its outlet in the Pacific. In the North and Central Macrozones, Andean mining activity exerts pressure on the quality of the water resource, locally creating conditions that encourage the mobilization of metals and metalloids, the acidification of waters and an increase in dissolved salts. The development of agricultural activities and the location of urban and industrial centers in valleys in the Central-South zone leads to an increase in the concentrations of nutrients and anthropic pollutants that impair the quality of lakes and lagoons, creating mesotrophic and eutrophic conditions, especially in lakes and lagoons in coastal areas. Towards the Southern Macrozone, low population density and socioeconomic activities produce waters of exceptional quality. There, aquaculture exerts some of the greatest pressure at the local level, and there is also localized pressures from livestock, mining and urban centers.

Levels of access to safe drinking water and sanitation in the country are high, managed through a system of sanitary service concessions in urban areas that serve the bulk of the population. Compliance with drinking water quality standards is high, and there are plans to improve gaps in compliance in northern Chile through desalination. Approximately 30% of the wastewater is disposed of through submarine outfalls into the Pacific Ocean, while only 5% of treated water contemplates the removal of nutrients. In addition to improving these aspects, there is a constant challenge for the sanitary industry and its regulator, the SISS, to progress towards greater adaptability, resilience of the urban sanitary infrastructure, together with more sustainable performance and lower rates. In rural areas, although Chile's performance at the regional level is good, there is still a long way to go to achieve full access to potable water and safe wastewater management.

The development of national strategies and policies for water management in recent years consider IWRM as a fundamental pillar, seeking to overcome limitations arising from the fragmentation of competences and agendas between different State institutions. Additionally, the pursuit of common well-being with a long-term vision through IWRM conflicts with the pre-eminence of the WRs established in the Water Code, which have private property characteristics and are tradable. The modifications to the Water Code under discussion will be crucial to a binding, effective and operative implementation of the vision of water as a national good for public use.

In addition to an institutional and regulatory framework compatible with IWRM in Chile, there are other major challenges for the improvement and protection of water quality, which can be summarized in three areas: (1) definition of science-based public policies where there is a common understanding of the processes that regulate water quality, where the use of conceptual and quantitative models together with monitoring and surveillance programs are crucial to building, continuously improving and legitimizing this common understanding for decision making; (2) developing and implementing more comprehensive water quality monitoring and monitoring plans, which involves improving the density, frequency and quantity of parameters in a manner consistent with the dynamics of natural and anthropogenic pressures on water quality and the responses of aquatic systems. A clear example of this is the dynamics of metals and metalloids that have natural sources and can be mobilized by mining activities, exerting pressure on the resources used to supply cities, agriculture and sustain aquatic ecosystems. It is also necessary to characterize the occurrence and transformations of emerging pollutants with potential risks for human and ecosystem health; and (3) develop technologies to improve and protect water quality in more sustainable ways, considering the water-energy-food nexus in order to have more adaptable, resilient systems.

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10. References

Abarca, M. *et al*. (2017). Response of suspended sediment particle size distributions to changes in water chemistry at an Andean mountain stream confluence receiving arsenic rich acid drainage. *Hydrological Processes*, 31(2): 296-307.

Alsina, M.A. *et al*. (2014). Arsenic speciation in sinter mineralization from a hydrothermal channel of El Tatio geothermal field, Chile. *Journal of Hydrology*, 518: 434-446.

Aracena, A., Muñoz, G. (2017). *Remoción de Arsénico en el Agua Potable de la Región de Tarapacá.* XXII Congreso Chileno de Ingeniería Sanitaria y Ambiental AIDIS Chile. Iquique, Chile: AIDIS.

Arce, G. *et al*. (2017). Enhancement of particle aggregation in the presence of organic matter during neutralization of acid drainage in a stream confluence and its effect on arsenic immobilization. *Chemosphere*, 180: 574-583.

Arumi, J.L., Oyarzun, R., Sandoval, M. (2005). Natural protection against groundwater pollution by nitrates in the Central Valley of Chile. *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques,* 50(2): 331-340.

Bondarczuk, K., Markowicz, A., Piotrowska-Seget, Z. (2016). The urgent need for risk assessment on the antibiotic resistance spread via sewage sludge land application. *Environment International,* 87: 49-55.

Boyer, E.W. *et al*. (2006). Riverine nitrogen export from the continents to the coasts. *Global Biogeochemical Cycles,* 20(1): n/a.

Bugueño, M., Acevedo, S., Bonilla, C., Pizarro, G., Pasten, P. (2014). Differential arsenic binding in the sediments of two sites in Chile's lower Loa River basin. *Science of the Total Environment,* 466: 387-396.

Bundschuh, J. *et al*. (2012). One century of arsenic exposure in Latin America: a review of history and occurrence from 14 countries. *Sci Total Environ,* 429: 2-35.

Calderon, R. *et al*. (2014). Perchlorate Levels in Soil and Waters from the Atacama Desert. *Archives of Environmental Contamination and Toxicology,* 66(2): 155-161.

California Environmental Protection Agency (2015). *Public Healt Goal for Perchlorate in Drinking Water.* California: CEPA.

Capaccioni, B. *et al*. (2011). Geochemical and isotopic evidences of magmatic inputs in the hydrothermal reservoir feeding the fumarolic discharges of Tacora volcano (northern Chile). *Journal of Volcanology and Geothermal Research,* 208(3): 77-85.

Carraro, E. *et al*. (2016). Hospital effluents management: Chemical, physical, microbiological risks and legislation in different countries. *Journal of Environmental Management,* 168: 185-199.

Carvalho, I.T., Santos, L. (2016). Antibiotics in the aquatic environments: A review of the European scenario. *Environment International,* 94: 736-757.

Casas Ledón, Y., Rivas, A., López, D., Vidal, G. (2017). Life-cycle greenhouse gas emissions assessment and extended exergy accounting of a horizontal-flow constructed wetland for municipal wastewater treatment: A case study in Chile. *Ecological Indicators,* 74: 130-139.

Comisión Nacional de Medio Ambiente (2003). *Estrategia Nacional de Biodiversidad.*

Consejo Nacional de Innovación para el Desarrollo (2016). *Ciencia e Innovación para los Desafíos del Agua en Chile: Estrategia Nacional de Investigación, Desarrollo e Innovación para la Sostenibilidad de los Recursos Hídricos.* Santiago: CNID.

Contreras, M.T. *et al*. (2015). Potential accumulation of contaminated sediments in a reservoir of a high-Andean watershed: Morphodynamic connections with geochemical processes. *Water Resources Research,* 51(5): 3181-3192.

Crites, R.W., Middlebrooks, E.J., Bastian, R.K., Reed, S.C. (2014). *Natural Wastewater Treatment Systems.* Boca Raton, FL: CRC Press.

Crump, C. *et al*. (2000). Does perchlorate in drinking water affect thyroid function in newborns or school-age children? *Journal of Occupational and Environmental Medicine,* 42(6): 603-612.

Dadea, C., Fanfani, L., Keegan, T.J., Farago, M., Thornton, I. (2001). Sequential extraction in stream sediments from the Loa basin (Northern Chile). *Water-Rock Interaction,* Vols 1 and 2: 1055-1058.

Dirección General de Aguas (2014). *Análisis crítco de la red de calidad de aguas superficiales y subterráneas de la DGA*. S.I.T N° 337. Santiago, Chile: Ministerio de Obras Públicas, Dirección General de Aguas, Departamento de Conservación y Protección de Recursos Hídricos.

Dirección General de Aguas (2016). *Atlas del Agua Chile 2016.* Serie de Estudios Básicos DGA. Santiago, Chile: DGA.

Donoso, G., Cancino, J., Magri, A. (1999). Effects of agricultural activities on water pollution with nitrates and pesticides in the Central Valley of Chile. *Water Science and Technology,* 39(3): 49-60.

Dumont, E., Harrison, J.A., Kroeze, C., Bakker, E.J., Seitzinger, S.P. (2005). Global distribution and sources of dissolved inorganic nitrogen export to the coastal zone: Results from a spatially explicit, global model. *Global Biogeochemical Cycles,* 19(4): GB4S02.

Espejo, L. *et al*. (2012). Application of water quality indices and analysis of the surface water quality monitoring network in semiarid North-Central Chile. *Environmental Monitoring and Assessment,* 184(9): 5571-5588.

European Environment Agency (1999). *Environmental Indicators: Typology and Overview.* Technical report No.25. Copenhagen European Environment Agency.

Evans, G.W. & Kantrowitz, E. (2002). Socioeconomic status and health: The potential role of environmental risk exposure. *Annual Review of Public Health,* 23: 303-331.

Fernandez, E., Grilli, A., Alvarez, D., Aravena, R. (2017). Evaluation of nitrate levels in groundwater under agricultural fields in two pilot areas in central Chile: A hydrogeological and geochemical approach. *Hydrological Processes,* 31(6): 1206-1224.

Ferreccio, C., Sancha, A.M. (2006). Arsenic exposure and its impact on health in Chile. *J Health Popul Nutr,* 24(2): 164-75.

Flores, M. *et al*. (2017). Surface water quality in a sulfide mineral-rich arid zone in North-Central Chile: Learning from a complex past, addressing an uncertain future. *Hydrological Processes,* 31(3): 498-513.

Fuentes, I., Casanova, M., Seguel, O., Najera, F., Salazar, O. (2014). Morphophysical pedotransfer functions for groundwater pollution by nitrate leaching in Central Chile. *Chilean Journal of Agricultural Research,* 74(3): 340-348.

Gaete, H., Aranguiz, F., Cienfuegos, G., Tejos, M. (2007). Heavy metals and toxicity of waters of the aconcagua river in Chile. *Quimica Nova,* 30(4): 885-891.

Galleguillos, G., Oyarzun, J., Maturana, H., Oyarzun, R. (2008). Arsenic capture in dams: the Elqui River case, Chile. *Ingeniería Hidráulica en México,* 23(3): 29-36.

Gibbs, P.J., Miskiewicz, A.G. (1995). Heavy-Metals in Fish Near a Major Primary-Treatment Sewage Plant Outfall. *Marine Pollution Bulletin,* 30(10): 667-674.

Gobierno de Chile (2017). *Informe de Diagnóstico e Implementación de la Agenda 2030 y los Objetivos de Desarrollo Sostenible en Chile.*

Guerra, P., Gonzalez, C., Escauriaza, C., Pizarro, G., Pasten, P. (2016a). Incomplete Mixing in the Fate and Transport of Arsenic at a River Affected by Acid Drainage. *Water Air and Soil Pollution,* 227(3): 20.

Guerra, P. *et al*. (2016b). Daily Freeze-Thaw Cycles Affect the Transport of Metals in Streams Affected by Acid Drainage. *Water*, 8(3).

Hansen, A.M. (2012). Lake sediment cores as indicators of historical metal(loid) accumulation - A case study in Mexico. *Applied Geochemistry,* 27(9): 1745-1752.

Instituto Nacional de Estadísticas (2015). *Compendio Estadístico.* Santiago de Chile.

Iturriaga, S., Baixas, J.I., Croxatto, F., Ibieta, P., Quintana, F. (2013). TEAM MAPOCHO 42K, 2013. *Arq* (85): 82-87.

Jackson, W.A. *et al*. (2015). Global patterns and environmental controls of perchlorate and nitrate co-occurrence in arid and semi-arid environments. *Geochimica et Cosmochimica Acta,* 164: 502-522.

Jackson, W.A., Bohlke, J.K., Gu, B.H., Hatzinger, P.B., Sturchio, N.C. (2010). Isotopic Composition and Origin of Indigenous Natural Perchlorate and Co-Occurring Nitrate in the Southwestern United States. *Environmental Science & Technology,* 44(13): 4869-4876.

Kadlec, R., Wallace, S. (2009). *Treatment wetlands.* Boca Raton, FL: CRC Press.

Kadlec, R.H., Knight, R.L. (1996). *Treatment wetlands.* Boca Raton, FL: CRC Press.

Landrum, J. *et al*. (2009). Partitioning geochemistry of arsenic and antimony, El Tatio Geyser Field, Chile. *Applied Geochemistry,* 24(4): 664-676.

Leiva, E. *et al*. (2014). Natural attenuation process via microbial oxidation of arsenic in a high Andean watershed. *Science of the Total Environment,* 466: 490-502.

Lizama Allende, K., McCarthy, D.T., Fletcher, T.D. (2014). The influence of media type on removal of arsenic, iron and boron from acidic wastewater in horizontal flow wetland microcosms planted with Phragmites australis. *Chemical Engineering Journal,* 246(0): 217-228.

Lybrand, R.A. *et al*. (2016). Nitrate, perchlorate, and iodate co-occur in coastal and inland deserts on Earth. *Chemical Geology,* 442: 174-186.

Magaritz, M., Aravena, R., Pena, H., Suzuki, O., Grilli, A. (1990). Source of Ground-Water in the Deserts of Northern Chile - Evidence of Deep Circulation of Ground-Water from The Andes. *Ground Water,* 28(4): 513-517.

Martinez, J.L. (2009). Environmental pollution by antibiotics and by antibiotic resistance determinants. *Environmental Pollution,* 157(11): 2893-2902.

Meybeck, M. (1982). Carbon, nitrogen and phosphorous transport by world rivers. *American Journal of Science,* 282: 401--450.

Ministerio de Obras Públicas (2012). *Estrategia Nacional de Recursos Hídricos 2012-2025.*

Ministerio del Interior y Seguridad Pública-Delegación Presidencial para los Recursos Hídricos (2015). *Política Nacional para los Recursos Hídricos 2015.*

Ministerio del Medio Ambiente (2013). *Estrategia Nacional de Crecimiento Verde.*

Ministerio del Medio Ambiente (2015). *Organigrama de la Institucionalidad Ambiental-Chile 2015.*

Ministerio del Medio Ambiente (2016). Plan Nacional de Cuentas Ambientales. In: *Ambiental*, D.d.I.y.E. (Editor).

Ministerio del Medio Ambiente (2017a). *Registro de Emisiones y Transferencias de Contaminantes.*

Ministerio del Medio Ambiente (2017b). Tercer Reporte del Estado del Medio Ambiente. In: *Ambiental*, D.d.I.y.E. (Editor).

Ministerio del Medio Ambiente (2018). *Consejo de Ministros para la Sustentabilidad aprueba nueva Estrategia Nacional de Biodiversidad para la próxima década.*

Ministerio de Relaciones Exteriores (2016). Decreto 49. Crea Consejo Nacional para la Implementación de la Agenda 2030 para el Desarrollo Sostenible. Chile.

Montecinos, M. *et al*. (2016). P*ersistence of Metal-rich Particles Downstream Zones of Acid Drainage Mixing in Andean Rivers.* Fall Meeting American Geophysical Union, San Francisco, USA.

Murray, K.E., Thomas, S.M., Bodour, A.A. (2010). Prioritizing research for trace pollutants and emerging contaminants in the freshwater environment. *Environmental Pollution,* 158(12): 3462-3471.

OECD (2011). *Water Governance in OECD Countries: A Multi-level Approach.* OECD Studies on Water. OECD Publishing.

OECD (2012). *Water Governance in Latin America and the Caribbean.* OECD Publishing.

OECD (2017). *Gaps and Governance Standards of Public Infrastructure in Chile: Infrastructure Governance Review.* OECD Publishing, Paris.

Orellana, S. (1985). *Hidrogeoquímica del río Loa: un prototipo para el estudio de hoyas hidrográficas en el norte de Chile.*

Oyarzun, J. *et al*. (2013). Hydrochemical and isotopic patterns in a calc-alkaline Cu- and Au-rich arid Andean basin: The Elqui River watershed, North Central Chile. *Applied Geochemistry,* 33: 50-63.

Oyarzun, J. *et al*. (2012). Abandoned tailings deposits, acid drainage and alluvial sediments geochemistry, in the arid Elqui River Basin, North-Central Chile. *Journal of Geochemical Exploration,* 115: 47-58.

Parker, D.R. (2009). Perchlorate in the environment: the emerging emphasis on natural occurrence. *Environmental Chemistry,* 6(1): 10-27.

Pasten, P. *et al*. (2015). Geochemical and Hydrologic Controls of Copper-Rich Surface Waters in the Yerba Loca-Mapocho System, American Geophysical Union, Fall Meeting 2015. *American Geophysical Union*, San Francisco, USA.

Pell, A. *et al*. (2013). Occurrence of arsenic species in algae and freshwater plants of an extreme arid region in northern Chile, the Loa River Basin. *Chemosphere*, 90(2): 556-64.

Petrie, B., Barden, R., Kasprzyk-Hordern, B. (2015). A review on emerging contaminants in wastewaters and the environment: Current knowledge, understudied areas and recommendations for future monitoring. *Water Research*, 72: 3-27.

Pflieger, G. (2008). Achieving universal access to drinking water and sanitation networks in Santiago de Chile: An historical analysis 1970-1995. *Journal of Urban Technology,* 15(1): 19-51.

Pizarro, J., Rubio, M.A., Castillo, X. (2003). Study of chemical speciation in sediments: An approach to vertical metals distribution in Rapel reservoir (Chile). *Journal of the Chilean Chemical Society,* 48(3): 45-50.

Pizarro, J., Rubio, M.A., Matta, A. (2009). Difussion of Fe, Mn, Mo and Sb in the Sediment-Water Interface of a Shallow Lake, Laguna Caren, Santiago (Chile). *Fresenius Environmental Bulletin,* 18(12): 2336-2344.

Pizarro, J., Vergara, P.M., Cerda, S., Briones, D. (2016). Cooling and eutrophication of southern Chilean lakes. *Science of The Total Environment,* 541: 683-691.

Pizarro, J., Vergara, P.M., Rodriguez, J.A., Sanhueza, P.A., Castro, S.A. (2010a). Nutrients dynamics in the main river basins of the centre-southern region of Chile. *J Hazard Mater,* 175(1-3): 608-13.

Pizarro, J., Vergara, P.M., Rodriguez, J.A., Valenzuela, A.M. (2010b). Heavy metals in northern Chilean rivers: spatial variation and temporal trends. *J Hazard Mater,* 181(1-3): 747-54.

Plaza de los Reyes, C., Vidal, G. (2015). Effect of variations in the nitrogen loading rate and seasonality on the operation of a free water surface constructed wetland for treatment of swine wastewater. *Journal of Environmental Science and Health,* Part A, 50(13): 1324-1332.

Prieto, A.L. *et al*. (2016). Performance of a composite bioactive membrane for H2 production and capture from high strength wastewater. *Environmental Science: Water Research and Technology,* 2(5): 848-857.

Renner, R. (2006). Fertilizer from Chile puts perchlorate on the table. *Environmental Science & Technology,* 40(21): 6524-6525.

Ribbe, L., Delgado, P., Salgado, E., Flugel, W.A. (2008). Nitrate pollution of surface water induced by agricultural non-point pollution in the Pocochay watershed, Chile. *Desalination*, 226(1-3): 13-20.

Ribeiro, L. *et al*. (2014). Water Quality Assessment of the Mining-Impacted Elqui River Basin, Chile. *Mine Water and the Environment,* 33(2): 165-176.

Roberts, P.J.W. *et al*. (2010). *Marine wastewater outfalls and treatment systems.* Colchester: IWA Publishing. 528 pp.

Romero, L. *et al*. (2003). Arsenic enrichment in waters and sediments of the Rio Loa (Second Region, Chile). *Applied Geochemistry,* 18(9): 1399-1416.

Roth, F., Lessa, G.C., Wild, C., Kikuchi, R.K.P., Naumann, M.S. (2016). Impacts of a high-discharge submarine sewage outfall on water quality in the coastal zone of Salvador (Bahia, Brazil). *Marine Pollution Bulletin,* 106(1-2): 43-48.

Segura, R., Arancibia, V., Zuniga, M., Pasten, P. (2006). Distribution of copper, zinc, lead and cadmium concentrations in stream sediments from the Mapocho River in Santiago, Chile. *Journal of Geochemical Exploration,* 91(1-3): 71-80.

SISS (2013). *SISS fiscaliza avances de obras de empresa NOVAGUAS para mitigar presencia de arsénico en agua potable.*

SISS (2014). http://www.siss.cl/577/w3-article-11091.html.

Smedley, P.L., Kinniburgh, D.G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry,* 17: 517-568.

Smith, A.H. *et al*. (2011). Evidence from Chile that arsenic in drinking water may increase mortality from pulmonary tuberculosis. *Am J Epidemiol,* 173(4): 414-20.

Smith, S.V. *et al*. (2003). Humans, hydrology, and the distribution of inorganic nutrient loading to the ocean. *Bioscience*, 53(3): 235-245.

Smith, S.V.a.S.D.P.a.T.-M.L.a.B.J.D.a.S.P.T.a.R.N. (2002). Nitrogen in aquatic ecosystems. *Ambio*, 31: 102-112.

Soto, D. (2002). Oligotrophic patterns in southern Chilean lakes: the relevance of nutrients and mixing depth. *Revista Chilena de Historia Natural,* 75(2): 377-393.

Soto, D., Campos, H. (1995). Los lagos oligotróficos asociados al Bosque templado húmedo del sur de Chile. En: Armesto, M., Khalin, C., Villagrán, C. (Eds.). *Ecología de los bosques templados de Chile.* Santiago: Editorial Universitaria. pp. 134-148.

Srinivasan, A., Viraraghavan, T. (2009). Perchlorate: Health Effects and Technologies for Its Removal from Water Resources. *International Journal of Environmental Research and Public Health,* 6(4): 1418-1442.

Suárez, F., Urtubia, R. (2016). Tackling the water-energy nexus: an assessment of membrane distillation driven by salt-gradient solar ponds. *Clean Technologies and Environmental Policy,* 18(6): 1697-1712.

Tapia, J., Audry, S. (2013). Control of early diagenesis processes on trace metal (Cu, Zn, Cd, Pb and U) and metalloid (As, Sb) behaviors in mining- and smelting-impacted lacustrine environments of the Bolivian Altiplano. *Applied Geochemistry,* 31: 60-78.

Tapia, J. *et al*. (2009). Study of the copper, chromium and lead content in Mugil cephalus and Eleginops maclovinus obtained in the mouths of the Maule and Mataquito rivers (Maule Region, Chile). *Journal of the Chilean Chemical Society,* 54(1): 36-39.

Tellez, R.T. *et al*. (2005). Long-term environmental exposure to perchlorate through drinking water and thyroid function during pregnancy and the neonatal period. *Thyroid*, 15(9): 963-975.

Tercer Tribunal Ambiental de Chile (2017). *Corte Suprema confirma fallo de Tribunal sobre norma de calidad ambiental de la cuenca del río Valdivia.*

Thapalia, A., Borrok, D.M., Van Metre, P.C., Musgrove, M., Landa, E.R. (2010). Zn and Cu Isotopes as Tracers of Anthropogenic Contamination in a Sediment Core from an Urban Lake. *Environmental Science & Technology,* 44(5): 1544-1550.

UN Water (2017a). *Integrated Monitoring Guide for Sustainable Development Goal 6 on Water and Sanitation – Targets and global indicators.*

UN Water (2017b). *Step-by-step Methodology for Indicator 6.3.2 on Ambient Water Quality.*

UN Water (2017c). *Step-by-step Monitoring Methodology for SDG Indicator 6.6.1 on water-related ecosystems.*

United Nations (2001). *Road map towards the implementation of the United Nations Millennium Declaration: report of the Secretary-General,* A/56/326, 6 September. New York: UN.

United Nations (2015). Transforming our World: the 2030 Agenda for Sustainable Development. In: General_Assembly (Editor), A/RES/70/1, 21 October.

United Nations World Water Assessment Programme (2017). *The United Nations World Water Development.*

Report 2017. *Wastewater: The Untapped Resource.* Paris: UNESCO.

VanDerslice, J. (2011). Drinking Water Infrastructure and Environmental Disparities: Evidence and Methodological Considerations. *American Journal of Public Health,* 101: S109-S114.

Vega, A.S., Lizama, K., Pastén, P. (2018). Water Quality: Trends and Challenges. In: Donoso, G. (Ed.), Water Policy in Chile. *Global Issues in Water Policy,* pp. 255.

Vega, A.S., Planer-Friedrich, B., Pasten, P.A. (2017). Arsenite and arsenate immobilization by preformed and concurrently formed disordered mackinawite (FeS). *Chemical Geology,* 475: 62-75.

Vikesland, P.J. *et al*. (2017). Toward a Comprehensive Strategy to Mitigate Dissemination of Environmental Sources of Antibiotic Resistance. *Environmental Science & Technology,* 51(22): 13061-13069.

WHO, UNICEF (2017a). JMP launch version July 12 2017. *Progress on Drinking Water, Sanitation and Hygiene - 2017 Update and SDG Baselines.*

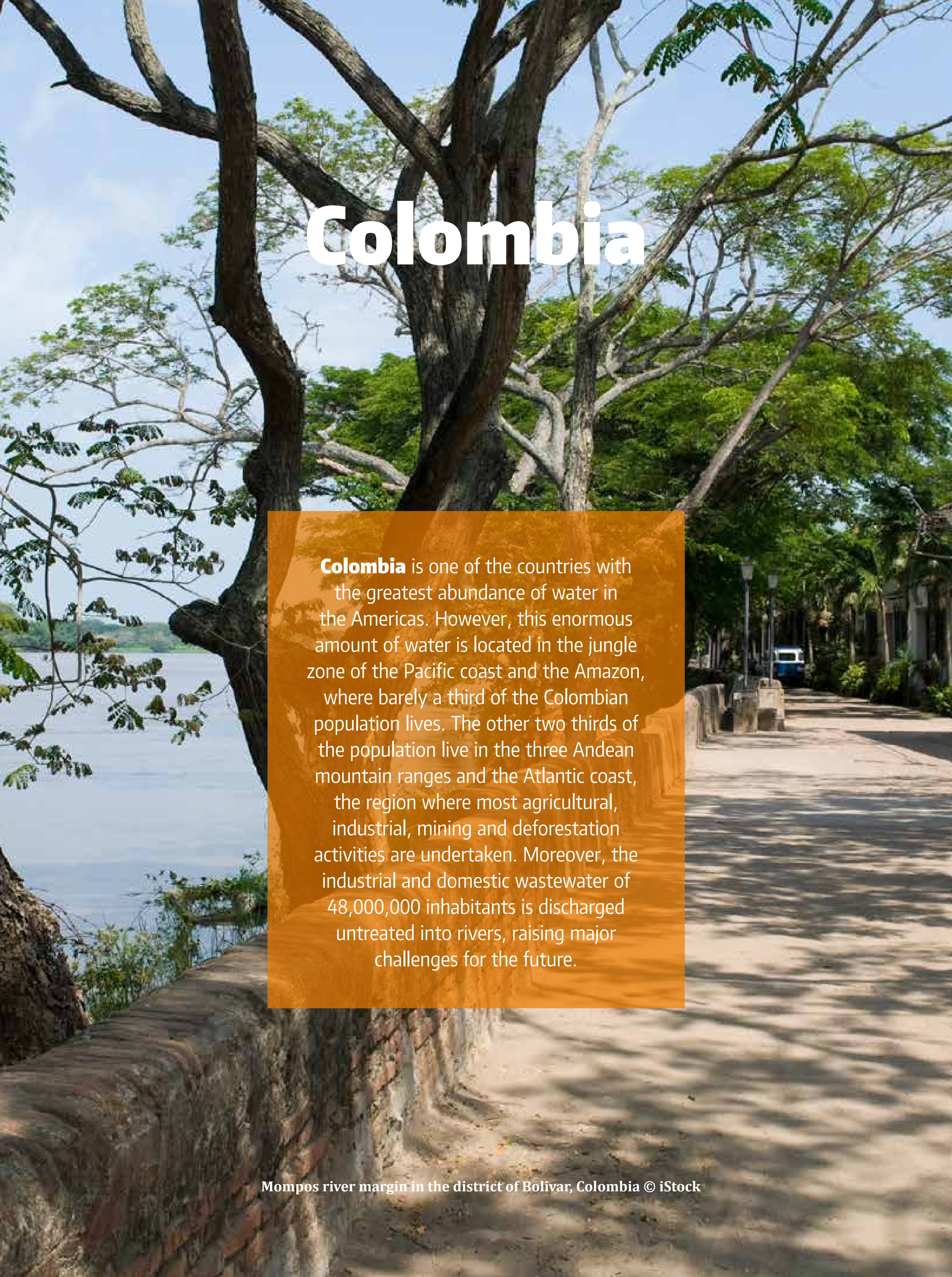
WHO, UNICEF (2017b). *Progress on Drinking Water, Sanitation and Hygiene: Annexes.*

Wilkinson, J., Hooda, P.S., Barker, J., Barton, S., Swinden, J. (2017). Occurrence, fate and transformation of emerging contaminants in water: An overarching review of the field. *Environmental Pollution,* 231: 954-970.

Yang, H.D., Rose, N.L. (2003). Distribution of mercury in six lake sediment cores across the UK. *Science of the Total Environment,* 304(1-3): 391-404.

Yevenes, M.A., Arumi, J.L., Farias, L. (2016). Unravel biophysical factors on river water quality response in Chilean Central-Southern watersheds. *Environmental Monitoring and Assessment,* 188(5): 17.

Colombia



Colombia is one of the countries with the greatest abundance of water in the Americas. However, this enormous amount of water is located in the jungle zone of the Pacific coast and the Amazon, where barely a third of the Colombian population lives. The other two thirds of the population live in the three Andean mountain ranges and the Atlantic coast, the region where most agricultural, industrial, mining and deforestation activities are undertaken. Moreover, the industrial and domestic wastewater of 48,000,000 inhabitants is discharged untreated into rivers, raising major challenges for the future.

Mompos river margin in the district of Bolivar, Colombia © iStock

Water Quality in Colombia

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1. Introduction

Colombia is located in the northwest corner of South America. It is the fourth largest country in the region after Brazil, Argentina and Peru. It is the only country in South America with 1,600 kilometers of coastline on the Caribbean Sea and 1,300 kilometers on the Pacific Ocean and is politically-administratively divided into 33 departments and 1051 municipalities. However, 70% of the population live in only 10 of them, which are the main cities in the country, meaning that pressure on the water resources of these cities is fairly high.

From a hydrological point of view, Colombia comprises five hydrographic areas, as can be seen in **Figura 1** (1-Caribbean, 2- Magdalena-Cauca, 3- Orinoco, 4- Amazon and 5-Pacific), which in turn are divided into Hydrographic Zones and subdivided into Hydrographic Subzones (HIMAT, Resolution 0337, 1978).

The concept of water quality is based on the Water Framework Directive of the European Community (EU, 2007), which defines it as the conditions that must be met in water so that it maintains a balanced ecosystem and meets certain ecological quality objectives, which go beyond evaluating the requirements for a particular use (IDEAM, 2015).

In Colombia, the assessment of the status and trends in surface water quality conditions and the pressures on pollution potentially exerted on the water systems and water bodies of the country has been developed by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) within the framework of the National Water Studies (IDEAM, 2010 y 2015)

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This evaluation has been developed on the basis of the physical, chemical and biological characteristics, based on the systematic monitoring of variables measured in the national reference network of the IDEAM, which includes the analysis of concentrations and loads of metals in sediments, ammoniacal nitrogen, percentage of oxygen saturation, nutrient imbalance and the Water Quality Index (ICA) (IDEAM, 2015).

Figure 1. Hydrographic areas of Colombia

Source: http://www.minambiente.gov.co/index.php/gestion-integral-del-recurso-hidrico/p

2. Institutional authority and governance

2.1 Legal framework

Environmental regulations in Colombia are extensive and have developed since the National Code of Natural Resources in the year 1974 (Decree-Law 2811/1974). In this document, the Colombian State delegated the responsibility for guaranteeing the quality of water for human consumption and for the activities in which its use is necessary. This raised the need to control water quality, through periodic analyses of its physical, chemical and biological characteristics, in order to be suitable for the purposes for which it is intended.

Law 9 of 1979, called the Health Code, regulates aspects of water, both marine and continental, related to its purification and, in general, to issues related to the quality of water for human consumption or which may affect human health. The regulatory decree of this law, 1594 of 1984 (Compiled in Regulatory Decree 1076 of 2015), regulates everything related to liquid discharges, which has been partly repealed, by Decree 3930 of 2010 (Compiled in the Single Regulatory Decree 1076 of 2015) in relation to the regulation of Water Resource Management as an instrument that allows monitoring and pollution control. Likewise, Law 1333 of 2009 established the environmental sanctioning procedure governing all environmental infringement processes.

The Political Constitution of 1991 contains approximately 60 provisions related directly or indirectly to the environmental issue, thus raising the environmental issue to constitutional rank. In view of the environmental responsibilities assigned by the Constitution, the Colombian State considered it necessary to create an environmental system led by an entity of the highest administrative hierarchy, which would be able to respond adequately to the mandates of the new Political Charter, as well as to the international commitments assumed by the country (IDEAM, 2002)

Law 99 of 1993 created the Ministry of the Environment (Art. 2) as the governing body of the country's environmental management, responsible for defining the policies and regulations to which the recovery, conservation, protection, management, use and exploitation of renewable natural resources and the environment must be subject in order to ensure sustainable development. It organized the SINA (the National Environmental System), under the coordination of the Minambiente, comprising the set of guidelines, standards, activities, resources, programs and institutions that allow the development of the principles and rules contained in this law.

Decree 1640 of 2012 (Compiled in Decree 1076 of 2015) establishes the monitoring and follow-up of water resources as a legal function of the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) and INVEMAR at the national level, of regional autonomous corporations (CAR) at the regional level, and urban environmental authorities and disaster prevention and response agencies at the local level in accordance with the functions established in Decree 1323 of 2007.

2.2 Monitoring Water quality in Colombia

According to a study carried out by the CTA (Technology Center of Antioquia) in 2015, the IDEAM carried out an evaluation, validation and consolidation of water quality information in lotic water bodies of Colombia (IDEAM, 2015b), in which two main sources of information were considered: the first was created at the national level by the IDEAM through the National Water Resources Monitoring Plan (PNMRH) (2010-2022 Plan) and supported by the reference network established for the water quality component and the National Water Study 2014 (IDEAM, 2015a). The second, was compiled at the regional level, with the database from 2010 to 2014 consolidated in the Integrated Water Resource System (SIRH) based on the information reported by the CARs, together with the information consolidated from different databases from the Environmental Authorities for a period of evaluation from 2010 to 2013, which had not yet been reported to the SIRH. The regional information was compiled, processed and validated by the National University of Colombia within the framework of the "Multivariate statistical analysis of surface water quality. Contract 428-12" project (IDEAM and UN, 2014).

From the databases mentioned earlier, the IDEAM consolidated water quality information from 4195 specific monitorings carried out in the country between 2010 and 2014. However, only 77% of the information, in other words, 3229 monitorings undertaken in 476 sites, distributed in 108 Hydrographic Subzones of the 311 into which the country is divided, presented information that could be validated for its potential future use. Some of the validation criteria were aspects such as georeferencing and coherence in the ranges of variation of the results reported for some of the physicochemical variables (IDEAM, 2015b).

Figura 2 presents a consolidation of the information mentioned above by hydrographic area. Of the 476 sites where water quality has been monitored in the country, 77% were carried out in the Magdalena-Cauca Hydrographic Area (AH), which corresponds to 81% (2609) of the total monitoring undertaken between 2010 and 2014, which could be validated. It is worth noting that, of this last percentage, and although AH Magdalena Cauca is the most highly monitored area in the country, 44% of the information had not been consolidated in the SIRH, showing that a high percentage of water quality information generated in the country has not been disclosed to the public.

The problem of monitoring water quality at the national and regional levels lies in the limited coverage of measurement points of physicochemical variables in the various water bodies in the country, which is insufficient to have a baseline, evaluate and monitor the possible effects caused by anthropic activities.

IDEAM currently operates and maintains a total network of 4667 monitoring stations for water resources, of which 3091 are meteorological (66%), 1327 are hydrological (29%), 96 are hydro-meteorological (2%) and 153 analyze surface water quality (3%). These stations are distributed among the 11 operating areas covering the entire country. At these 153 stations, between 2010 and 2014, 476 water quality monitorings were carried out, of which 77.0% were conducted in the Magdalena-Cauca Hydrographic Area (HA), 15.0% in the Orinoco HA, 4,0% in the Caribbean Hydrographic Area and 2.0% in the Pacific and Amazon HA.

The above shows that one of the main problems for determining the status of surface water quality in Colombia is the limited coverage of the sites for monitoring the physicochemical, microbiological and hydrobiological variables in the various water bodies of the country, which is insufficient to have a baseline, evaluate and monitor the possible effects caused by anthropic activities (CTA, 2017).

Pollution pressures on the country's water systems and water bodies are analyzed on the basis of the estimation of specific pollutant loads discharged by the industrial, domestic, livestock slaughter and coffee processing sectors. This estimate is made for each of the variables comprising the Potential Alteration Index of Water Quality (IACAL): Biological

Oxygen Demand BOD, Chemical Oxygen Demand COD, Total Suspended Solids TSS, Total Nitrogen TN and Total Phosphorus TP.

Likewise, the pressure from mercury dumping in gold and silver mining and the chemical substances used in agriculture is also determined.

In Colombia there is a lack of coverage of laboratories accredited with IDEAM for the analysis of certain water parameters under the NTC-ISO-IEC 17025:2005 norm. By 2016, there were 138 accredited laboratories, 123 (89%) of which are in the Magdalena-Cauca HA, six in the Pacific HA, four in the Caribbean HA, four in the Orinoquía HA and one in the Amazon HA. Of these 138 laboratories, only 15% have accredited the water quality parameters established in the ICA (dissolved oxygen saturation, total suspended solids, chemical oxygen demand, total nitrogen/total phosphorus ratio, pH, electrical conductivity and fecal coliforms) (CTA, 2017).

This raises the need to strengthen the infrastructure and equipment required for regional water quality monitoring. This includes strengthening the accreditation process of water laboratories and establishing protocols and procedures that comply with the guidelines of the Quality Management Systems in the country.

3. Problems that affect water quality

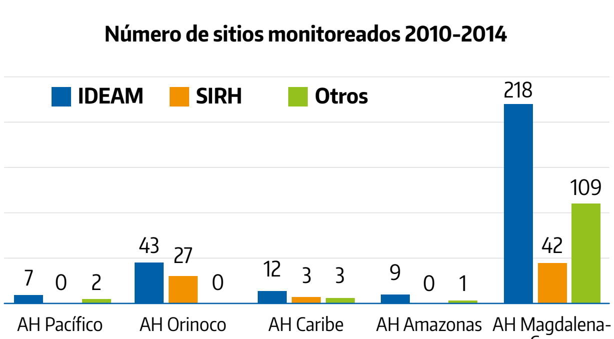
3.1. Wastewater

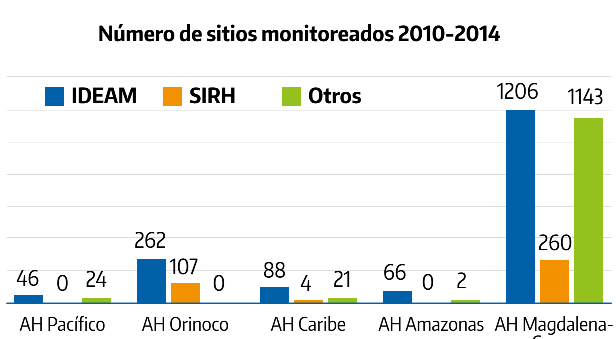
Wastewater creation is an inevitable product of human activity. It can be defined as the waters coming from the water supply system of a population after having been modified by different uses -in domestic, industrial and community activities- (Rolim, 2000), which are subsequently collected through the sewerage system to be sent to a wastewater treatment plant (WWTP). Proper wastewater treatment and disposal requires knowledge of its physical, chemical and microbiological characteristics and the effects these can have on the receiving body (Romero, 2004).

In Colombia, the most up-to-date, comprehensive assessment of the discharge of wastewater into water bodies was conducted in the 2014 National Water Study (IDEAM, 2014). However, the information used has gaps and corresponds to different years (2008 for domestic wastewater, 2010 for industrial wastewater, 2012 for the discharge of wastewater from coffee processing and livestock slaughter), which constitutes a limitation when evaluating the problem of wastewater in Colombia. At the same time, the National Development Plan 2010-2014 "Prosperity for All" was designed to increase the percentage of treated wastewater from 27.5% to 36% during this four-year period (Superintendencia de Servicios Públicos Domiciliarios –SSPD– 2014). This would entail the construction of new treatment plants, optimization of current plants and sanitation investment plans, which would make it possible to improve the quality of the water in receiving bodies.

According to the National Water Study (IDEAM, 2014), the main sources of water pollution in Colombia are domestic wastewater and industrial waste-

Figure 2. Number of sites monitored and number of monitorings carried out in each of the hydrographic areas of Colombia between 2010 and 2014





Source: CTA, 2017.

water, mainly from cattle slaughter, coffee processing, mercury dumping in mining, chemical use for crops and the use of agrochemicals, where most of the components present usually consist of organic matter, nutrients, metals, microorganisms and suspended solids.

Water Quality Index (ICA)

According to IDEAM (2011), the Water Quality Index (ICA) is the numerical value between 0 and 1, which rates the water quality of a surface stream, in terms of human well-being, regardless of its use. Based on the measurements obtained for a set of five (or six) physicochemical variables recorded in monitoring station j at time t, the WQI calculation includes the weighting of six (6) variables: dissolved oxygen, chemical oxygen demand, electrical conductivity, total suspended solids, pH and NT/PT ratio (IDEAM, 2014). The weights in each case are shown in **Table 1.**

The final results are classified according to the value obtained by the WQI of 0 -1, where values close to 0 are indicative of poor water quality while those close to 1 indicates good water quality. **Table 2** shows the values in each classification and the warning signal for each case.

According to studies conducted by the IDEAM (2012), the WQI of 153 water courses was calculated in 226 stations in Colombia, within which 36% of the water flows yielded ICA values between 0.71-0.83, indicating that they are sources of acceptable water; 41% of the water courses obtained a WQI of between 0.51-0.70 indicating average water quality; 22% of the water flows obtained a WQI of between 0.27 and 0.50, indicating poor water quality conditions; and lastly 1% obtained a WQI classified as very bad, corresponding to Bogotá River current at the Alicachín el Salto station. The Bogotá and Sogamoso rivers showed low WQI values, which is associated with discharges from dumps in large cities. Conversely, the highest WQI (0.86) was found in Sombrerillos River, in the San Agustín sector of El Huila.

Index of the potential alteration of IACAL water quality

The Potential Alteration Index of Water Quality (IACAL) refers to the pressure on water quality con-

Table 1. Variables and weights of the six variables for ICA

Variable	Unit of Measurement	Weighing
Dissolved oxygen (DO)	% saturation	0,17
Total suspended solids (SST)	mg/L	0,17
Chemical Oxygen Demand (COD)	mg/L	0,17
NT/PT	-	0,17
Electric conductivity (CE)	µS/cm	0,17
pH	Ph Units	0,15

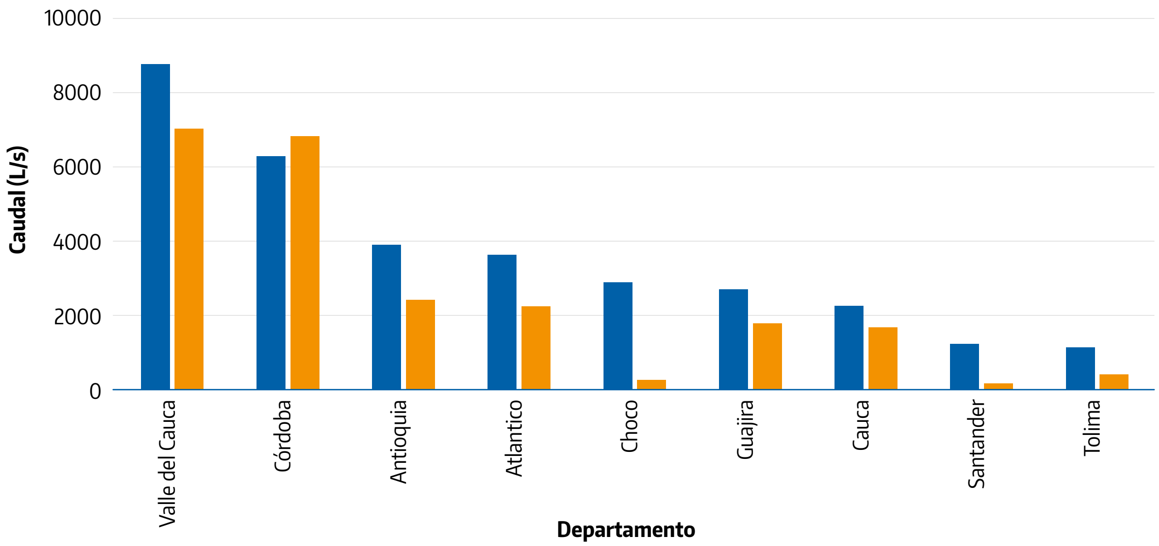
Source: IDEAM, 2011.

Table 2. Water quality rating according to the final results of the WQA

ICA result	Water quality classification	Warning sign
0,00 – 0,25	Very bad	Red
0,26 – 0,50	Poor	Orange
0,51 – 0,70	Average	Yellow
0,71 – 0,90	Acceptable	Green
0,91 – 1,00	Buena	Blue

Source: IDEAM, 2011.

Figure 3. Design flows and treatment in the main departments of Colombia



Source: Modified from SSPD, 2014

ditions in the country's surface water systems. It is evaluated on the basis of the average of the hierarchies assigned to the pollutant loads of organic matter, suspended solids and nutrients, produced by the domestic sector in 1099 municipalities and the industrial sector (to 4 ISIC23 digits) of 186 municipalities and the agricultural sector (coffee and coca crops) (IDEAM, 2011).

Overview of wastewater treatment in Colombia

According to the Superintendency of Public Domestic Services (SSPD) (2014), in Colombia, 492 municipalities have wastewater treatment systems, equivalent to only 44% of the total number of municipalities (1,122 municipalities registered in the DANE in 2012), reflecting a serious problem of sanitation, handling of discharges and water quality of the receiving bodies. These 492 municipalities have 620 treatment plants, of which: 29 are preliminary treatment plants, accounting for 4.68% of the total, with an average treated volume of 69.30 L/s; 86 are primary treatment plants (13.87% of the total), with an average treated volume of 109,933.84 L/s; 365 are secondary treatment plants (58.87% of the total), with an average flow of 12,735.88 L/s; 2 are tertiary plants (0.32% of the total) with a flow of 2.80 L/s; and, finally, 138 plants do not record information or are no longer operating.

On the other hand, to date only the department of Córdoba has recorded that the flow treated by the treatment plants is greater than the design (**Figura 3**), which requires investment plans for infrastructure to guarantee its adequacy and improvement. The other plants in the remaining municipalities still do not exceed the design flows, a positive situation since it can guarantee the treatment of dumping for a few more years, which means better conditions for water quality.

The total BOD load generated by the domestic and industrial and coffee sectors (**Figura 4**) was estimated at 819,235 tons per year, 11% of which was removed through wastewater treatment. This means that the biodegradable organic load discharged into water systems in Colombia in 2008 amounted to 729,300 tons, equivalent to 2026 tons per day. The domestic sector contributed 65% of the total BOD contaminant load; industry, 29%; and the coffee sector, 6%. The domestic sector removed 16% of the BOD. The total load of chemical oxygen demand (COD) discharged into the country's water bodies in 2008 was estimated at 1,618,200 tons, equivalent to 4,500 tons/day. Of this polluting load, the industry contributed 39%; the domestic sector, 58%; and the coffee sector, 3% (Orjuela *et al.*, 2010). The domestic sector (municipal wastewater) accounts for most of the dumping of the organic load in the country, followed by the industrial sector. This panorama, accompanied by the low reductions of these contributions for wastewater treatment, creates the need for enormous future efforts in the water sanitation sector, not only in the construction of new infrastructure, but also in the optimization of existing infrastructure and the application of new paradigms such as wastewater recovery and use.

In 2012, in 179 municipalities (of the 1100) located in 15 departments, a load of 205 tons of mercury discharged into soil and water was estimated, of which 27.5% corresponds to its use for silver processing and 72.5% for gold processing. The departments with the highest gold and silver production are Antioquia with 42% and 53% respectively, followed by Chocó with 37% and 24% and Bolívar with 6% of gold, Caldas with 3% of gold and 13% of silver. Likewise, the highest use of mercury for gold processing is found in the departments of Bolívar (304 t.), Chocó (195 t) and Antioquia (170 t) (MADS, 2012).

The estimated potential demand for fertilizers in 2012 was about 2,516,084 tons in solid presentation and 2,915 thousand liters in liquid formulations, mostly (37.5%) NPK compounds (Nitrogen, Phosphorus and Potassium). One of the possible impacts caused by the uncontrolled demand for fertilizers when the latter reach water bodies due to runoff, is the eutrophication of surface water flows, causing a decrease in dissolved oxygen and the deterioration of aquatic fauna.

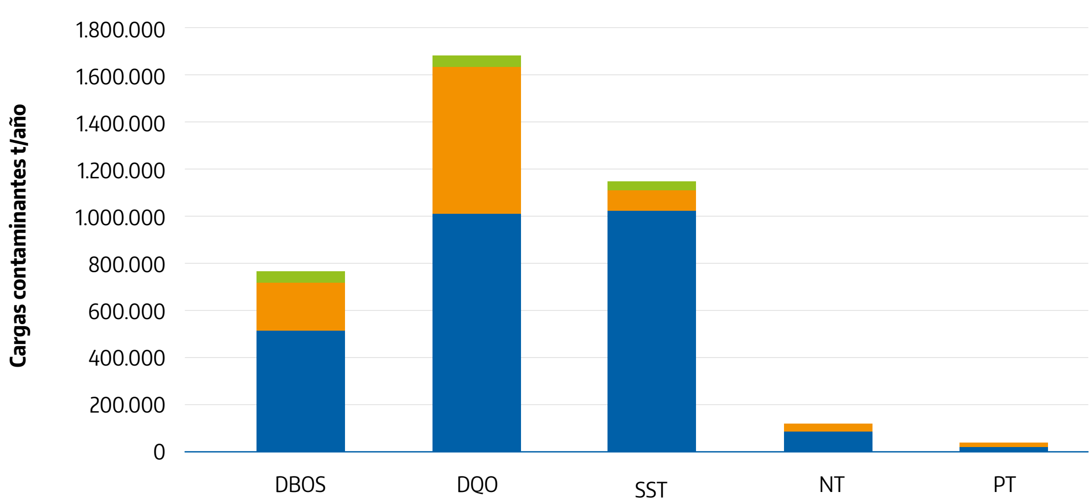
The ENA (2014) has determined two indicators associated with water quality: the Potential Alteration Index of Water Quality (IACAL) and the Water Quality Index (ICA), whose results are observed in the **Figura 5.**

3.2 Agrochemicals

Historically, agriculture has been the main axis for the development of countries (Pingali, 2006). In this respect, the World Bank (2008) emphasizes that agriculture contributes to the general development of nations in three ways: as an economic activity, a means of subsistence and an environmental service provider. In 2012, Colombia consolidated its position as the fifth largest economy in Latin America and, in this context, agriculture accounted for 7% of the country's GDP (OECD, 2014).

In terms of water resources, the main pollutants at the agricultural level are animal waste, antibiot-

Figure 4. Polluting loads potentially discharged into water sources in Colombia (t/year), year 2012



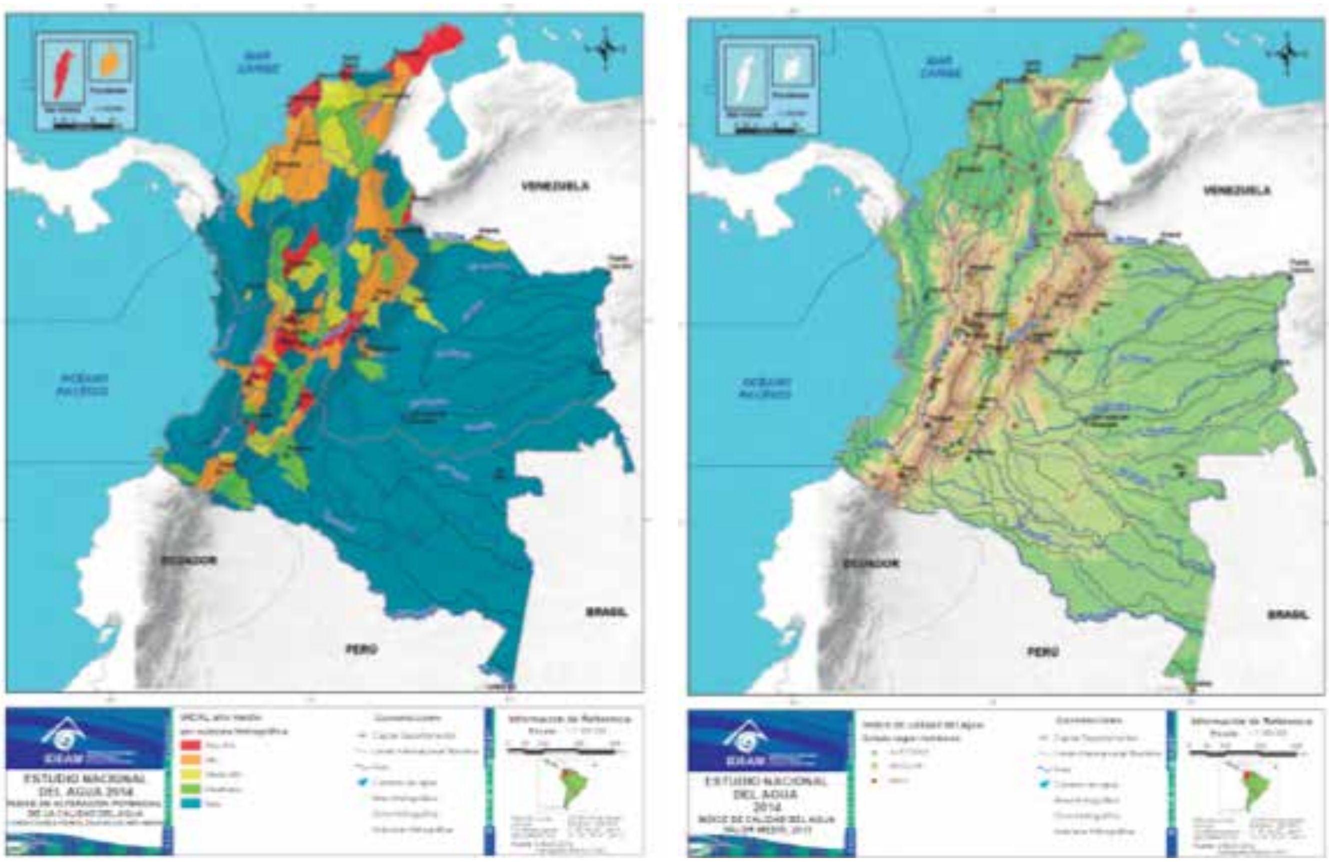
	DBOS	DQO	SST	NT	PT
Café	20.549	26.995	16.663		
Industria	213.857	626.900	84.700	20.216	2.248
Doméstico	522.439	1.021.721	1.034.323	106.139	29.667

Source: IDEAM, 2015.

Figure 5. Indices associated with Water Quality in Colombia

Potential Alteration Index of Water Quality

Water Quality Index



Source: IDEAM, 2015.

ics, hormones, fertilizers and pesticides used to fumigate fodder crops (FAO, 2012), as well as insecticides, used for the eradication of pests that attack crops and animals. Thus Colombia is positioned as one of the main consumers of chemical fertilizers in Latin America, where it is estimated that approximately 70% of the nitrogen and phosphorus used for crops is lost, mainly through runoff and leaching, which results in an increase in the eutrophication of water bodies. Moreover, in the 2012 tax reform, VAT for fertilizers and pesticides was eliminated, leading to the excessive use of these products, creating a subsidy with a negative impact on the environment (OECD, 2014). In 2007, the regulation called "Extended liability of the REP producer" was implemented, initially in the field of pesticide packaging and expired pesticides. This regulation obliges producers to remove used containers, with the goal of reaching 75% of containers collected in 2019 (OECD, 2014).

On the other hand, illegal crops require the application of significant amounts of agrochemicals, both in the crop itself and in the efforts to eradicate them. A good example is aerial and manual fumigation of coca crops using glyphosate. In coca crops, an application of pesticides of 344,000 k powder and 677,000 liters in liquid form was estimated for 2012 (IDEAM, 2015). Pesticides used in drug precursors are illegally trafficked from Ecuador, Peru and Brazil; for which there is obviously no accurate information available (Ministry of the Environment, 2000).

Livestock activity is among the most harmful sectors to the environment, contributing, among other aspects, to water pollution (FAO, 2012). In Colombia, according to the Agustín Codazzi y Corpoica Geographic Institute (2002), about 45% of the territory is used for cattle activity, 96.2% extensive and 3.8% intensive (Cuenca *et al.* , 2008). This situation has led to the elimination of forests, causing an enormous impact on the environment particularly because of the application of fertilizers and pesticides to control pests that affect pastures.

Production and sale of chemical pesticides for agricultural use

Data provided by the Colombian Agricultural Institute (ICA) make it possible to measure the degree of pesticide use in Colombia. Given the characteristics of rainfall, richness of the water system and ways of using pesticides, there is a significant likelihood that these substances reach water bodies, both surface and underground. A clear example of this is the chemical characteristics of pesticides, which makes them persistent pollutants that resist photochemical, chemical and biochemical degradation to varying degrees, meaning that they can have a long average life in the environment (Malato *et al.*, 2001, Albert, 1998, and Tomin, 1997). However, in the available statistics, there are no specific indicators to identify the behavior of pesticides with respect to consumption per crop, consumption per unit area or consumption per region or department. These information gaps make it difficult to identify risks and prioritize solutions (Ministry of the Environment, 2000).

Tabla 3 presents the production and sale in Colombia of pesticides and fertilizers for 2013 according to their presentation in powder or solution, indicating that on average, 63% and 73% of pesticide production is sold in powder and solution in Colombia respectively; the remaining percentages are intended for export.

At the same time, an analysis of the evolution of the sale of pesticides in the period 2008-2013 (**Figura 6**) shows that historically, the most commonly sold presentation is liquids, perhaps because of the ease of handling and application, compared with the solid presentation, which requires more expensive prior preparation.

Tabla 4 shows the percentage share by use for the chemical pesticides produced and sold in Colombia in 2013. This table shows that most fungicides are commercialized in solid form, whereas herbicides are mainly commercialized in liquid form.

The main active ingredients classified by type of use and marketed in Colombia in 2013 (**Tabla 5**) in-

Table 3. Production and sale of chemical pesticides and fertilizers for agricultural use in 2013

Input	Powder or granular (kg)		Solution (L)	
	Production	Sale	Production	Sale
Pesticides	16.593.118	10.458.747	61.876.753	45.384.728
Fertilizers	1.429.851.104	1.671.955.457	1.802.289	2.617.340

Source: ICA, 2014.

Figure 6. Evolution of sale of pesticides in Colombia 2008-2013

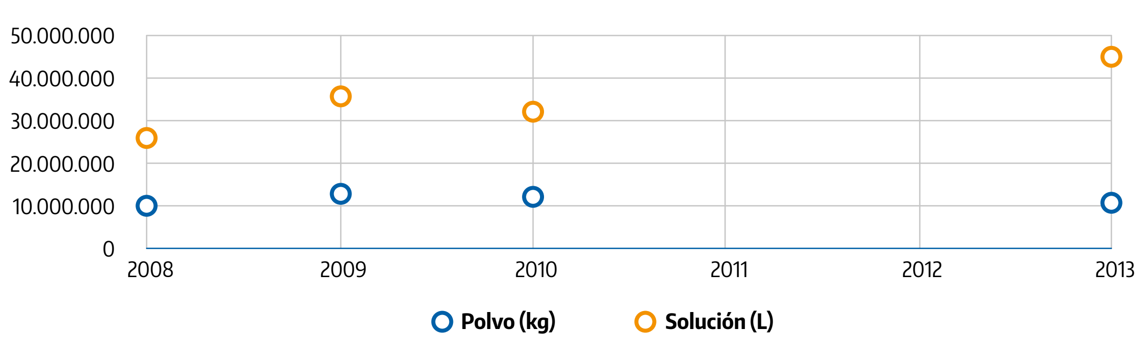


Table 4. Classification of pesticides produced and sold in Colombia by type of action in 2013

Type of action	Solid presentation (%)		Liquid presentation (%)	
	Production	Sale	Production	Sale
Fungicides	88,74	63,66	24,97	17,48
Insecticides	10,64	24,73	22,28	14,99
Herbicides	0,34	11,04	49,94	63,64

Source: ICA, 2014.

clude active substances such as Chlorpyrifos, Mancozeb and Glyphosate. Chlorpyrifos is an organophosphorus insecticide, considered a neurotoxin that irreversibly inhibits the Acetylcholinesterase enzyme (AChE), essential for the functioning of the central nervous system in humans and insects. Mancozeb is a low-cost fungicide with a high action spectrum, frequently used in soils for growing vegetables and certain tubers. Its main environmental problem is that it rapidly degrades into a more toxic metabolite: Ethylenethiourea (ETU) has carcinogenic, teratogenic and mutagenic characteristics (Domínguez *et al*., 2009). Lastly, glyphosate is a herbicide commonly used for the eradication of coca crops.

Table 5. Main active ingredients sold in Colombia in 2013

Action	Active ingredient	kg	L
Insecticides	Chlorpyrifos	1.707.363	2.961.488
Herbicides	Glyphosate	126.294	9.606.238
	Paraquat	-	2.920.678
	Propanil	96.394	1.696.440
	2,4-D	24.264	3.296.486
	Aminopyralid + 2,4-D	-	2.246.066
	Picloram + acid 2,4 D	-	2.744.117
Fungicides	Mancozeb	2.786.243	3.108.146

Source: ICA, 2014.

Environmental impact

According to the National Water Study (IDEAM, 2015), a greater presence of pesticides has been detected in water currents in areas near its application, increasing the risk of poisoning via water for human consumption and affecting flora and fauna. The mainland Caribbean region in Colombia receives approximately 90% of the liquid waste from the population, industry and major crops (potatoes, grasses, plantain, sugar cane, coffee and vegetables), whereas the Cauca and Magdalena river basins concentrate the population settled in the Andean and Caribbean regions (Ministry of the Environment, 2000). In this region, the excess of nutrients (Nitrogen and Phosphorus) creates eutrophication processes while the misuse of pesticides negatively affects non-target control species (Ministry of the Environment, 2000).

Monitoring alternatives

The qualitative and quantitative evaluation of pesticides in water bodies is a complex task because a wide variety of substances are used (organophosphates, carbamates and dithiocarbamates, pyrethroids, among others). Accordingly, pesticides used as indicators should usually be selected on the basis of their use, physical-chemical properties and persistence in the environment (Narváez *et al*., 2012). Another restriction on monitoring pesticides is that the amount of these pollutants transported to the water body is usually small and its concentrations are at the level of traces and sub-traces and, lastly, pesticides can degrade in natural environments forming degradation products, due to hydrolysis, photolysis, rust-reduction and biodegradation (Narváez *et al*., 2012). It is therefore essential, in addition to monitoring parental substances, to evaluate the main degradation products of the pesticides selected as indicators, because in many cases they are more toxic and persistent than the original substances.

3.3 Eutrophication

Eutrophication is the process whereby aquatic ecosystems are enriched with nutrients from mainly domestic and agricultural sources, the most important of which are nitrogen and phosphorus (**Figura 7**).

At first sight, it might seem that it would be good for waters to be full of nutrients, because that could lead to higher primary productivity, but the situation is not that simple. The problem is that if there are excess nutrients, phytoplankton and aquatic plants grow in abundance, leading to an imbalance of respiration and photosynthesis in the ecosystem, with oxygen loss at night and over-saturation in the day. Excess biomass leads to the decomposition of organic matter, which requires heavy oxygen consumption, which produces gases such as methane and hydrogen sulfide, causing bad odors and anoxic environments, which prevent the normal development of aquatic fauna (Roldán and Ramírez, 2008).

Eutrophication Sources

Most eutrophication sources are the result of anthropic activities such as domestic and industrial wastewater, pesticide sprays, fertilizers in agriculture, aquaculture practices and mining activities (**Figure 8**).

Effects of eutrophication

Some effects of eutrophication are the mortality of fish due to the lack of oxygen during the night, the invasion of lakes and reservoirs by aquatic vegetation and phytoplankton blooms. Due to these problems, numerous cases of fish mortality have recently occurred in Colombia, mainly in the River Magdalena, Betania Reservoir, Ciénaga Grande de Santa Marta and the River Porce (**Figure 9**).

Possible solutions

The point is to prevent the entry of nutrients into aquatic ecosystems through proper watershed management.

Limnological studies should be undertaken to show the status of eutrophication in order to apply corrective measures. These include: the use of weed killers –even though their inefficiency and danger of intoxication for large areas have been proven–, the mechanical removal of vegetation-so far the most effective, but expensive-and artificial aeration -which in large areas is neither effective nor practical (**Figure 10**).

Impact of eutrophication on the structure of planktonic communities in Colombia

Tropical aquatic ecosystems are naturally susceptible to eutrophication processes when subjected to high average annual temperatures, which promote periods of intense, constant biological activity (Northcote, 1991).

Studies on the lentic ecosystems of the country subjected to eutrophication processes by direct and indirect impacts such as urban, industrial and agricultural discharges and processes of land clearance, deforestation and the alteration of flows, have found planktonic communities with low taxa representativeness (phytoplankton: 21 species, zooplankton: 10 species), dominated by a few species that effectively occupy a broad spectrum of niches and monopolize available resources (Rodríguez-Sambrano and Aranguren-Riaño, 2014).

Thus, phytoplankton taxa associated with eutrophic conditions such as *Coelastrum microporum*

Figure 7. Types of eutrophication in lakes and reservoirs

Oligotrophic lagoon

Mesotrophic reservoir

Eutrophic lagoon

Hypereutrophic reservoir

Photos: G. Roldán.

Figure 8. Eutrophication sources in lakes and reservoirs

Wastewater | **Aerial spraying *** | **Aquaculture** | **Alluvial mining**

Photos: G. Roldán. *Aerial spraying photo: fumigacionesx.blogspot.com/p/consecuencias.html

Figure 9. Effects of eutrophication on lakes and reservoirs

*** Fish mortality** | **Development of aquatic vegetation** | **Phytoplankton Bloom**

Photos: G. Roldán. *Source: Internet.

Figure 10. Some remedies for eutrophication

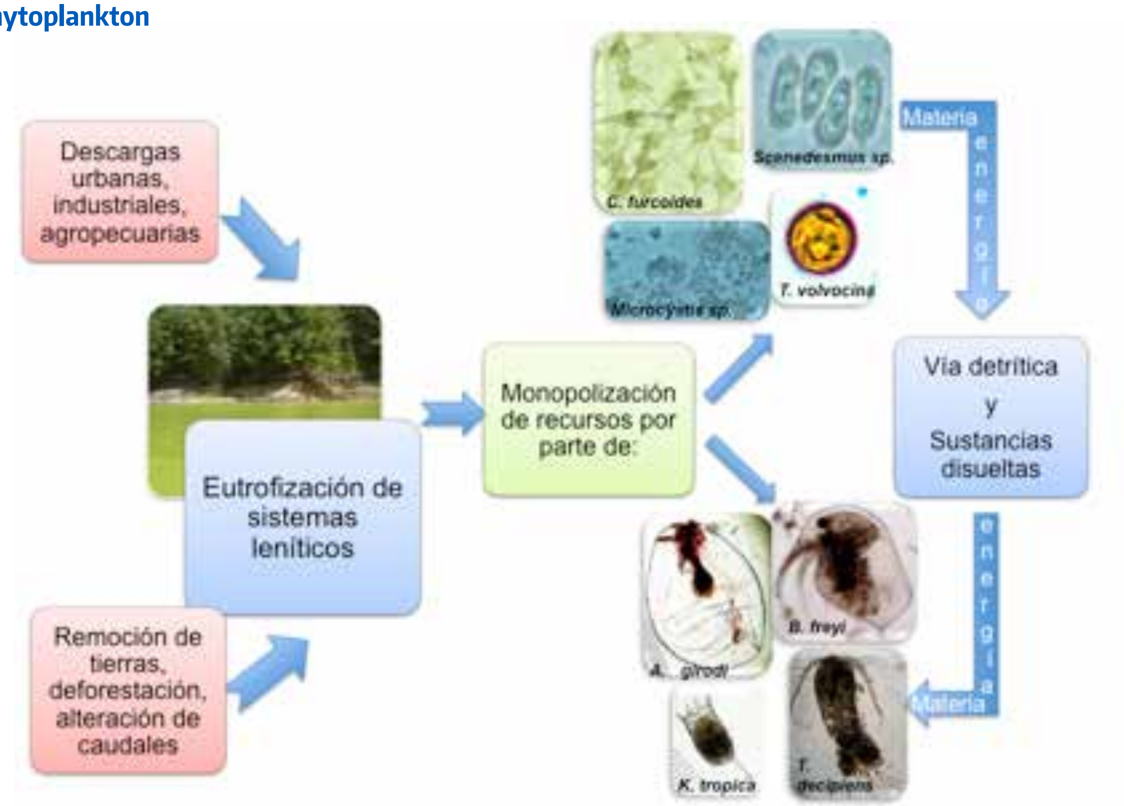
Physical and chemical studies | **Study of vegetation** | **Control with herbicides *** | **Mechanical removal** | **Aeration**

Photos: G. Roldan. *Source: Internet.

(Clorophyta), *Euglena* sp., *Trachelomonas volvocina* (Euglenophyta) (Rodríguez-Sambrano and Aranguren-Riaño, 2014), *Ceratium furcoides* (Dinophyta) (Bustamante-Gil *et al.*, 2012) and *Dactylococcopsis acicularis* (Cyanophyta), as well as genera such as *Microcystis* and *Scenedesmus* in general (Vásquez, Ariza and Pinilla, 2006) have been found.

Within zooplankton, density, and in some cases biomass has been dominated by rotifers such as *Asplanchna girodi* and *Keratella tropica*, cla-

Figure 11. Food webs show that the flow of energy, carbon and nutrients may be stored in phytoplankton



Photographs of zooplankton: Silvia Villabona González, Mónica Tatiana López and Cristina Gil, Universidad Católica de Oriente.

docerans such as *Bosmina longirostris* (possibly *B. freyi*) and *Ceriodaphnia cornuta* and copepods such as *Metacyclops mendocinum* and *Thermocyclops decipiens* (Guevara, Lozano, Reinoso and Villa, 2009, Rodríguez-Sambrano and Aranguren-Riaño, 2014, Villabona-González, Buitrago-Amariles, Ramírez-Restrepo and Palacio-Baena, 2014, Villabona-González, Ramírez-Restrepo, Palacio-Baena and Costa Bonecker, 2015). It has also been reported that zooplankton biomass, especially that of microcrustaceans, is affected by eutrophication processes, as this increases with the trophic state and at the same time, coincides with the increase in phytoplankton biomass (Villabona *et al.*, 2015).

Regarding food webs, it was found that it is possible that the flow of energy, carbon and nutrients stored by phytoplankton is mainly oriented to the detritic pathway and dissolved substances and that therefore the latter are the main source of carbon for zooplankton (**Figura 11**) (Villabona-González *et al.*, 2015, López-Muñoz, Ramírez-Restrepo, Palacio-Baena, Echenique, De Mattos-Bicudo and Parra-García, 2016).

The impact of eutrophication obviously significantly limits the totality of the ecosystem services these aquatic systems can provide, in response to the gradual loss at a spatio-temporal level of the potential of the water supply and the hydrobiological resources that may be generated.

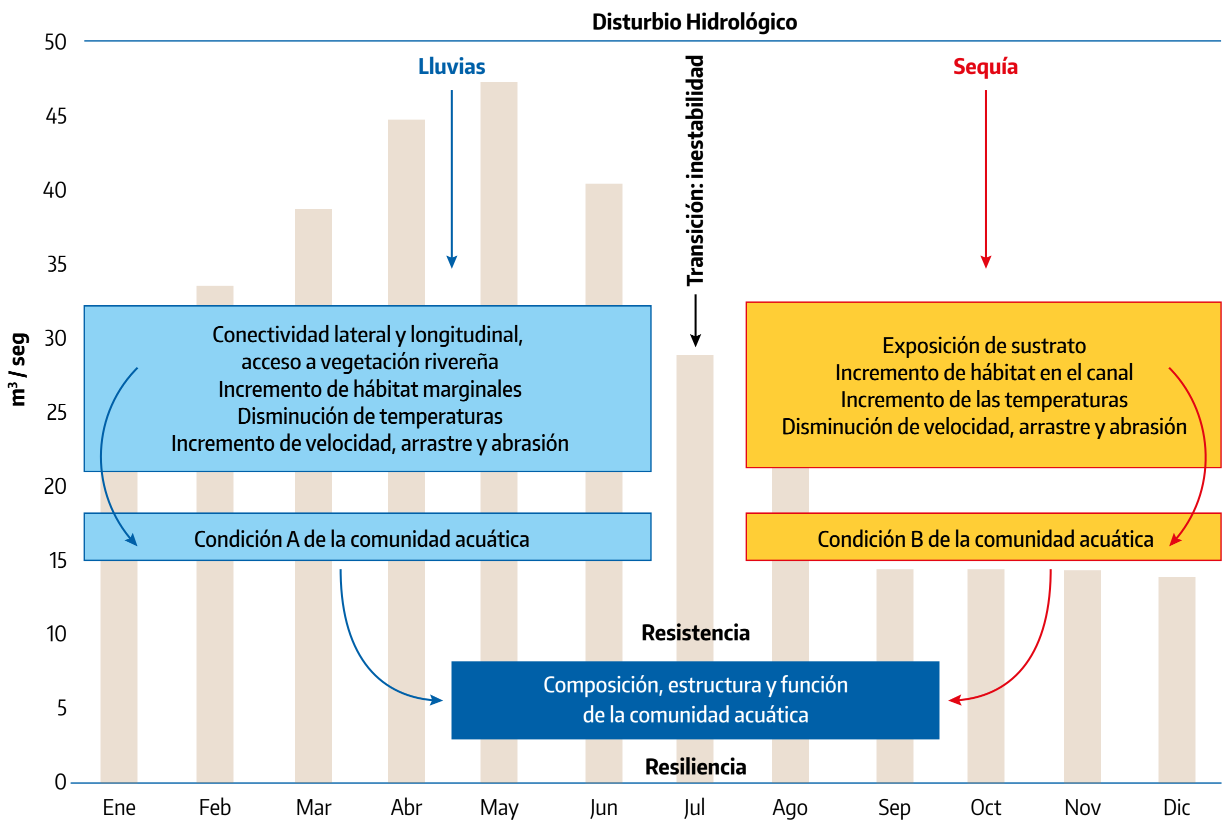
3.4 Ecological effects

Hydrology is a very important factor in the integrity of aquatic ecosystems, since it determines aspects of the hydraulics, geomorphology and physicochemistry of the waters and, therefore, the ecology of the system. Some studies on water resources in Colombia have shown the importance of this factor in the conservation of both water and aquatic ecosystems, as well as the extent of the threat it faces. The Humboldt Institute (Colombia anfibia, 2016) assessed the degree of transformation of Colombian wetlands, showing that 24.2% (corresponding to 7,332,656 ha) of these have been transformed, especially in the center-west of the country, and identifying four major drivers of transformation: water demand, pollution, land overuse and loss and/or modification of the ecosystem. The impacts associated with hydrological change (alteration of flows) correspond to this last driver, which, according to the study, is the main one in the Colombian interior wetlands, particularly the inter-Andean valleys and the plains of the eastern plains, followed by coastal lagoons and mangroves.

In the neotropical Andean rivers, little is known about the relative influence of the physical and chemical variables associated with the water cycle (**Figure 12**), except for a few studies such as those by Lowe-McConnell, 1979, 1999; Rivera-Rendón *et al.*, (2004); Pouilly *et al.*, (2006); Domínguez and Fernández (2009); Ríos-Pulgarín (2015) and Ríos-Pulgarín *et al.*, (2016). This lack of information regarding the response patterns of the various local aquatic communities has led to the generalization of patterns found in other systems, which fail to take into account regional particularities and create a lack of congruence between the scale of ecological knowledge and the scale on which management efforts, and river management, conservation and restoration are undertaken (Ríos-Pulgarín, 2015).

Other environmental variables associated with the water cycle, such as dissolved oxygen, are heavily influenced by the cyclical occurrence of the El Niño and La Niña / Pacific Oscillation (ENSO) phenomena, which affects regional hydrological conditions, with complex effects on fresh water ecosystems (Blanco, 2003). Studies by Ríos-Pulgarín *et al.* (2016) conclude that climatic variability related to ENSO is associated with a substantial variation in the flow, temperature and chemical composition of water, in Andean piedmont rivers, but with specif-

Figure 12. General model of the relationship between the variability of the flows in an Andean river and certain ecological aspects defining the structure of the aquatic community throughout the water cycle



ic characteristics for torrential rivers in basins with volcanic deposits.

Regarding its biological effects, it has been shown that floods during the wet phase of the ENSO (La Niña) phenomenon reduce the number and diversity of benthic invertebrates in both Andean rivers (Ríos-Pulgarín *et al*., 2016) and those in Nuevo México (Moles, 1990), and that the recovery rate after floods by the communities seems to depend on the local frequency of the latter. One of the few studies carried out in the Andean region on these effects was undertaken on a dry forest stream in the Colombian western mountain range during the ENSO events of 1997-1999 (Blanco, 2003) and the study by Ríos-Pulgarín *et al*. (2016) in the Guarinó River, in the foothills of the central mountain range, during the ENSO period 2007-2010. These studies found spatial variability in the response of associations of aquatic organisms. In particular, the study by Ríos-Pulgarín *et al*. (2016) identified changes in the associations of fish, macroinvertebrates and periphyton that were directly related to the ENSO period, but with different responses between benthic and ichthyofauna communities. Maximum values of abundance of ficoperifiton and macroinvertebrates occurred during El Niño (2009-2010), due to relatively stable hydrological conditions, less depth and less turbidity, which promotes photosynthesis and higher temperatures. Although high flows encouraged fish due to increased habitat supply, they affected the benthos due to increased trawling. The increase in flows specifically affects abundance due to the frequency or magnitude of the flood, which limits the colonization of more unstable substrates (Blanco, 2003, Biggs *et al*., 2005). However, for many groups, diversity values do not reflect the variability due to the change of species, which alters the composition depending on the adaptations to different conditions, but it does not affect the wealth of species.

3.5 Deforestation

In Colombia, deforestation has increased in recent years due to the "needs" and human beings' drive to expand. Some of the activities associated with this goal include the expansion of the agricultural frontier, the establishment of monocultures, the food needs associated with population growth, the overexploitation of mineral resources and the establishment of illicit crops. The expansion of the agricultural and livestock frontier, together with colonization, account for 73% of deforestation in Colombia, altering the climate and the water, carbon and nitrogen cycles (Romero *et al*., 2008).

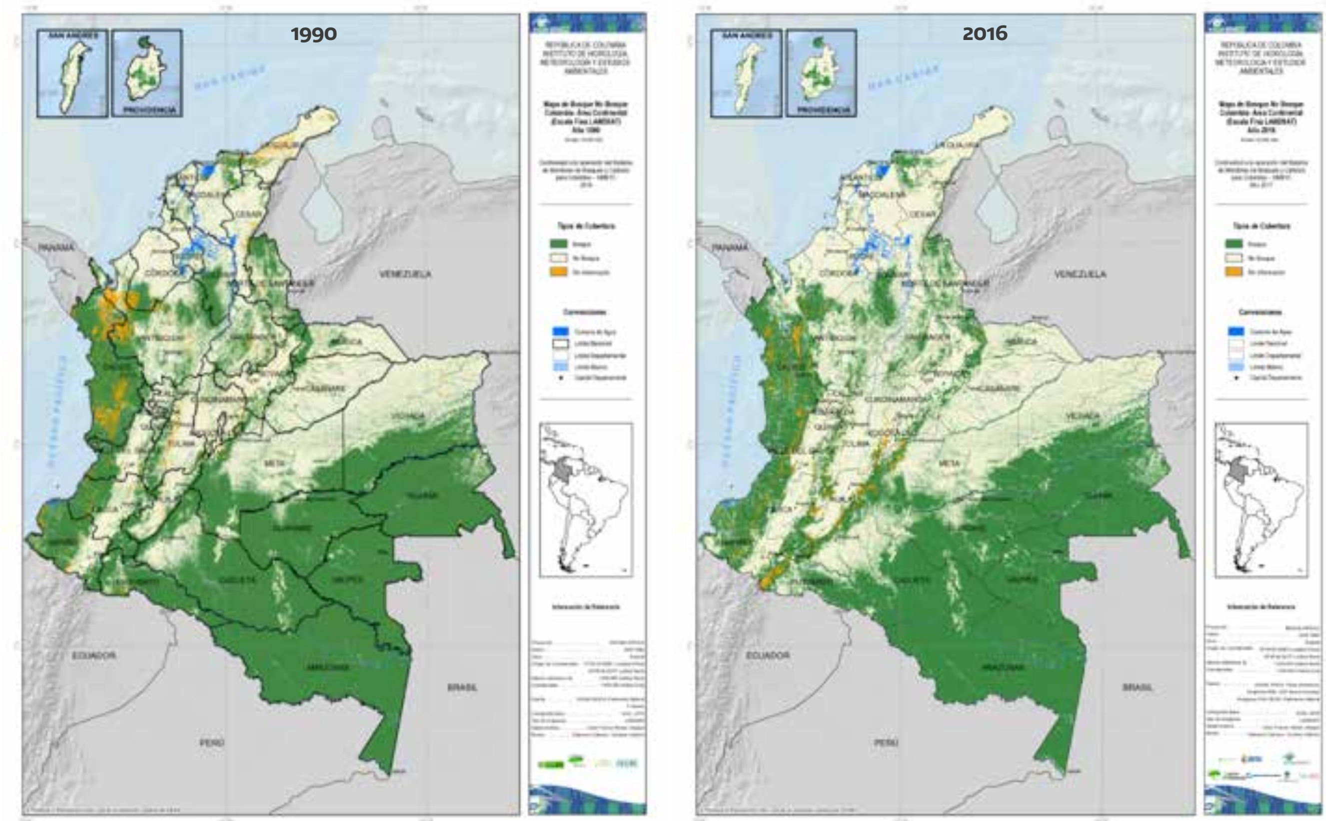
The deforestation of tropical forests obviously poses an enormous threat, with adverse consequences for all levels of the ecological relationship with which it interacts. These include the physicochemical and biotic quality of the water in the various basins affected by this problem. It is striking how various studies by the environmental authorities - the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), the Alexander von Humboldt Research Institute of Biological Re-

Table 6. Evolution of deforestation in Colombia

Period	Surface Covered by Natural Forest (ha)	Deforested area (ha)	Annual Deforestation Average (ha/yr)
1990 2000	64.128.972 61.474.388	2.654.584	265.458
2000 2005	61.811.060 60.232.884	1.578.176	315.635
2005 2010	60.449.256 59.039.119	1.410.137	282.027
2010 2012	60.036.759 59.704.620	332.139	166.070
2012 2013	58.936.251 58.815.317	120.934	120.934

Source: IDEAM (2014)

Figure 13. Map showing deforestation in Colombia between 1990 and 2016



Source: IDEAM, 2014.

sources and other agencies concerned to natural resources – show a rise in deforestation rates in the country (**Figure 13**) Table 6 shows the evolution of deforestation between 1990 and 2013.

According to the IDEAM, in the period between 1990 and 2013, the country lost 6,095,312 ha of natural forest with an annualized average of approximately 265,000 ha a year (**Tabla 6**).

Data generated by the Forest and Carbon Monitoring System (SMBYC), shows that the annualized deforestation rate has decreased, the most critical period being 2000-2005, which saw a loss of -0.52%, as opposed to -0.21% registered in 2012-2013 (Galindo *et al*., 2014).

The Forest and Carbon Monitoring System (SMBYC and IDEAM) periodically releases the Early Warning for Deforestation (AT-D), a tool for taking actions to reduce deforestation in Colombia. These reports are drawn up on the basis of images from remote sensors. At the departmental level, the regional trend detected by the early warning system for deforestation shows that in 2014, 70% was concentrated in seven departments: Putumayo, Caquetá, Nariño, Meta, Chocó, Antioquia and Guaviare (IDEAM, 2015).

Some other studies, with a more specific level of sectorization, indicate annual deforestation rates in the Colombian Amazon of 3.73 and 0.97% in the areas of high population growth of the high Putumayo and Macarena, respectively, and 0, 31, 0.23 and 0.01% in the relatively sparsely populated areas of the indigenous population (Armenteras, Rudas, Rodríguez, Sua and Romero, 2006). These figures amount to a total area of 4,200,000 ha, identified through remote sensing and geographic information systems.

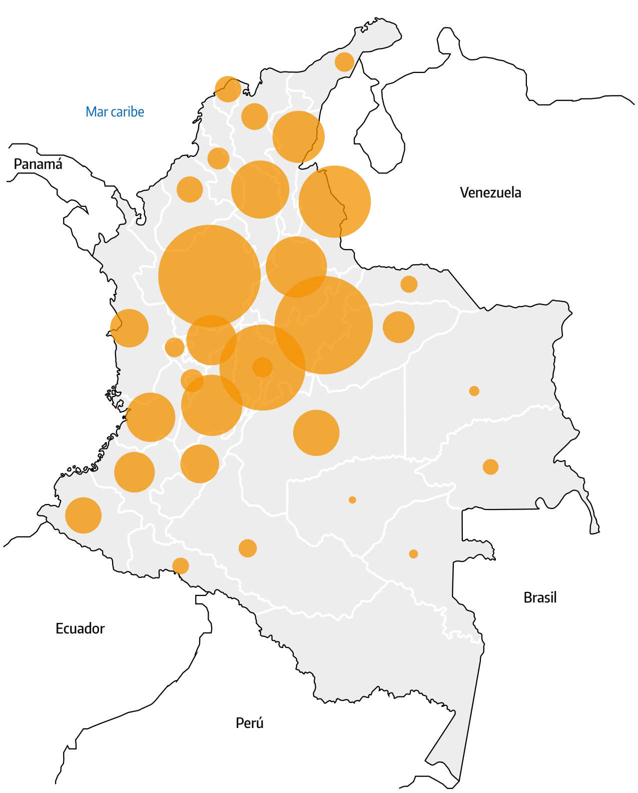
Deforestation in Colombia is a process that has been galvanized by various direct or indirect causes. The determinants of this phenomenon are mainly economic and related to processes of adjusting the productive forces in the country, namely: pastures, and the expansion and control of illicit crops, agroindustrial expansion, among others (IDEAM, INVEMAR, SINCHI, IIAP, IAvH, 2016).

In Colombia, the departments with a magnitude of erosion of more than 70% of their total area are: Cesar, Caldas, Córdoba, Cundinamarca, Santander, La Guajira, Atlántico, Magdalena, Sucre, Tolima, Quindío, Huila and Boyacá. In general terms, 40% -equivalent to 45,379,058 ha of the mainland and island area of Colombia- have some degree of soil degradation due to erosion. Of this part of the affected territory, 20% (22,821,889 ha) has slight erosion, 17% (19,222,575 ha) moderate erosion, 3% (3,063,204 ha) severe erosion and 0,2% (271,390 ha) extremely severe erosion (IDEAM, MADS, UDCA, 2015). Other studies describe the increase in sediment contributions in the various basins of the Colombian Andes in the past 30 years, all associated with deforestation processes (Restrepo and Escobar, 2016).

Recent studies have estimated that 9% of the sediment load in the Magdalena River basin is due to deforestation; 482 tons (T) of sediments have been produced due to forest separation in the past three decades. Erosion rates in the Magdalena drainage basin increased by 33% between 1972 and 2010, increasing the sediment load of the river by 44 T/year. Much of the river basin (79%) is under severe erosion conditions due partly to the removal of more than 70% of natural forests between 1980 and 2010 (Restrepo, Kettner, Syvitski, 2015).

All these allochthonous contributions of sediments lead to a decrease in the environmental and physicochemical quality of the water sources. This is associated with the high levels of turbidity produced in the receiving sources and the ecological, physical and chemical repercussions related to a greater magnitude in variables of environmental interest such as suspended solids, conductivity, availability of nutrients (nitrogen and phosphorus), and an increase in the demand for biological and chemical oxygen (BOD5 and COD, respectively).

Figure 14. Mining map of Colombia (2016)



Source: www.portafolio.co/negocios/mapa-minero-en-colombia-2016-501060

3.6 Heavy metals

The load of solids associated with deforestation processes is not the only source of contamination that can affect water quality; depending on the type of land use, various concentrations of other pollutants may flow into the water course. This is the case of mining, an activity that contributes a considerable amount of heavy metals to the water sources adjacent to the extractive process. The presence of heavy metals and complex organic substances, among others, in water resources has been responsible for innumerable situations of impact on the aquatic ecosystem and public health in general (Thomann, 1982).

In Colombia, several studies have been carried out to quantify the concentrations of heavy metals in water, sediments and fish tissues. Some of the best studies have been undertaken by Galiano-Sedano (1976, 1977), Research on mercury content, and Galiano-Sedano (1979), Studies on industrial waste pollution, in the waters of Colombian rivers.

Other studies, such as the one by Pulido (1985) and the University of Antioquia (1988) on the Cauca River basin, describe the high concentrations of mercury found in water and sediments, especially in the Cauca Antioquía region, where contributions of metallic mercury of 270 kg/day and 9.553 ton/day of sediments were found. In the Amazonian terri-

Figure 15. Gold mining scene in Chocó

Source: https://www.noticiasrcn.com/nacional-regiones-pacifico/mineria-ilegal-e-informal-amenaza-los-rios-del-choco

tory, the total mercury concentration was evaluated in water, sediment and fish species samples of different trophic levels in four localities in the Colombian Amazonia. Total mercury values in water did not exceed 0.001mg/l. In sediment, the concentrations were between 0.0016 and 0.0591 mg/kg Hg, which, in light of international standards, is recorded as a low risk effect (Núñez-Avellaneda, Agudelo and Gil-Manrique, 2014). The **Figura 14** shows the mining map in the country while the **Figura 15** shows a mining scenario in the Chocó.

Mainland contributions resulting from soil erosion and leaching due to the indiscriminate felling of forests in the Magdalena-Cauca, Sinú-San Jorge, Atrato and Orinoco river basins, gold mining, oil exploitation, agricultural activities and agriculture and the growing industrial activity of the capital cities, as well as the port cities, have begun to create extremely diverse environmental problems (Mancera-Rodríguez, Álvarez-León, 2006). It is estimated that between 1980 and 2000, colonization in the Magdalena River basin alone has destroyed 3.5 million hectares of forests, sediment transport amounts to 133,000 tons/year and, in several river stations, concentrations of heavy metals (cadmium, iron, mercury, lead, zinc) exceed the permitted levels in natural waters (National Planning Department, 1995).

3.7 Emerging contaminants

There is currently a growing interest in emerging pollutants (EC), as they are compounds of various origin and chemical natures, whose presence in the environment, or possible consequences, have largely gone unnoticed, causing environmental problems and health risks. These compounds are scattered in the environment and have been detected in water supply sources, groundwater and even drinking water. They are relatively little known compounds, in terms of their presence, impact and treatment. In most cases they are unregulated pollutants, which could be the object of future regulations, which warrant further research on their potential effects on health and monitoring of their incidence. Some of the main ones are pesticides, pharmaceutical products, illicit drugs, "lifestyle" compounds and personal hygiene items (Gil *et al*., 2012).

The article by Gil *et al*. (2012) mentions that glyphosate is now the most commonly used weed-killer in the world, which has seen a dramatic increases in its use in agriculture since the introduction of glyphosate-resistant crops. Microbial degradation produces amino methyl phosphonic acid (AMPA) and it has been proven that AMPA causes health problems. The high solubility in water of glyphosate and its metabolite has meant that analysis is difficult.

In Antioquia, in a study carried out in the municipality of San Pedro, the use of high-toxicity pesticides such as Lorsban (Chlorpyrifos), Ráfaga (Chlorpyrifos), Látigo (Chlorpyrifos), Neguvon (Metrifonate), Furadán (Carbofurán), Ganabaño and (Cypermethrin) is a cause for concern. They are subsequently washed away by the rains and end up in wastewater and rivers.

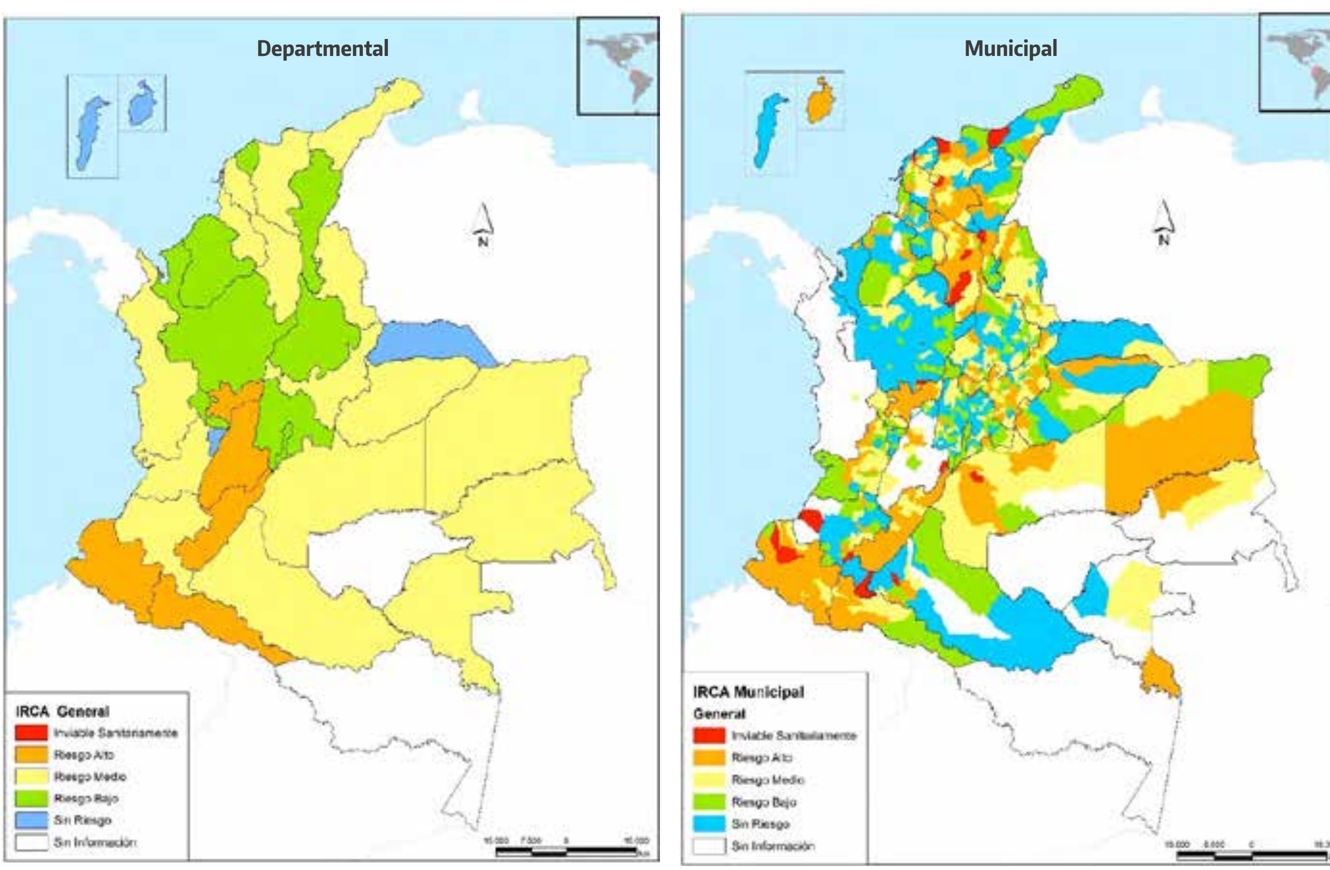
In Colombia, a study conducted at the Universidad del Norte Hospital in Barranquilla, found that effluents discharged into the city's sewer system and subsequently into the river, contained substances of pharmaceutical origin, showing that wastewater treatment systems must be reframed. The most commonly used substances in hospitals in this category are analgesics, anti-inflammatory drugs such as diclofenac, ibuprofen and other medicines such as aspirin, antiseptics such as triclosan, hormones such as estriol and estrone, stimulants such as caffeine, and other legal drugs in hospital centers such as morphine. An analysis of the chemical and biological content of the hospital's waste revealed the presence of heavy metals (mercury, platinum, gadolinium), anesthetics (alkylphenol, propofol), cytostatics, disinfectants, analgesics and anti-inflammatory drugs, contrast media and absorbable organic compounds.

Since both illicit drugs and their metabolites are highly resistant to elimination using conventional physicochemical and biological treatments, advanced oxidation processes, ozonation and osmosis must be used. However, most treatments do not include them due to their high costs, which means that both drugs and metabolites are released into surface water and even drinking water.

Other emerging contaminants include hormones, caffeine and nicotine, ingredients used in personal hygiene products, disinfection by-products, industrial compounds and food additives, but there is not much data or information on them.

Although the country has resources for the construction of plants and reactors for domestic and industrial wastewater treatment, the search for effective treatments for the removal of emerging pollutants (EP) lacks information on the mechanisms of occurrence and transformation of these substances. That is why the research proposed in this regard should focus on finding ways to adapt exist-

Figure 16. Distribution of risk levels by department and municipality in Colombia, 2015



Source: Sistema de Información de la Vigilancia de la Calidad del Agua para Consumo Humano (SIVICAP), Grupo Calidad de Agua-DRSP, Instituto Nacional de Salud.

ing water treatment technologies in advanced processes for removing emerging pollutants.

3.8 Salinization

The threat of rising sea levels in Colombian coastal and island areas is not limited to the flooding of certain areas, but also includes coastal erosion and surface and groundwater salinization.

A specific case of this phenomenon of salinization can be seen in the impacts on the Ciénaga Grande de Santa Marta lagoon complex. To maintain its water balance, this lagoon must receive water from the rivers that run down from the mountain range. However, since the 1990s, farmers, agricultural companies and inhabitants of the banana area began to use them disproportionately for their economic activities, dramatically reducing the volume of fresh water. During the summer months, irrigation districts capture 80% of the average flow of rivers. Only 40% of the captured volume returns to natural drainage, loaded with agrochemicals. This increase in salinization and the decrease in water inflows interrupted fish migrations for reproductive cycles, which added to the increase in fishing pressure and the use of harmful and illicit methods (dynamite or nets such as bowling), reducing the number of fish and other species. It is not known how many remain of the 126 species that once lived in that ecoregion (http://sostenibilidad.semana.com/medio-ambiente/articulo/cienaga-grande-enferma-cronica/33752).

Another case is the coastal aquifer of the Banana Hub of Urabá, located north-west of the department of Antioquia. This aquifer, covering approximately 1,030 km^2 (103,000 ha), is characterized by forming part of the mainland and having a coastal strip that receives marine influence. It is the main source of supply for the banana industry and urban and rural communities. There are approximately 550 active wells in the area, mostly to meet the demand for plantain cultivation, one of the country's main export products. The hydrochemical characterization of the Plantain Hub of Urabá was based on the sampling of 26 groundwater points (consisting of 16 deep wells and 10 piezometers), a sample of seawater and a sample of surface water, distributed over a area of 8,916 km^2. The analysis and processing of the groundwater samples in the study area, aided by the evaluation of certain ionic relationships and the incorporation of hydrogeological information available in the area -such as vertical electric soundings, geology and hydraulics- showed that there is a incipient state of possible salinization in the coastal aquifer of the Plantain Hub. This is exacerbated specifically in the northern sector, an area where there is currently no intensive exploitation of underground water resources, but where in preventive and management terms, continuous monitoring mechanisms and a hydrogeochemical evaluation should be undertaken of the coastal aquifer of the Plantain axis of Urabá the processes, to measure both salinity and other processes that may affect the quality of waters in this area (Paredes *et al.*, 2010).

4. Social and economic aspects

4.1 Health

As for the quality of water for human consumption, the Environmental Health Directorate of the Ministry of Health produces a consolidated national report where the main indicator is the risk index of water quality for human consumption (WQRI), showing the degree of risk of occurrence of diseases related to non-compliance with the physical, chemical and microbiological characteristics of water for human consumption.

Figure 16, drawn from a 2015 study (Minsalud, 2016) based on the departmental consolidations, calculated from samples collected from the supply networks of service providers in the respective municipalities monitored by the health authorities, shows that:

- 10.0%, corresponding to three departments (Quindío, Arauca, San Andrés and Providencia), were classified at having no risk, with a range of 0.0-5.0.
- 26.6% is equivalent to seven departments (Antioquia, Atlántico, Cesar, Córdoba, Cundinamarca, Risaralda, Santander) and Bogotá DC, classified as having a low risk level corresponding to a range of 5.1-14.0.
- 46.7% corresponds to 14 departments (Bolívar, Boyacá, Caquetá, Cauca, Casanare, Guainía, La Guajira, Magdalena, Meta, Norte de Santander, Sucre, Vaupés, Valle del Cauca and Vichada), classified as having a medium-level risk of 14.1-35.0.

- In 16.7%, five departments (Caldas, Huila, Nariño, Tolima and Putumayo) were observed to have high risk levels (35.1-80.0).
- Departments with WQRI classified as having an unviable health level (80.1-100.0) were not recorded.

In the SIVICAP system, there were reports of 1,017 municipalities (92.2%). The general municipal WQRI (**Figura 17**) reported 279 municipalities (27.5%) classified as risk-free, complying with the required potability standards; 177 with a low risk (17.4%) and 264 with a medium risk (25.9%). 280 municipalities were classified at the high risk level, (27.5%) and 17 (1.7%) were non-sanitary. The latter were located in Antioquia (Algeria, Cisneros); Bolívar (Norosí, Santa Catalina, Santa Rosa Del Sur); Caquetá (Morelia); Cauca (Piamonte, San Sebastián, Timbiquí); Cesar (Tamalameque), La Guajira (Dibulla); Magdalena (Sitionuevo, Zapayán); Meta (El Castillo); Nariño (Magüí, Olaya Herrera) and Tolima (Villarrica).

Basic microbiological and physicochemical characteristics in Colombia

According to the Minsalud report (2016), in 2015, 45,948 samples were analyzed in Colombia, 27,418 of which were collected in the urban area and 13,805 in the rural area, with 4,725 samples without data from the collection site. The samples were evaluated considering the percentage of acceptability of the main microbiological and physicochemical characteristics: total coliforms, *E. coli*, color, turbidity, pH, CRL, and considering the relative risk of each one of them within the WQRI indicator and the standardization of the number, since these are the minimum characteristics that must be evaluated by the health authorities of all the providers of the independent aqueduct service of the population supplied.

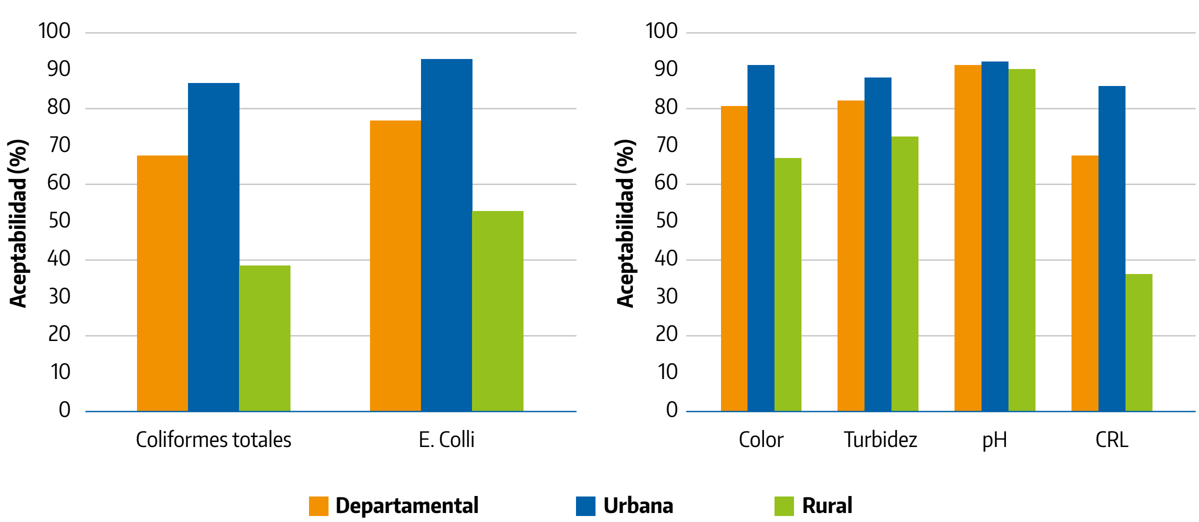
Quality of water consumed in Colombia in 2015

Table 7 shows the result of the water ladder (Minsalud, 2016). Considering the total population (43'173,748) surveyed in 2015, it showed that 30,201,730 inhabitants (70.0%) drank drinking water, reflecting an increase over the year 2014 when 29,423,817 inhabitants did so (67.28%). A population of 4,889.175 (11.3%) had safe water (includes low and medium risk). 5,496.013 inhabitants (12.7%), drank water with little or no treatment while 2,586.829 inhabitants (6.0%) may have drunk water directly from the source (unviable samples, as regards health).

Water-born Diseases in Colombia

Studying water-borne diseases in Colombia shows the extent to which lack of access to drinking water affects the health of the population. An important input for studying them is to determine the in-

Figure 17. Acceptability of microbiological and physicochemical characteristics, 2015



Source: SIVICAP, Grupo Calidad de Agua–DRSP, Instituto Nacional de Salud.

Tabla 7. Ladder of water for human consumption in Colombia 2015

Health Surveillance		Water for Human Consumption Colombia											
PCM Method		Improve Water						Unimproved Water				Not reported	
Calidad del agua		Potable		Segura				Entubada		Directa fuente			
Risk level		No Risk		Low Risk		Medium Risk		High Risk		Unfeasible		No information on risk	
Level	**Pop.**	**%**	**Pop.**	**%**	**Pop.**	**%**	**Pop.**	**%**	**Pop.**	**%**	**Pop.**	**%**	**Pop.**
Urban	35,952,016	78.8	28,346,731	1.2	439,271	9.1	3,265,027	7.3	2,614,644	3.6	1,286,342	2.4	894,919
Rural	7,221,732	25.7	1,854,999	1.0	70,099	15.4	1,114,778	39.9	2,881,369	18.0	1,300,487	36.4	4,134,738
National	**43,173,748**		**30,201,730**		**509,369**		**4,379,805**		**5,496,013**		**2,586,829**		**5,029,657**

Source: ICA, 2014.

cidence of these diseases in the country. However, the burden of morbidity related to them is currently unknown due to the large number of diseases comprising this group, which are analyzed independently. This is the case of hepatitis A, typhoid and paratyphoid fever, cholera, EDA, cryptosporidiosis, giardiasis and leptospirosis, among others. There are also difficulties in researching the environmental risk factors associated with diseases, which is essential to determining whether they are water-borne. **Table 8** shows the incidence rate of diseases directly related to water in Colombia in 2015.

As can be seen, the highest incidence rate in Colombia is associated with acute diarrheal diseases, mainly in Amazonas, Bogotá and Quindío.

4.2 Poverty

"The only way to reduce poverty is to provide access to drinking water," according to Professor Juan Saldarriaga of the Universidad de los Andes (Conference of Water Distribution Systems (WSDA), Cartagena, July 27, 2016). The country is one of the richest in terms of water, our rivers produce 50,000 m^3 per person annually, those of Germany 2,000 and traditionally dry places, such as Egypt, barely 1,000, However, the amount of water wasted in distribution networks in Colombia is extremely high: 48% of what is captured at the water source is lost. This is a worrying figure given that the acceptable rate of loss is between 10% and 20%. Colombian law establishes a ceiling of 30% loss, indicating that there is an 18% gap. Coverage is extremely low, especially in scattered rural areas. The best way to increase people's health is to bring drinking water to homes and the only way to reduce poverty is by having access to clean water, says Professor Saldarriaga. Why do poor people end up buying the most expensive water? Where does the problem lie? This does not happen in cities, the problem is in scattered rural areas where obtaining water is expensive and quality is less than optimal. It is expensive because it is carried in wagons, donkeys and mules, and people buy water in cans and buckets. Thus water is much more expensive in cubic meters than in the highest strata of cities (https://www.elespectador.com/noticias/medio-ambiente/unica-forma-de-reducir-pobreza-tener-acceso-agua-potabl-articulo-645702).

In Colombia, despite the fact that poverty and extreme poverty gradually decreased from 2009 to 2015, the change is still not significant. Poverty decreased by 21.6% during that period of time and extreme poverty by 9.1%. However, in June 2015, 13 million inhabitants still lived in poverty and 3.6 million in extreme poverty.

In comparison with the average for Latin American countries, Colombia has greater poverty and a greater number of people at risk of falling into poverty, which, added to the inequity in access to water resources and, therefore, to access to water unsuitable for human consumption, has serious consequences for the population (**Figure 18**).

That is why ensuring water availability is another of the objectives posing an enormous challenge for Colombia. The recent phenomenon of El Niño has entailed major consequences, which have had visible social and economic repercussions, including price increases and water shortag-

Table 8. Incidence of diseases directly related to water in Colombia in 2015

Territorial Entity	Mortality rate from ADD in Under-5s	General rate of incidence of ADD	Rate of incidence of Cholera	Rate of Incidence of Hepatitis A	Rate of incidence of typhoid and paratyphoid fever	Rate of incidence of Leptospirosis WQRI	IRCA
Amazonas	191,8	103,2	0.00	7,9	NN	9,18	NR
Antioquia	22,6	63,7	0.00	5,3	1,29	3,2	6.88
Arauca	120,2	35,5	0.00	1,1	NN	1,1	1.51
Atlántico	4,6	59,1	0.00	3,0	0,08	2,8	10.20
Bogotá	1,7	100,1	0.00	1,2	0,04	0,4	7.35
Bolivar	33,9	49,5	0.00	0,6	0,05	1,7	22.13
Boyacá	NN	50,5	0.00	2,7	NN	0,1	28.03
Caldas	12,6	50,2	0.00	2,7	0,40	0,6	54.26
Caquetá	18,4	56,0	0.00	0,2	NN	0,6	14.98
Casanare	NN	44,2	0.00	2,5	NN	0.00	19.34
Cauca	37,5	45,3	0.00	4,8	0,57	0,5	14.72
Cesar	81,5	55,4	0.00	0,9	0,19	0,1	13.37
Choco	334,7	30,4	0.00	0,4	1,58	0,3	NR
Córdoba	5,5	37,6	0.00	1,3	NN	0,9	9.97
Cundinamarca	NN	58,8	0.00	0,9	0,07	0,4	7.07
Guainía	382,6	37,2	0.00	4,8	NN	NN	16.66
Guajira	102,0	66,1	0.00	3,6	NN	1,1	18.31
Guaviare	69,4	38,0	0.00	10,8	NN	77,4	NR
Huila	52,6	54,3	0.00	5,5	0,86	1,7	45.53
Magdalena	50,4	48,5	0.00	1,9	0,2	0,87	28.67
Meta	42,6	68,7	0.00	4,8	1,53	0,93	32.15
Nariño	18,2	65,8	0.00	2,7	0,68	1,4	50.27
Norte de Santander	7,9	55,0	0.00	3,7	6,00	0,7	17.16
Putamayo	50,6	52,6	0.00	2,0	NN	0,8	50.49
Quindío	NN	77,7	0.00	2,5	NN	0,8	4.21
Risaralda	78,9	62,6	0.00	3,2	0,31	3,9	13.34
San Andrés	NN	53,8	0.00	NN	NN	1,3	2.08
Santander	NN	41,9	0.00	1,6	0,24	1,01	9,48
Sucre	47,4	48,9	0.00	2,9	0,35	1,4	15.25
Tolima	7,9	57,4	0.00	2,8	0,07	1,9	42.52
Valle	5,5	62,1	0.00	2,4	0,24	2,0	14.86
Vaupés	NN	22,7	0.00	NN	NN	NN	18.52
Vichada	995,7	36,4	0.00	2,8	NN	0.00	23.52
National	**29,6**	**63,33**	**0.00**	**2,6**	**0,54**	**1,62**	**23.40**

No risk	Low risk	Medium risk	High risk	Unviable	No report
0-5	5,1 - 14	14,1-35	35,1-80	80,1-100	NR

Note: ADD: Acute Diarrheal Diseases; WQRI: Risk index related to water quality for human consumption; NN: did not notify; NR: did not report information. *Indicators of morbimortality: Mortality rate is equal to number of deaths/population per 1'000,000 inhabitants; incidence is equal to new cases/population at risk per 100,000 inhabitants. The incidence rate of ADD is estimated at 1,000.

es (https://www.dinero.com/economia/articulo/pobreza-desigualdad-america-latina/215261).

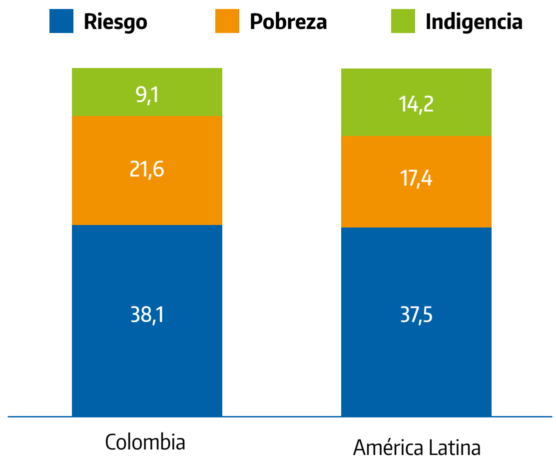
For example, the recent situation in La Guajira is critical. People are experiencing serious difficulties obtaining water, according to Oneida Pinto, the governor of La Guajira. “This is just one case, because this not only occurs in this region, but many other municipalities around the country have water shortage problems. Without drinking water, it is impossible to live, which requires an immediate intervention that will permit access to water”.

The UNDP (2005-2015) states that “If we want to mitigate water scarcity, it is essential to protect and recover the ecosystems related to this resource, such as forests, mountains, wetlands and rivers. It also requires more international cooperation to stimulate water efficiency and support treatment technologies in developing countries”.

According to IDEAM studies (2015), many of the water systems currently supplying the Colombian population show high vulnerability to maintaining their water availability. According to the general estimates for average hydrological conditions, approximately 50% of the population of municipal urban areas is exposed to water supply problems because of the conditions of availability, regulation and pressure that exist on the water systems that serve them. This situation becomes even more critical in dry years, when this figure can amount to 80%. According to these figures, the situation is alarming due to the lack of water; However, this is not the only thing that worries us, since shortages or periods of scarcity add to the contamination of water sources, causing the deaths of around 6,000 children every day due to diarrheal diseases” (Molinares-Hassan and Echeverría-Molina, 2011).

This situation is basically due to the fact that the population does not have sufficient income to connect to the aqueduct service, since the Colombian State, for example, despite having a clear policy of subsidies, which helps pay the fees of users categorized in strata 1, 2 and 3, does not have enough to subsidize demand for the majority of the most vulnerable population in the country whose plots of land are beyond the reach of water service. The population is divided into socioeconomic strata ranging from 1 to 6, with 1 corresponding to the poorest population and 6 to the highest level (Molinares-Hassan and Echeverría-Molina, 2011).

Figura 18. Pobreza en América Latina y Colombia



Fuente: Oxfam, cálculos Dinero. http://www.elcampesino.co/la-pobreza-en-america-latina-y-colombia /

4.3 Education

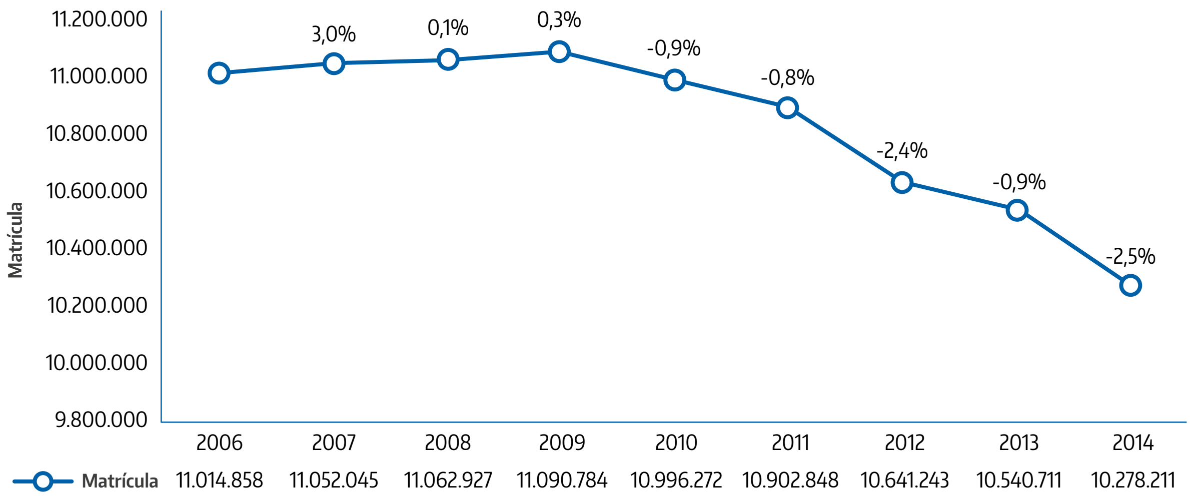
According to the UNDP, guaranteeing an inclusive, equitable and quality education and promoting lifelong learning opportunities is one of the main issues. Between 2010 and 2014, the number of enrollees was reduced by 6.5%. Nearly 720,000 people dropped out of the formal education system comprising students at the preschool, elementary middle and high school levels. This is an issue that warrants attention, because “the objective of achieving an inclusive, quality education for everyone is based on the firm conviction that education is one of the most powerful and proven engines for guaranteeing sustainable development”, according to the UNDP.

Figure 19. Evolution of graduates in Colombia
Growth of enrolment

Source: DANE (2014). Enrolment. Enrolment.

Colombia has a National Environmental Education Policy led by the Ministry of Education. The Environmental Education Program has enabled many of the School Environmental Projects (PRAE) regarded as significant to explain the various problems related to water resources in different parts of the country. Through its training strategy, the Program seeks to ensure that PRAE will contribute to

Figure 19. Evolution of graduates in Colombia



Source: DANE (2014).

the search for solutions to the environmental problems of the context (local-global), and in the case of the status of water in Colombia, from understanding the interactions established between the components of the natural and socio-cultural system, to describing their evolution and possibilities of transformation, in terms of quality of life and environmental sustainability. In the future, this will enable us to have a population with a deeper commitment to water.

4.4 Gender

"Worldwide progress in access to potable water and progress in access to basic sanitation services has been particularly slow and the goal is unlikely to be achieved, which will have serious consequences for women and girls, particularly those living in vulnerable situations" (Molina, 2016). Lack of access to drinking water affects women and infants in particular, since it is they who are responsible for providing water in rural and urban areas, fetching it at great distances and in precarious conditions.

The death of children due to the contamination of water sources is an event that directly affects the performance of women's work in the private sphere of the home, since it reflects the vulnerability to which they is subjected together with children, and correlates with the need for water. The discourse on the progress of welfare rights of the State could be reoriented from a gender perspective, based on the visualization and evaluation of women's work as a subject which, from a private perspective, could contribute to the implementation of public policies, with a two-way task of constructing a social framework within the State and the recognition of the identity of the latter The above shows an overview based on the amount of freshwater available from nature without being affected by other variables such as pollution, population or available infrastructure (Molinares-Hassan and Echeverría-Molina, 2011).

In Colombia, the state policy in favor of women has had a number of positive aspects. It includes, for example, the creation of Counseling for the Equality of Women and laws such as the 1009 Law of 2006, designed to reduce discrimination against women. However, it is important to reflect on how effective they have been (Molinares-Hassan and Echeverría-Molina, 2011).

If access to water by marginal communities remains limited, even if there is an inclusion policy in favor of women and they participate in decision-making regarding how to administer and operate aqueducts and fresh water sources, this will affect their human rights, since the role they assume within the domestic administration of this resource will make their health and workload greater than that imposed on men. In other words, the different directives of international organizations, and the internal rules regarding service management show that this is not a question of discrimination against women, but rather of low coverage and poor quality service. This only affects women and girls because of existing gender relations in relation to the administration of water (Molinares-Hassan and Echeverría-Molina, 2011).

There are cases such as La Guajira, where women from Wayuu communities must walk long distances - at least three times a day - in order to look for water for the survival of their families, since climate change has caused a major impact on the country. The last few years have been very dry and up to 12 months have elapsed with no rain and high temperatures, as a result of which the Wayuu and Jagüeyes reserves have dried up, forcing women to look further afield for water.

Paradoxically, a dam costing $270 million USD was built in this area in 2010 with the aim of taking water to nearly 400,000 people. It stores 93 million cubic meters of water with a discharge rate of 7,760 liters per second. But the aqueducts remain dry and communities continue to lack water.

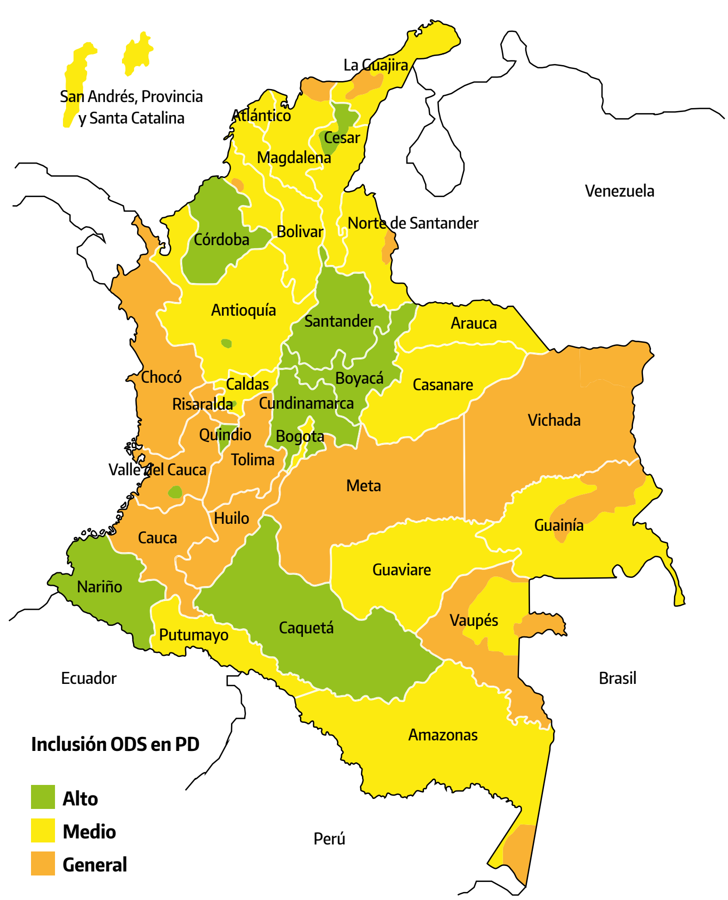
Just as there are complex cases such as the one in La Guajira, there are successful cases where women have achieved great success in accessing public services. One of these is the experience of "Women managers of public assets, a participatory experience in gender and water in El Hormiguero, Valle del Cauca, Colombia" (García and Bastidas, 2003), in which the determination and drive of women made it possible to undertake the water supply project and for them to become part of important positions in water user associations, and for men to assume non-directive positions, giving strength to the shared community work between men and women to provide basic services to its population.

5. Achieving Sustainable Development Goals

According to the UNDP report on the Millennium Development Goals (MDGs) of 2015, Colombia is among the Latin American countries that have made the most progress in this area. However, significant challenges remain. The advances have not been homogeneous throughout the country. Enormous differences persist in levels of well-being between population groups and regions. While one in four Colombians in urban areas is affected by poverty, in the rural area, the ratio is 1:2. Poverty is concentrated in the Pacific and Caribbean regions, where departments such as Chocó, Cauca and La Guajira - with large Afro-descendant and indigenous populations - have poverty rates above 50%, five times the rate found in Bogotá. Twenty-five per cent of the Colombian population lives in rural settings and 47% of them lack access to drinking water, 94% have no access to sewerage and sanitation, and 12% are illiterate. To make matters worse, the poverty rate among the displaced population is three times higher than the national rate and the extreme poverty rate four times higher (UNDP, 2015).

Colombia's progress enabled it to lead the proposals to define the 2030 agenda and the Sustainable Development Goals (SDGs), and the Peace Agree-

Figure 20. Inclusion of SDGs in the Territorial Development Plans



Source: DNP, 2016

ment incorporates 68 SDG goals through commitments and actions that seek to generate social and economic conditions for the consolidation of peace and the guarantees of non-repetition (DNP, 2017).

Objective 6, "Ensure availability and sustainable management of water and sanitation for all," is contained in the Peace Agreement within the framework of the Comprehensive Rural Reform (DNP, 2017).

Of 63 territorial plans analyzed (32 departmental and 31 capital cities), 100% of the Territorial Development Plans (PDT) included the SDGs and, on average, the PDT included 30% of the SDG targets applicable at the territorial level (110).

6. Successful experiences in improving water quality and quantity

6.1 Comprehensive Water Management Plan in the municipality of El Retiro (Antioquia)

Integral Water Resource Management (IWRM) plans are framed within the National Policy for the Integral Water Resource Management, whose aim is "to guarantee the sustainability of water, through efficient, effective management and use, linked to land use planning and the conservation of the ecosystems that regulate the water supply, regarding water as a factor of economic development and social welfare, and implementing equitable and inclusive participation processes": In other words, the National Policy recognizes the role of water as an integrating element of the territory (CTA, 2017).

Figure 21. Map of the Municipality of El Retiro

This project was implemented under the cooperation agreement between the Regional Autonomous Corporation of the Negro and Nare river basins (Cornare), the municipality of El Retiro and the Antioquia Science and Technology Center Corporation, between September 2016 and May 2017.

The municipality of El Retiro (**Figure 21**), which is part of the Oriente region of the department of Antioquia, is located in the Valles de San Nicolás de Cornare Subregion. It has 21 lanes distributed throughout 24,283.53 ha that border the municipalities of Rionegro, La Ceja, Montebello, Caldas and Envigado. Geographically, in the MAGNA-SIRGAS coordinate system, the municipality is delimited by the following coordinates: 1,150,964.76-1,173,168.94m North and 832,140.59-849,111.07m East.

The general objective was to formulate the Comprehensive Water Resource Management Plan of the Municipality of El Retiro in order to determine the status of water at the municipal level and define the strategies required for its management and efficient use in harmony with the environmental, economic and social dynamics of the municipality.

In order to achieve this objective, field work was carried out in order to collect information on the current environmental and socioeconomic status, in both urban and rural areas. Based on the existing cartography, maps of vegetation cover and areas of special management, water supply and environmental flows, a water regulation index, vulnerability index and water use index were prepared **(Figure 22**).

Water quality studies were also conducted, contamination sources determined and water samples analyzed to determine their physical and chemical status. The **Tabla 9** shows the water quality indexes reported.

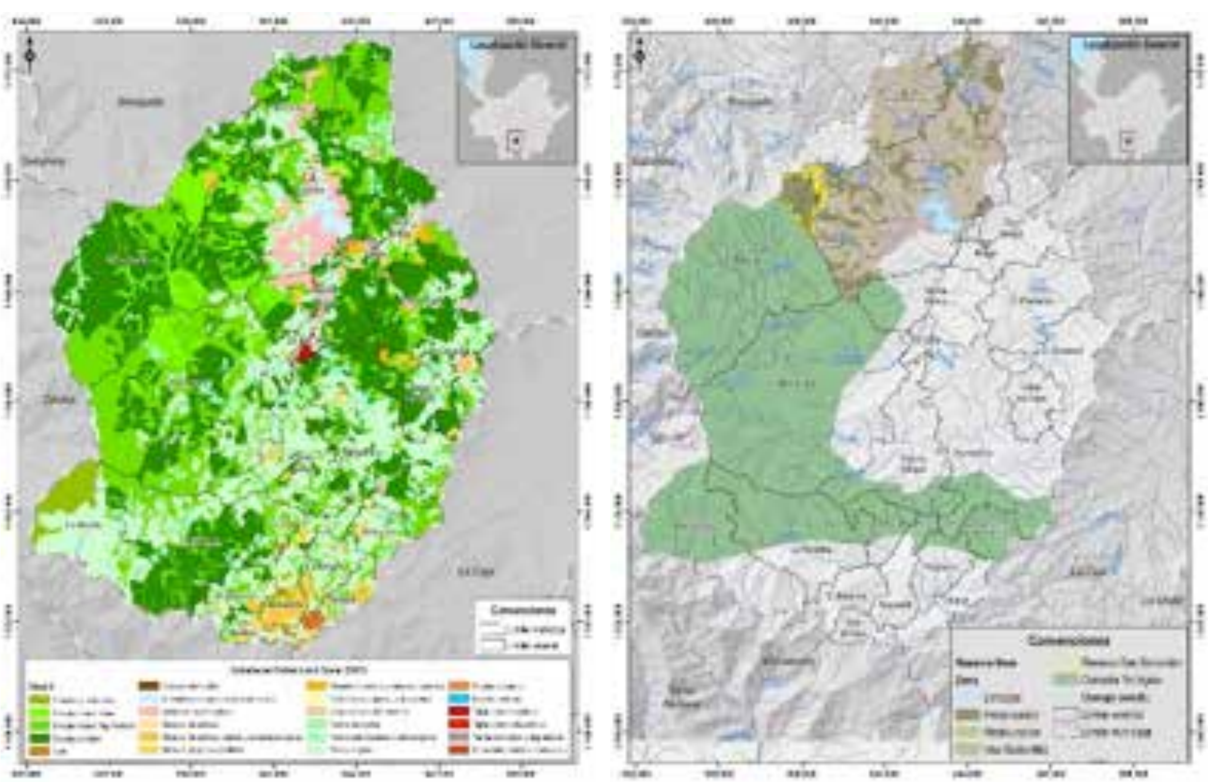
The quality of the ecosystem services offered by the region was also determined. Several working groups were organized with the community and a description made of the various sectors and

Table 9. Water quality indices reported

Sampling point	ICA	ICOMO	ICOSUS	ICOTRO	Year
Amapola School (Pantanillo basin)	Good	Average	Excellent	Eutrophic	1997
Rochera Amapola (Pantanillo basin)	Good	Good	Excellent	Eutrophic	1997
Truchera Pantanillo	Average	Average	Good	Eutrophic	1997
Bocatoma Pantanillo	Good	Excellent	Excellent	Eutrophic	1997
Puente colorado La Fe	Good	Average	Excellent	Eutrophic	1997
Puente La María La Fe	Good	Average	Excellent	Eutrophic	1997
Pantanillo, estación Guarango	Good	Good	Excellent	Eutrophic	2003
Pantanillo, Guarango1km past PuroCuero	Good	Good	Excellent	Mesotrophic	2004
Pantanillo River, near the La Fe reservoir	Good	Average	Excellent	Eutrophic	2004
Bocatoma acueducto AguaPlan	Good	---	---	---	2009
Estación Hierbal (after the municipal WWTP Villa Elena and before the La Fe reservoir)	Good	---	---	---	March 2011

Figure 22. Coverage and special management areas of the municipality of El Retiro

a) Plant cover b) Special management areas



actors that use water and have an impact and may be affected by decisions on water management. An analysis of governance was also undertaken in the municipality.

Finally, a prospective study was undertaken in the municipality of El Retiro in order to design future scenarios for the sustainable use of water resources and, thus be able to draw up a plan for integral water resource management in the municipality.

One of the fundamental characteristics of the project was the participatory process, so several meetings were held with the mayor and other administrative officials to discuss the results of the study and draw up an action plan to guide the municipality, in the short and medium term, the implementation of works that will make it possible to recover its waters and forests, in order to become an environmental sustainability model. Several meetings were also held with the community in order to publicize the results of the study and the programs the municipality should develop in the future for the good of the community (**Figura 23**).

Results of Management Plan and Recommendations

In accordance with the approach to the vision and integrated water management developed in the present study, a number of recommendations were put forward to complement the aspects developed in the programs and projects. The recommendations focused on the following areas: a) basin management and conservation, b) responsible community commitment, and c) wastewater treatment and recovery.

The previous results were delivered to the municipal authorities of El Retiro in a special session in which they broadly discussed what actions would be taken, in order for the municipality to successfully implement comprehensive water resource management including basin management, the education of the population regarding water use and saving and the recovery of municipality wastewaters.

Figure 23. Socialization of the project with the community of El Retiro (2017)

The management plan not only became the main project of the municipality, from which the majority of the decision-making for the sustainability of the latter is derived, but also serves as a reference for other municipalities in the region.

6.2 Water Quality Monitoring Protocol in Colombia

The National Water Resources Monitoring Program (PNMRH) is the instrument identified by PNGIRH to meet the need for systematic, coherent and appropriate monitoring to support the implementation and monitoring of the policy, together with the other programs in the National Hydrological Plan 2010-2022 (IDEAM and UN, 2016).

In the PNMRH, water quality is one of the fundamental axes in water resource monitoring, together with surface water, groundwater, lentic bodies and wetlands, bioindication and sediments. Water quality monitoring is crucial because it provides information on the quality conditions of currents, rivers, groundwater and aquatic systems, showing how these conditions vary over time at the national, regional and local levels, and in what way natural factors and human activities affect these conditions (WMO, 2013).

The PNMRH is therefore constituted within the framework that integrates and links the strategies and actions to improve the generation of knowledge and information for integral water resource management at the national and regional level in the country, and is the reference that guides and defines the route to follow to determine and monitor the behavior of the water cycle in Colombia, in terms of quality and quantity, in accordance with the National Integrated Water Resource Management Policy (PNGIRH) (IDEAM and UN, 2016).

In order to comply with this, it is necessary to strengthen the monitoring of water quality in Colombia within the framework of the PNMRH. To this end, the IDEAM designed a protocol for monitoring water quality, through a road map socialized in November 2017, which began to operate in 2018. A summary of the contents of this road map is given in **Figure 24.**

Figure 24. Summary of roadmap for monitoring surface water quality in Colombia

Source: CTA, 2017.

The road map begins with the five strategic lines defined in the PNMRH (IDEAM and UN, 2016), for each of which objectives are defined that can be achieved by undertaking activities to be carried out in a coordinated manner within different time frames. Each objective has an associated target and each activity creates products designed to achieve the goal within the stipulated planning horizon.

Planning horizons have been established in the short (2020), medium (2022) and long term (2030). The first two horizons are aligned with the PNGIRH and the PNMRH and, the last one, with the SDGs.

7. Conclusions and Recommendations

Colombian rivers and seas receive and transport pollutant loads of water used in the various socio-economic processes and mostly discharged without prior treatment. They also receive high volumes of sediments originated by erosion processes, either of natural origin or as a result of human action (Colombian Environmental System -SIAC-).

These actions are steadily increasing due to population growth and economic activities, and constant monitoring and control is required to take the necessary actions to address this problem in order to reduce its impact on natural and social processes, particularly human health (SIAC).

Water quality analysis is supported by the measurements undertaken by the IDEAM Network and information from economic sectors which systematically collect water quality data, represented and spatialized in indicators of water quality, and the potential threat of contamination. (SIAC).

In 2012, the biodegradable organic load (DBO5) discharged into water systems after treatment in Colombia amounted to 756,945tt/year, equivalent to 2,102 t/day. Industry accounts for 28% of this total, the domestic sector 69% and the coffee sector 3%. Eighty per cent of the BOD5 load was contributed by 55 municipalities, mainly by the metropolitan areas and major cities in the country: Bogotá, Medellín, Cali, Barranquilla, Cartagena, Bucaramanga, Cúcuta, Villavicencio and Manizales (SIAC).

The total national load discharged into the bodies of water of chemical oxygen demand (COD), after treatment, is 1,675,616 t/year, equivalent to 4,654 t/day, of which the industry contributes 37%, the domestic sector 61% and the coffee sector 2%. As for Total Suspended Solids, 1,135,726 t/year are dumped, equivalent to 3,154 t/day. The industrial sector contributes 7%, the domestic sector 91% and the coffee subsector 1%. In 2012, in 179 municipalities located in 15 departments, an estimated load of 205 tons of mercury was discharged into the soil and water, of which 27.5% corresponds to silver processing and 72.5% to gold processing.

The subzones most severely affected by the mercury discharges associated with gold processing correspond to: Magdalena (Brazo Morales), Bajo Nechí, Sucio, Bajo Nechí, the Taraza, Man, Quito, Cajón, Tamaná rivers and San Juan (SIAC).

Flow alterations will have different effects depending on the habitat, the region and the characteristic of the flow that is modified, making it difficult to offer general predictions about the response of communities or their persistence or resilience. Given that Andean rivers are under significant pressure to regulate the flow, the best way to guarantee adequate use and management would be for concessions and licenses to begin with eco-hydraulic and biological studies and studies on the alteration of previous habitats, which consider the interaction or synergy between hydroclimatic changes and artificial regulation processes, ensuring the permanence of true “ecological flows” in our rivers.

The polluting contributions of distributed or diffuse origin associated with agricultural expansion activities, mining and others related to deforestation can ostensibly be reduced through forest areas on the banks of streams. Forest restoration programs with native species must be implemented by the competent authorities, because this is the best way to contribute to the restoration of forests and, therefore, to the protection of the hydric resource associated with them.

Paying special attention to the regional hydroclimatic variability and the different geomorphological characteristics in each basin is essential when making decisions in context, so that they not only guarantee the physicochemical quality of water, but also its availability for aquatic communities and their ecosystemic services to society.

8. References

Albert, L.A. (1998). *Los plaguicidas persistentes y sus efectos a largo plazo.* II Simposio Internacional Sobre Agricultura Sostenible. México.

Alcaldía Mayor de Bogotá. Decreto 2811 de 1974 de Nivel Nacional por el cual se dicta el Código Nacional de Recursos Naturales Renovables y de Protección al Medio Ambiente.

Armenteras D., Rudas G., Rodriguez N., Sua S., & Romero M. (2006). Patterns and causes of deforestation in the Colombian Amazon. *Ecological Indicators.* Volume 6. pp. 353–368.

Banco Mundial (2008). *Informe sobre el desarrollo mundial 2008. Agricultura para el desarrollo.* Colombia: Banco Mundial, coeditado con Mundi-Prensa y Mayol Ediciones, S.A.

Biggs, J.F., Nikora, V.I. & Snelder, T.H. (2005). Linking scales of flow variability to lotic ecosystem structure and function. *River research and applications* 21, 283–298.

Blanco, J. F. (2003). Interannual variation of macroinvertebrate assemblages in a dry-forested stream in western Cordellera: a role for El Niño and La Niña. *Boletin ecotropica: Ecosistemas tropicales* No. 37, 3-30

Bustamante-Gil C., Ramírez-Restrepo J. J., Boltovskoy A., Vallejo A. (2012).. Spatial and temporal change characterization of *Ceratium furcoides* (Dinophyta) in the equatorial reservoir Riogrande II, Colombia. *Acta Limnologica Brasiliensia* 24 (2): 207-219.

Centro de Ciencia y Tecnología de Antioquia (CTA) (2017). *Diseño de una red de monitoreo de la calidad del agua superficial para el Área Hidrográfica Magdalena–Cauca y hoja de ruta para el fortalecimiento del monitoreo de la calidad del agua superficial en Colombia.* Medellín: Centro de Ciencia y Tecnología de Antioquia.

Centro de Ciencia y Tecnología de Antioquia (CTA), Municipio de El Retiro y Cornare (2017). *Informe final. Plan de Gestión Integral del Recurso Hídrico del Municipio de El Retiro.* Informe técnico. Medellín: Línea de Agua y Medio Ambiente. 250 pp.

Colombia Anfibia (2016). *Un país de humedales.* Volumen 1 y 2. Bogotá D.C.: Instituto Humboldt.

Comisión Europea (2007). *La Directiva Marco del Agua de la UE.* En: http://ec.europa.eu/environment/pubs/pdf/factsheets/wfd/es.pdf

Cuenca, N., Chavarro, F. y Díaz, O. (2008). El sector de ganadería bovina en Colombia. Aplicación de modelos de series de tiempo al inventario ganadero. *Revista Facultad de Ciencias Económicas: Investigación y Reflexión.* 16 (1):16-21

Departamento Nacional de Planeación (DNP) (1995). CONPES-2764. Informe Técnico. Bogotá D.C.

Departamento Nacional de Planeación (DNP) (2017). *Avances y desafíos para el seguimiento de los ODS en Colombia.* Presentación de Felipe Castro Pachón en el Primer Congreso Andino de Datos de los ODS. Marzo de 2017. Disponible en: https://www.dane.gov.co/files/images/eventos/ods/presentaciones/Alianzas/avances-desafios-seguimiento-ODS-colombia.pdf

Domínguez, E. y Fernández, H. (2009). *Macroinvertebrados bentónicos sudamericanos: Sistemática y biología.* Tucumán: Fundación Miguel Lillo. 654 pp.

ENA (2014). *Estudio nacional del agua: información para la toma de decisiones.* Bogotá D.C.

Galiano-Sedano F. (1976). *Investigación sobre el contenido de mercurio en aguas de ríos colombianos.* Informe Técnico. Proy. IIT/Colgate Palmolive/COLCIENCIAS. Bogotá D.C.

Galiano-Sedano F. (1977). Mercurio total en aguas de los ríos colombianos. *Rev IIT Tecnol* 105: pp. 9-18.

Galiano-Sedano F. (1979). Estudios sobre la contaminación de residuos industriales en aguas de ríos colombianos. *Rev IIT Tecnol* 117 pp. 40-47.

Galindo G., Espejo O. J., Ramírez J.P., Forero C., Valbuena C.A., Rubiano J. C., Lozano R.H., Vargas K.M., Palacios A., Palacios S., Franco C.A., Granados E.I., Vergara L. K. y Cabrera E. (2014). *Memoria técnica de la Cuantificación de la superficie de bosque natural y deforestación a nivel nacional. Actualización Periodo 2012-2013.* Bogotá D.C.: Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM). 56 pp.

García V, Mariela y Bastidas F, Sandra (2003). *Mujeres gestoras de lo público. Una experiencia participativa en género y agua en El Hormiguero, Colombia.* Universidad del Valle - Instituto de Investigación y Desarrollo en Agua Potable, Saneamiento Básico y Conservación del Recurso Hídrico – Centro Interregional de Abastecimiento y Remoción de Agua (CINARA), Marzo 17 de 2003.

Gil, M.J, A. M. Soto, J. I. Usma, O. D. Gutiérrez (2012). Contaminantes emergentes en aguas, efectos y posibles tratamientos. Revista: *Producción + Limpia* - Julio - Diciembre Vol.7, No.2 – 52-73

Guevara G., Lozano L., Reinoso G., Villa F. 2009. Horizontal and seasonal patterns of tropical zooplankton from the eutrophic Prado Reservoir (Colombia). Limnologica 39: 128-139.

Instituto de Hidrología, Meteorología y Adecuación de Tierras (HIMAT) (1978). Resolución 00337 del 4 de abril de 1978.

Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) (2002). *Perfil del Estado de los Recursos Naturales y el Medio Ambiente en Colombia.* Tomo I. Bogotá D.C.

Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) (2010). *Estudio Nacional del Agua 2010.* Bogotá D.C.

Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) (2011). *Hoja metodológica del indicador Índice de calidad del agua (Versión 1,00).* Sistema de Indicadores Ambientales de Colombia - Indicadores de Calidad del agua superficial. Bogotá D.C.

Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), MADS, U.D.C.A (2015). *Estudio nacional de la degradación de suelos por erosión en Colombia-2015.* Bogotá D.C.: IDEAM. 188 pp.

Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) (2015). *Estudio Nacional del Agua 2014.* Bogotá D.C. 496 pp.

Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) (2015). *Tomo II: Deforestación y afectación de los ecosistemas por ocupación del territorio y actividades económicas.* Bogotá D.C. 385 pp.

Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), INVEMAR, SINCHI, IIAP, IAvH (2016). *Informe del Estado del Medio Ambiente y de los Recursos Naturales 2015.* Documento Síntesis. Bogotá D.C. 75 pp.

Instituto Geográfico Agustín Codazzi-Corporación Colombiana de Investigación Agropecuaria (CORPOICA) (2002). *Zonificación de los conflictos de uso de las tierras en Colombia, capítulo II cobertura y uso actual de las tierras de Colombia.*

López-Muñoz M., Ramírez-Restrepo J. J., Palacio-Baena J. A., Echenique R., De Mattos-Bicudo C. y Parra-García E. (2016). Biomasa del fitoplancton eucariota y su disponibilidad para la red trófica del embalse Riogrande II (Antioquia, Colombia). *Rev. Acad. Colomb. Cienc. Ex. Fis. Nat.* 40(155): 244-253.

Lowe-Mcconnell, R.H. (1979). Ecological aspects of seasonality in fishes of tropical waters. *Symposia of the Zoological Society of London* 44, 219–241.

Lowe-Mcconnell, R.H. (1999). *Estudos Ecológicos de Comunidades de Peixes Tropicais.* São Paulo: USP. 535 pp.

Malato, S., Blanco, J., Estrada, C.A. y Bandala, E.R. (2001). Degradación de plaguicidas, en Miguel A. Blesa, *Eliminación de contaminantes por catálisis heterogénea,* Red CYTED VIII-G, pp. 269-284.

Mancera-Rodríguez, N. y Álvarez-León, R. (2006). Estado del conocimiento de las concentraciones de mercurio y otros metales pesados en peces dulceacuícolas de Colombia. *Acta Biológica Colombiana,* Vol. 11 No. 1, pp. 3-23.

Ministerio de Salud y Protección Social (MINSALUD), Subdirección de Salud Ambiental (2016). *Informe nacional de calidad del agua para consumo humano INCA 2015*. Bogotá D.C., Diciembre de 2016.

Ministerio del Medio Ambiente (2000). Informe Nacional sobre el Uso y Manejo de Plaguicidas en Colombia, Tendente a Identificar y Proponer Alternativas para Reducir el Escurrimiento de Plaguicidas al Mar Caribe. Proyecto PNUMA/UCR/CAR/Global Environment Facility.

Ministerio del Medio Ambiente (2015). *Objetivos de Desarrollo Sostenible: la erradicación de la pobreza.* Disponible en: www.minambiente.gov.co/index.php/gestion-integral-del-recurso-hidrico

Molina Sánchez, Nelson Enrique (2016). La pobreza en América Latina y Colombia. *Periódico El Campesino.* 3 de enero de 2016. Disponible en: www.elcampesino.co/la-pobreza-en-america-latina-y-colombia/

Molinares-Hassan, Viridiana y Echeverría-Molina, Judith (2011). El derecho humano al agua: posibilidades desde una perspectiva de género. 19 International Law. *Revista Colombiana de Derecho Internacional,* 269-302 (2011).

Molles, M.C. & Dahm Jr. C.N. (1990). A Perspective on El Niño and La Niña: Global Implications for Stream Ecology. *Journal of the North American Benthological Society* 9 (1), 68-76.

Narváez, J.F. (2015). *Dinámica de plaguicidas y algunos productos de degradación en los embalses La*

Fe y Riogrande II por medio de muestreadores pasivos. Tesis doctoral en Ingeniería énfasis ambiental, Universidad de Antioquia, Facultad de Ingeniería.

Narváez, J.F., López, C. y Molina, F. (2013). Passive Sampling in the study of dynamic and environmental impact of pesticides in water. *Rev. Fac. Ing. Uni. Ant.* 68: 147-159.

Narváez, J.F., Palacio, J., Molina, F. (2012). Persistencia de plaguicidas en el ambiente y su ecotoxicidad: una revisión de los procesos de degradación natural. *Gestión y Ambiente.* 15 (3): 27-38.

Northcote T. (1991). Eutrofización y problemas de polución. En: Dejoux, C., Iltis A (eds.), El Lago Titicaca: Síntesis del Conocimiento Limnológico. *Actual. Hisbol-ORSTOM,* La Paz: 563-572.

Organisation for Economic Co-operation and Development (OECD)/ Economic Commission for Latin America and the Caribbean (ECLAC) (2014). *Environmental Performance Reviews: Colombia 2014.* Disponible en: www.oecd.org/env/country-reviews/oecd-environmental-performance-reviews-colombia-2014-9789264208292-en.htm

Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO) (2012). *El estado mundial de la pesca y la acuicultura.* Consultado en Julio de 2015. Disponible en http://www.fao.org/docrep/015/al989e/al989e00.pdf

Paredes Zúñiga, Vanessa; Vargas Azofeifa, Ingrid; Vargas Quintero, María Consuelo; y Arellano Hartig, Federico (2010). Hidrogeoquímica en el acuífero costero del eje bananero de Urabá. *Revista Ingenierías Universidad de Medellín,* vol. 9, No. 17, pp. 51-62. Medellín. ISSN 1692-3324 - julio-diciembre de 2010. 228 pp.Pingali, P. (2006). *Agricultural Growth and Economic Development: a view through the globalization lens.* Presidential Address to the 26th International Conference of Agricultural Economists, Gold Coast, Australia, August 2006.

Pouilly, M., Barrera, S. & Rosales, C. (2006). Changes of taxonomic and trophic structure of fish assemblages along an environmental gradient in the Upper Beni watershed (Bolivia). *Journal of Fish Biology* 68, 137-156.

Programa de las Naciones Unidas para el Desarrollo (PNUD) (2015). *Objetivos de Desarrollo del Milenio.* Informe 2015.

Programa de las Naciones Unidas para el Desarrollo (PNUD) (2016). *Informe sobre Desarrollo Humano. Más allá de la escasez: Poder, pobreza y crisis mundial del agua.*

Pulido A. (1985). *Estudio de algunos parámetros ambientales de la explotación aurífera de Mineros de Antioquia en la cuenca del Río Nechí: Impacto ambiental preliminar.* Universidad de Antioquia.

Restrepo, J.D. & Escobar, Heber A. (2016). Sediment load trends in the Magdalena River basin (1980–2010): Anthropogenic and climate-induced causes, Geomorphology. Disponible en: https://doi.org/10.1016/j.geomorph.2016.12.013

Restrepo J.D., Kettnerb A.J., Syvitskib J.P.M. (2015). Recent deforestation causes rapid increase in river sediment load in the Colombian Andes. *Anthropocene*, Vol. 10, June 2015, pp. 13–28. Disponible en : http://dx.doi.org/10.1016/j.ancene.2015.09.001

Richter BD, Warner AT, Meyer JL, & Lutz K (2006). A collaborative and adaptive process for developing environmental flow recommendations. *River Res. Applicat.* 22: 297-318.

Ríos-Pulgarín, M.I. (2015). *Régimen hidrológico y estructura de la comunidad acuática del Río Guarinó, Magdalena medio colombiano, entre 2007 y 2010. Un estudio de caso para sistema de piedemonte andino durante fenómenos ENSO.* Tesis Doctoral en Ecología. Medellín: Universidad Nacional de Colombia, Departamento de Ciencias Forestales.

Ríos-Pulgarín, M.I., Arango-Jaramillo, MC., Barletta, M., y Mancera-Rodríguez (2016). The role of the hydrological cycle on the temporal patterns of macroinvertebrate assemblages in an Andean foothill stream in Colombia. *J. Limnol.,* 75(s1): 107-120. DOI: 10.4081/jlimnol.2016.1394

Ríos-Pulgarín, M.I., Barletta, M y Mancera, N.J. (2015). "The role of the hydrological cycle on the distribution patterns of fish assemblages in an Andean stream". En: Inglaterra *Journal of Fish Biology* ISSN: 1095-8649 ed: v.jfb_12757 p. 1-32.

Ríos-Pulgarín, MI., Gil-Guarín, IC, Barletta, M. y Mancera-Rodríguez Néstor J. (2016). Effects of the hydrological cycle on the phycoperiphyton assemblage in an Andean foothill stream in Colombia. *J. Limnol.,* 75(s1): 121-136. DOI: 10.4081/jlimnol.2016.1429

Ríos-Pulgarín, M.I. Barletta, M. and Mancera-Rodriguez, N.J. (2016). Hydrological cycle effects on the aquatic community in a Neotropical stream of the Andean piedmont during the 2007–2010 ENSO events. *Journal of Fish Biology* (2016) doi:10.1111/jfb.12885, available online at wileyonlinelibrary.com

Rivera-Rondón C. y Díaz-Quirós Y.C. (2004). Grandes taxones de fitobentos y su relación con la hidrología, física y química de pequeños ríos andinos. Universitas Scientiarun, *Revista de la Facultad de Ciencias Pontificia Universidad Javeriana* 9, 75-96.Rodríguez-Sambrano A.P., Aranguren-Riaño N.J. (2014). Comunidad planctónica de un embalse con alta tensión ambiental: La Playa, cuenca alta del Río Chicamocha (Tuta, Boyacá), Colombia. *Biota Colombiana* 15 (2): 95-110.

Roldán, G. y Ramírez, J.J. (2008). *Fundamentos de limnología neotropical.* Medellín: Editorial Universidad de Antioquia. Segunda edición. 440 pp.

Rolim, S. (2000). *Sistemas de lagunas de estabilización.* Bogotá D.C.: Mc Graw-Hill. Primera edición.

Romero M., Cabrera E. y Ortiz N. (2008). *Informe sobre el estado de la biodiversidad en Colombia 2006-2007.* Bogotá D.C.: Instituto de Investigación de Recursos Biológicos Alexander von Humboldt. 181 pp.

Superintendencia de Servicios Públicos Domiciliarios (SSPD) (2014). RESOLUCIÓN SSPD – 20141300018055 DE 2014 (mayo 29). *Diario Oficial* No. 49.171 del 3 de junio de 2014.

Thomann R.V. (1982). *Physico-Chemical and Ecological Modeling of the Fate of Toxic Substances in Natural Water Systems.* Prepared for the Conference on Modelling the Fate and Effect of Toxic Substances in the Environment. Copenhaguen (Denmark).

Tomin, C.D.S. (1997). *The Pesticide Manual, a World Compendium.* Croydon, UK: British Crop Protection Council. 11a Edición.

Universidad de Antioquia (1988). *Estudio del impacto ambiental por minería en el bajo Cauca y nordeste antioqueño.* Centro de Investigaciones, Universidad de Antioquia 4: pp. 29-39.

Vásquez C., Ariza A. y Pinilla G. (2006). Descripción del estado trófico de diez humedales del altiplano Cundiboyacense. *Universitas Scientiarum. Revista de la Facultad de Ciencias* 11 (2): 61-75.

Villabona-González S., Buitrago-Amariles R., Ramírez-Restrepo J.J. y Palacio-Baena J.A. (2014). Biomasa de rotíferos en dos embalses con diferentes estados tróficos (Antioquia, Colombia) y su relación con algunas variables limnológicas. *Actualidades Biológicas* 36 (101): 149-162.

Villabona-González S., Ramírez-Restrepo J.J., Palacio-Baena J.A. y Costa Bonecker C. (2015). Respuesta de la biomasa zooplanctónica a los gradientes de estado trófico y precipitación de un embalse tropical. *Rev. Acad. Colomb. Cienc. Ex. Fis. Nat.* 39(152): 374-388.

Costa Rica

Costa Rica is a land of contrasts: on the one hand, the country has been acknowledged for its efforts in the environmental field and conservation, as a result of which it is widely considered a green country and it has also achieved excellent drinking water coverage. On the other hand, however, the country has severe pollution in most of its urban and some of its rural rivers. Fortunately, although a great deal of work remains to be done, significant efforts are being made to address these problems.

Reserva de Monteverde, provincia de Puntarenas, Costa Rica © iStock

Water quality in Costa Rica

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1. General Introduction

1.1 Background, context and main problems

In Costa Rica, water has been used for human consumption, agriculture, tourism, industry, transportation and hydroelectric generation. The first four of these uses have the greatest potential to significantly alter the quality of the resulting water.

As happened in other parts of the world, the supply of drinking water through the construction of aqueducts was possibly the first step in the construction of infrastructure for water resource management in Costa Rica. The Guayabo National Monument, in the city of Turrialba, contains an aqueduct used from 1000 BCE to 1400 CE.

In the 17th century, water was used for domestic supply, livestock raising and agriculture. During the 18th century, livestock activity developed in the North Pacific, whereas in the Central Valley, water from rivers and streams (streams) was used in agriculture. In the 19th century, water was mainly used in coffee and banana monocultures and for washing gold as part of the mining process. The watercourse of rivers served as a means of transport for colonizing the northern zone, while the high water potential contributed to the generation of hydroelectric power. However, the type of agricultural production technology, coupled with the lack of awareness on the part of the population led to the deterioration of the quality of water resources, particularly surface water (Vargas Sanabria, 2001).

Perhaps the most obvious example of water pollution from agricultural causes was coffee activity (the leading Costa Rican export product for many years). Due to its impact on health, this pollution was strenuously opposed by the population, which created an environmental conflict (Montero Mora and Sandí Morales, 2009). This pollution continued to be a problem for a long time, affecting many rivers, until a series of actions were implemented to halt the dumping of coffee products into waterbodies, which include Resolution No. 210 of July 2, 1997, in which the Office of the Attorney General of the Republic ordered the Minister of Health to enforce legal actions to defend national waters due to contamination by the coffee processing agroindustry.

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Due to the lack of quality control, “Water was often an agent of death since it transported bacteria such as cholera, which caused nearly 10 000 deaths in 1856” (Vargas Sanabria, 2001). The first modern aqueduct was inaugurated in 1868 in San José (Vargas Sanabria, 2001). In 1915, five years before the construction of the first water treatment plant in the city of San José, renowned scientist Clodomiro Picado Twight, together with his collaborator Francisco Sancho, undertook the first microbiological and physical-chemical analyses of drinking water for this city (Picado Twight, 1915).

The first sewerage works were inaugurated in 1911, and were subsequently constructed in the main cities of Valle Central, at the beginning of the 1940s (Mora-Alvarado and Portuguez-Barquero, 2016). The treatment system was then built through stabilization ponds in Guanacaste (1959). Unfortunately, the treatment plants in Valle Central were abandoned in 1963 (Mora-Alvarado, 1992), thereby increasing the organic contamination of the basin formed by the Virilla and Tárcoles rivers. However, thanks to an agreement between the government and the National Institute of Aqueducts and Sewers, known as AyA (1972-1975), facultative ponds were built in a number of cities outside Valle Central, and the Limón Submarine Emissary was inaugurated in 2004 (Araya *et al*., 2009). Yet despite these works, Costa Rica ranks nearly last in treatment with conventional systems in Latin America (Reynolds, 2002, Mora-Alvarado and Portuguez-Barquero, 2016). Paradoxically, according to the Joint Monitoring Program of the United Nations Children’s Fund (UNICEF) and the World Health Organization (WHO), Costa Rica occupies one of the highest places in the region as regards the concept of “Improved Sanitation Instruments”. This is because the UNICEF/WHO concept covers the *disposal* of excreta, whether through sanitary sewers, untreated sewage, septic tanks or latrines, and does not focus on water *treatment* (UNICEF and WHO, 2006).

In contrast to the large percentage of drinking water supply coverage nationwide (93.5%), the most serious and visible problem of water quality in Costa Rica is the low percentage of wastewater treatment and the resulting contamination of rivers, particularly in urban areas. In the past four years, significant efforts have been made, including the start-up of the Los Tajos Treatment Plant and the installment of sewerage networks, collectors and sub-collectors for 11 of the San José cantons, from 4.2% wastewater sanitation coverage in 2014 to 12.4% in 2018. In 2016 the National Wastewater Sanitation Policy was approved (AyA, MINAE and MS, 2016), accompanied by a National Plan for Investments in Sanitation 2016-2045 (AyA, 2017b).

In recent years, significant efforts have been made to comply with the Millennium Development Goals and the Sustainable Development Goals (SDGs), including the provision of drinking water, sanitation and hygiene service. Although the situation in Costa Rica with respect to these aspects is better or similar to that of countries in the Central American region (given the country’s achievements in aspects such as drinking water supply, adequate basic sanitation to eliminate open fecalism and gender issues), serious problems related to the quality of surface water in rivers have yet to be solved. Moreover, more studies are required to determine the extent of groundwater contamination more accurately. The differences in the quality of drinking water available, as well as the wastewater in urban and rural areas is also an aspect requiring further study at the national level. Factor such as: a) administration systems in rural and urban aqueducts, b) natural conditions of surface and groundwater sources, c) sources and types of contamination, and d) the prevalence of different sanitation systems (sewage system, septic tank or septic tanks), account for the differences in water quality in urban and rural areas. The first inter-institutional efforts were recently made to measure the quality of the country’s waterbodies. Lastly as will be seen in later sections, there is a large body of legislation related to the quantity and quality of water resources, although in practice, these laws and regulations are often not enforced, due to several factors, including the low capacity for control of the authorities in charge, and the lack of human and economic resources.

1.2 Chapter objectives

The main objective of this chapter on water quality in Costa Rica is:

- To provide a diagnosis of the current and historical status of water quality in the country.
- Specific objectives include:
- Providing a vision of the laws and regulations related to water quality.

- Identifying the main problems impacting water quality in the country.
- Relating water quality to its social and economic impacts.
- Verifying the country's compliance with SDGs.
- Providing examples of challenges and successful experiences in the country.

The focus of the chapter is to summarize historical and current information on the main challenges in the country and the way they are addressed. The aim is to provide an overview of the situation, by way of a comparison with the results in the other American countries included this book. The idea is to seek or provide experiences that can be replicated in other parts of the continent.

2. Institutional authority and water quality governance

2.1 Legal framework

Detailed information on the laws, executive decrees and other regulations in the country is available in the Costa Rica System of Legal Information on the Attorney General's Office at http://www.pgrweb.go.cr/scij. The Costa Rican legal framework on water quality includes the following laws:

Water Law (Law No. This law has all the regulations related to water use and concessions. A new law was voted on by Congress in November 2017, but the Constitutional Tribunal described it was inviable due to the procedure used for its approval.

Article 114 of the Water Law states that the concessionaire of the latter must build public works such as bridges and culverts, and if they cross other aqueducts, they should not modify their quantity or quality.

General Drinking Water Law (Law No. 1634, 1953). Article 3 mentions that, "*it is the responsibility of the Ministry of Public Health and the AyA to select and locate the water destined for the pipeline service, the type of treatment of the latter and the type of potable water system to be built. It will also be responsible for the recommendations that must be given from the health point of view including the design, construction, operation and maintenance of drinking water systems*".

The Law stipulates that the AyA and the Ministry of Health must guarantee the quantity and quality of drinking water in works constructed partially or totally with funds from the Treasury or another form of guarantee from the government. Facilities, buildings or works included in areas close to the supply sources that affect the physical or chemical composition of water are prohibited.

General Health Law (Law No. 5395, 1973): Article 148 of the General Health Law (LGS) states that "*every person must also be diligent in complying with personal hygiene practices designed to prevent the emergence and spread of communicable diseases; preventing the contamination of vehicles of infection such as water and food, the infestation and contamination of movable and immovable property and the formation of foci of infection*". The law thereby implies that water pollution must be avoided by all people.

This law contemplates permit requirements for industrial or scientific activities to prevent water contamination by natural or artificially radioactive substances. Environmental alterations that produce a decrease in the quality or aesthetics of water, or make this good unusable, affecting possible future uses, health, flora or fauna, are also prohibited.

Title III, Chapter I of the LGS entitled "*Water for human use and consumption and the duties and restrictions to which people are subject in the matter*" in Article 264 states that "*water is a public good and its use for human consumption will have priority over any other use*". This chapter defines what is regarded as drinking water, the requirements of drinking water systems and which institutions are responsible for their administration and supervision. It is explicitly forbidden to contaminate water supplies and add anything foreign to water (except elements that improve water quality); water quality is regulated for diverse various such as food production, the operation of spas, crenotherapy establishments, swimming pools and similar establishments.

Article 275 of this chapter states that "*it is prohibited for any natural or legal person to contaminate surface, ground or territorial waters, directly or indirectly, by means of drainage or the voluntary or negligent discharge or storage of liquid, solid, gaseous, radioactive or non-radioactive waste, wastewater or substances of any nature which, by altering the physical, chemical and biological characteristics of water,* *make it dangerous for the health of people, and terrestrial and aquatic fauna or unserviceable for domestic, agricultural, industrial or recreational uses"*. Solid or liquid polluting waste may only be discharged with permission from the Ministry of Health. Contamination of watersheds is prohibited. Every person who owns real estate must provide the necessary drainage so that water does not become a source of infection. Owners must guarantee proper excreta and sewage disposal.

Organic Law of the Environment (Law No. 7554, 1995): Chapter III, entitled "Water", states that "*water is in the public domain, and its conservation and sustainable use are of social interest*". Certain criteria must be adopted for the conservation of water resources, such as the protection and conservation of ecosystems and the maintenance of the equilibrium of the water system. These criteria must be used in the design and implementation of any water resource management, the granting of concessions and permits for the use of the resource and soil and water conservation practices and works.

Chapter XV, entitled "Contamination", stipulates that the state, municipalities and other public institutions will prioritize the establishment of services such as excreta, sewage and rainwater disposal. "*In order to prevent water contamination, the competent authority shall regulate and ensure that water management and use do not alter the quality and quantity of this resource, according to the limits set in the corresponding regulations*". Moreover, "*wastewater of any origin must receive treatment before being discharged into rivers, lakes, seas and other bodies of water; in addition, it must reach the quality established for the receiving body, according to its current and potential use and its future use in other activities*". In any water management or use, the responsibility for the treatment of discharges corresponds to whoever produces the pollution. Individuals, legal entities, public or private are obliged to ensure that watersheds are not contaminated.

Forest Law (Law No. 7575, 1996): This law mentions the protection of water for urban, rural or hydroelectric use as one of the uses of forests. It establishes a forest fund to "*implement actions and projects designed to reduce pollution and the deterioration of renewable natural resources (soil, air and water)*". Article 33 of this law defines the protection areas that constitute fringes around the various waterbodies, including springs, streams, rivers, lakes and reservoirs as a measure to reduce the impact on water by preserving the forest cover near water sources.

These protection areas are defined by the waterbody and the inclination of the terrain as follows: a) 100 meters measured horizontally around permanent springs; b) 15 meters in rural areas and 10 meters in urban areas on either side of riverbanks, streams and streams if the terrain is flat and 50 meters in the event of rough terrain; c) 50 meters (measured horizontally) on the banks of lakes and natural reservoirs, as well as in artificial lakes and reservoirs built by the state. The limits for the recharge areas and the aquifers of the springs are determined in the complementary regulation to this Law.

Biodiversity Law (Law No. 7788, 1998): This law mentions payment for environmental services (including actual or potential water services), authorizing the collection of costs from users for these services. It includes wild protected areas such as geographic zones dedicated to the conservation of natural, cultural and ecosystem resources (including water resources).

A number of executive decrees (regulations) related to the issue of water quality are described below. In these decrees the various activities are regulated and the actions to be taken are detailed, together with the respective methodologies. In addition, each one establishes the entities responsible for its implementation and the composition of the technical committees in charge of reviewing and modifying each of these decrees.

Wastewater Discharge and Reuse Regulation (Decree No. 33601, MINAE-S, 2006): Given the importance of water and the fact that its contamination is one of the problems with the greatest negative impact on the environment, this regulation stipulates that wastewater discharges from any source must receive treatment before being discharged into rivers, lakes, seas and other waterbodies. They must also achieve the quality established for the receiving body, according to its current and potential use.

The regulation establishes the obligation of polluters to treat wastewater and prepare operational reports. The universal and complementary physical-chemical parameters to be measured are mandatory. Universals include the following: flow rate, biochemical oxygen demand, chemical oxygen demand, hydrogen potential, fats and oils, settleable solids, total suspended solids, methylene blue active substances and temperature. Complementary parameters required in particular applications include: total nitrogen, phosphates, heavy metals, cyanide, phenols, hydrocarbons, sulfides, fecal coliforms and color. Tables are included with the maximum limits allowed for universal and complementary parameters.

There is one chapter on the conditions and classification of wastewater reuse and another that describes the regulations related to sampling and analysis. There is also a standard for the content, procedure, preparation and signing of operational reports.

Regulation for the Evaluation and Classification of Surface Waterbodies (Decree No. 33903, MINAE-S, 2007): This decree proposes the technical tools for evaluating the quality of the surface waterbodies in the country, with an emphasis on lotic bodies (rivers and streams or streams), based on the measurement of physical-chemical parameters and the analysis of benthic macroinvertebrates, using the Dutch index and the BMWP-CR, respectively. It establishes the methodological details for taking samples, analyzing them, and calculating the indices and the ranges for the classification of water quality. It also defines the complementary parameters to be measured and the various classes according to the ranges obtained, as well as the potential uses for each of the five possible classes. The entity responsible for its implementation is the Ministry of Environment and Energy (MINAE), through its Water Directorate, and the Ministry of Health (MS) (MINAE/MS, 2007).

Regulation of the Environmental Fee for Discharges (Decree No. 34431, MINAE-S, 2008): In Article 4 of this decree, this fee is defined as "*an economic instrument for environmental regulation, based on the 'polluter pays' principle, which seeks the social objective of achieving a healthy, ecologically balanced environment, in accordance with the provisions of Article 50 of the Political Constitution, through the payment of a fee in cash, to those who use the environmental service of waterbodies, a public good, for the transport, and elimination of liquid waste originating at the point of discharge, which can cause harmful effects on water, related ecosystems, human health and productive activities*". The decree defines all the details related to the procedures for enforcement of the fee, and states that the resources derived from it will be administered by the MINAE and implemented, after consulting a Board of Directors, taking into account environmental and sanitation priorities.

Regulation for Drinking Water Quality (Decree No. 38924-S, 2015): This decree is designed "*to establish the maximum levels of components or characteristics of water that may pose a risk to the health of the community and problems for the preservation of water supply systems for the benefit of public health*". To achieve this objective, the recommended and maximum admissible values are established for the various physical, chemical, biological and microbiological parameters in their aesthetic, organoleptic aspects as well as their significance for health. The minimum frequency of analysis and the number of samples, as well as the doses for disinfection are also indicated.

2.2 Public institutions

Costa Rica has a series of institutions that govern the administration and control of water resources:

The person responsible for water in Costa Rica is the Minister of Environment and Energy (MINAE), since his brief includes the planning and execution of natural resource and environmental protection policies of the government, as well as direction, control, supervision, promotion and development in this field, specifically as regards surface and underground water. This is based on Law 7152 of the Constitution, issued in 1990. Through the Vice-Ministry of Water and the Water Directorate, this ministry allocates water concessions for various uses, charges for water use and discharges and supervises the quality of surface and groundwater bodies. The mission of the Directorate of Environmental Quality Management of MINAE is to "*design and implement the conceptual, technical and legal tools for the definition of strategies and public policies regarding environmental quality that promote the prevention, mitigation and reversal of the degradation of water, air and soil. It also establishes the monitoring and control mechanisms that guarantee compliance with the latter*".

The person responsible for ensuring the quality of water for human consumption and the quality of wastewater discharges is the Minister of Health, according to the Organic Law No. 5412 of the Ministry of Health, 1973. This is due to the fact that his attributions include everything related to the policies and technical norms and exercising jurisdiction and technical control, as well as undertaking the actions and activities to ensure public and environmental health. This is achieved through the Directorate of Protection of the Human Environment.

The AyA, in accordance with its constitutive Law, is the technical governing body responsible for drinking water supply and wastewater sanitation services as well as their operator. Its mission is to "*ensure universal access to drinking water and sanitation in a manner that is committed to health, the sustainability of water resources and the economic and social development of the country*". Wastewater collection and treatment is the responsibility of the AyA, in places where it provides water supply service. Its Constitutive Law stipulates that the AyA is responsible for: the collection, evacuation, treatment and disposal of domestic liquid waste; defining the sanitary sewer system as collection networks, collectors, treatment plants and everything required to receive, transport and treat sewage produced in households or workplaces.

In addition to the AyA, there are three types of entities responsible for drinking water supply and wastewater treatment services: 1) the Heredia Public Services Company (ESPH), 2) the Administrative Associations of Water Supply Systems and Communal Sewers (ASADAS), also known as Committees and/or Administrative Associations of Rural Aqueducts (CAARs), and 3) Municipalities. AyA is responsible for most of the distribution and sanitation in urban areas (approximately 50% of the population). The AyA also has a Sub-Department responsible for overseeing and supervising the management of ASADAS, entities created by the Law of Associations, which provide public service. They are non-profits, and apply the rate established by the Public Service Regulating Authority (ARESEP). The mission of the ESPH is to "*to provide quality services in the water, energy, sanitation, infocommunications and other sectors, which contributes value and development for society through the continuous improvement of their management*". In its current state, the ESPH is a legal hybrid: a municipal company in the province of Heredia which manages public resources and whose assets comprise all the aqueducts in the associated municipalities.

The National Service of Groundwater, Irrigation and Drainage (SENARA) was conceived from its outset as an institution with a strategic role in water management, both at the level of its direct participation and in coordination with other institutions in the agricultural and environmental sectors. It promotes agricultural development in the country, helps implement agricultural development projects, and attempts to create the rational, democratic modification of land ownership through the creation of irrigation districts. With regard to groundwater, SENARA is the technical-scientific body that researches, defines and protects aquifers and their recharge zones at the country level.

Other institutions related to water resources in Costa Rica include the Costa Rican Electricity Institute, the Climate Change Directorate, the National Meteorological Institute, the Ministry of Agriculture and Livestock and the Public Services Regulatory Authority.

2.3 Relations with NGOs and universities (scientific research)

In Costa Rica, most scientific research is conducted at three public universities: the Universidad de Costa Rica (UCR), the Universidad Nacional (UNA) and the Tecnológico de Costa Rica (TEC, formerly ITCR). Each of the latter have research centers, institutes and laboratories that undertake research projects related to the country's water resources. The analytical laboratories of CICA (Center for Research in Environmental Pollution, UCR), CEQUIATEC (Center for Research and Chemical and Microbiological Services, TEC), IRET (Regional Institute for Studies on Toxic Substances, UNA), and LASEQ (Analysis and Chemical Services Laboratory, UNA) and LAA (Laboratory of Environmental Analysis, UNA), have the respective accreditations of the Costa Rican Accreditation Entity (ECA) for various tests related to water quality analysis for different uses. Research on water issues is also conducted at other private universities, such as the Universidad EARTH (School of Agriculture of the Humid Tropical Region) and CATIE (Tropical Agricultural Research and Teaching Center).

Research conducted in the field of water is mainly related to the quality of surface waterbodies, especially in the Greater Metropolitan Area (e.g. Herrera *et al.*, 2013; Mena-Rivera *et al.*, 2017). Other studies have been carried out on the effect of pesticide use on different types of plantations (e.g. Castillo *et al.*, 2000, 2006; Echeverría *et al.*, 2012; Pérez-Castillo *et al.*, 2013; Rasmussen *et al.*, 2016, Carazo-Rojas *et al.*, 2018) and the use of biological indicators in the evaluation and monitoring of the quality of surface waterbodies, both rivers and lakes (e.g. Mafla, 2005; Michels *et al.*, 2006; Fernández and Springer, 2008; Stein *et al.*, 2008; Sedeño-Días *et al.*, 2012; Rizo-Patrón *et al.*, 2013, Gutiérrez-Fonseca and Lorion, 2014; Umaña-Villalobos, 2014; Céspedes-Vargas *et al.*, 2016; Kohlmann *et al.*, 2015; Svensson *et al.*, 2017; Umaña-Villalobos and Farah-Pérez, 2018).

Researchers with extensive experience from various universities collaborate regularly with central government and local governments, as well as certain Non-Government Organizations (NGOs) in the formulation, review and implementation of initiatives related to water resource management.

2.4 Monitoring and database

Given that most of the initiatives to evaluate the quality of inland waters in the country have been isolated efforts and specific studies for short periods, the need to establish a National Monitoring Program that includes the periodic evaluation of surface and groundwater quality was identified.

The National Plan for Quality Monitoring of the Surface Waterbodies of Costa Rica was prepared with the support of a group of professionals and academics specializing in water resources issues, from public universities and state institutions. This Plan defines the monitoring sites and establishes the frequency of the samplings, as well as the parameters to be measured in each of them, based on Decree 33903-MINAE for the Regulation of Evaluation and Classification of Surface Waterbody Quality. It began to be implemented in 2015, with the support of the three public universities (TEC, UCR and UNA), which undertake sampling and analysis of samples for a five-year period.

Their implementation is expected to generate baseline information (national database) to classify water quality in each of the country's 34 basins and thereby regulate the appropriate use of water resources. To ensure public access to the data generated from these monitoring, maps are being drawn up on the DA website (http://www.da.go.cr/), where the results for each of the sites included in the Plan will be available for consultation.

3. Main problems impacting water quality in the country

The main point of determining the quality of mainland waters continues to be the impact on human health, since it is mostly these sources that are used to supply the country's population. Potability criteria prevail when chemical analyses are conducted of potential sources of use (Executive Decree No. 38924-S, 2015). The cases where official entities have identified and quantified other possible sources of contamination in waterbodies are those in which human health has been compromised, as happened in Aguas Zarcas, in the northern zone of the country, due to the natural occurrence of arsenic in groundwater (Mollinedo, 2013).

Since September 2015, the country has had an updated regulation for drinking water quality (Executive Decree No. 38924-S, 2015). This regulation clearly defines the variables that must be quantified in water sources, both surface and ground, as long as they are intended for human consumption or in processes whose recipient is human beings. Costa Rica also has a Regulation for Wastewater Discharge and Reuse, the latest version of which was published in 2017. This regulation details the variables that must be quantified and the maximum limits allowed for the different types of wastewater according to the use they have had and the type of receiving body.

3.1 Urban waste

As regards surface waterbodies, there are differences between the rivers that run through urban areas and those that occur in rural areas. There are differences in terms of the contaminants with greatest visibility, which attract most media attention, such as solid waste of human origin: plastics, pieces of domestic materials, fragments of automotive vehicles and the remains of building materials, the most obvious example being what happens in the basin of the Río Grande de Tárcoles, since most of its tributaries run through the Greater Metropolitan Area (Soto, 2012; Gutiérrez Wa-Chong, 2018).

These rivers or small urban streams have been used for decades as landfills that receive much of the waste from the Metropolitan Area, which exemplifies the poor management of solid waste throughout the country, as well as the lack of a proper wastewater collection and treatment system. This situation is also affected by poor urban planning, which has permitted the existence of houses on the edges of these waterbodies. These homes, the vast majority of which are illegal, lack waste collection systems, as a result of which waste is directly dumped into rivers.

3.2 Fecal contamination

It is common for unpleasant odors to increase in rivers in the urban area during the dry season, due to the illegal dumping of wastewater with a high content of organic matter, in many cases with fecal material of human origin. In this regard, the National Water Laboratory of the AyA has issued reports in which it reports the quality of waters in various basins in the country, showing the high content of fecal coliforms in many of the sites sampled. For example, in the Tempisque River, discharge from the Liberia, Cañas and Bebedero rivers contributes a significant amount of fecal matter into its basin (Mora-Alvarado *et al*., 2002). Mora-Alvarado (2004) also reported a high concentration of fecal coliforms in the Río Grande de Tárcoles basin. Samplings in estuaries throughout the country were included in this study. In just under half of them, fecal coliforms were identified in high quantities, and samples were taken in reservoirs and lakes, the latter two being the sites with the best microbiological quality in the study. Other published studies, such as those by Calvo-Brenes and Mora-Molina (2012) and Barrantes *et al*., (2013) corroborated the high level of fecal contamination in many rivers in the Greater Metropolitan Area, particularly the María Aguilar and Torres Rivers.

3.3 Oil hydrocarbon pollution

As a result of human activities related to navigation and electric power generation, the presence of hydrocarbons in coastal sites has been reported, such as the Moín channels in the Caribbean and Estero de Puntarenas in the Pacific (Acuña *et al*. al., 2004). Although this is not desirable, it is expected in areas with high movement of vessels, to transport both passengers and raw materials. The presence of hydrocarbons has also been reported in surface and groundwater sources (Mora-Alvarado and Portuguez, 2010). These cases have been associated with human error and even negligence. Sites where hydrocarbons have been quantified include the Quebradas River in Pérez Zeledón, near the Moravia Sites, the Llano reservoir in Orosi, San Ignacio de Acosta, and the aquifer supervised by the Public Services Company of Heredia, contaminated with gasoline and diesel, which attracted a great deal of media attention. The majority of these cases have been point pollution events.

3.4 Rural zones

With regard to water sources in rural areas, the situation of solid waste is less dramatic, due to the simple fact of having a lower population density, but here the problem lies in the fact that many of these sources are primarily for agricultural use. This competition for water makes it necessary to resort to groundwater sources in these areas. Extensive crops in the area, which nonetheless are intensively produced, such as sugarcane, banana, oil palm or pineapple, are activities that require the use of an abundance of fertilizers and pesticides. In the case of fertilizers, their presence in surface waters has rarely been studied, for methodological reasons linked to the high solubility in water of the compounds used. These chemical substances (nitrogenous and phosphorous) are easily transported by runoff, especially in areas with high precipitation, which turns nearby rivers and reservoirs in the recipients of these substances. It is therefore not easy to demonstrate the presence of these sources of pollution in surface waters, unless the characteristics of the waterbody enable their main effect to be seen: eutrophication, the excessive increase of nutrients in water (mainly nitrate, ammonium and phosphate) and consequently the growth of aquatic plant species. These conditions may be the best indications of alterations in the natural concentration of these nutrient substances in water, while seasonal monitoring is the best way to record these variations (Jones *et al*., 1993, Umaña *et al*., 1999).

Despite this difficulty, for the State of the Nation report, Castillo *et al*. (2012) compiled the most relevant information on the quantification of nitrate, presumably of agricultural origin, in various bodies of surface and groundwater. The presence of nitrate was reported in wells in areas devoted to agriculture in both the Caribbean region and in Chorotega (Guanacaste). In terms of surface water, the anomalous presence of this nutrient was also measured in rivers and streams in Cartago, Guanacaste and Limón. Guevara and Herrera (2014) reported high concentrations of nutrients in some streams and rivers in the canton of San José, although because they are rivers located in the urban area, the mismanagement of domestic wastewater may be altering the natural concentration of these substances rather than agricultural activities.

3.5 Arsenic, an important case in public health

Due to the geological context of the country, characterized by volcanism and active faulting, arsenic of natural origin exists in the groundwater in certain regions in the north. The origin of arsenic has been studied by Alpízar and Vargas (2017) in a research project undertaken at the University of Costa Rica, through the Specific Agreement on Technical Cooperation with the AyA (2013-2016). This project characterizes the zones of Aguas Zarcas, in the province of Alajuela; Cañas, Bagaces, Los Chiles and La Cruz, in Guanacaste. This element is highly toxic, both cumulatively and specifically. According to the World Health Organization and the Drinking Water Regulation of Costa Rica, the maximum limit allowed for water for human consumption is 10 micrograms per liter. By 2013, 24 populations affected by the presence of this element had been identified, in both wells and surface sources. The communities are located in the provinces of Guanacaste and Alajuela: and include Aguas Zarcas, Cañas, Bagaces and La Cruz (Mollinedo, 2013). Arsenic appears naturally in a section of the Aguas Zarcas River in Lomas, three kilometers north of the town of Aguas Zarcas, where there is a fault zone eroded by water from this river. The findings regarding groundwater will be discussed in section h. of this document. Since the discovery of this pollutant, the main concern of state entities has been to ensure arsenic-free drinking water or, at least, with limits below the maximum allowed. To this end, the AyA has embarked on the task of finding new areas to drill wells where groundwater is free of the element, supply the affected communities with nearby aqueduct waters and dilute drinking water to bring the concentration below the maximum allowed (Mora-Alvarado, 2011, Córdoba, 2017).

In recent years, the effort to resolve this situation has not only focused on designing new aqueducts, such as the new aqueducts Cañas-Bebedero and Bagaces. In addition, six specialized plants were built for the removal of arsenic in La Cruz, Cañas and Bagaces, among other projects developed by the AyA. The AyA has also embarked on the search for technologies that can remove arsenic from the ground sources used, in association with state universities. For example, in the Vice-Rector's Office for Research of the University of Costa Rica, there are at least three registered projects related to the subject (Vicerrectoría de Investigación HYPERLINK "http://www.vinv.ucr.ac.cr/sigpro/web/").

3.6 Presence of pesticides

This issue has been important in recent years, since evidence has been found of the contamination of aquifers in crop areas, specifically in the communities of Milano, Cairo, La Francia and Luisiana, in the canton of Siquirres. This aquifer was contaminated by bromacil, a herbicide used in the cultivation of pineapple. Due to the high dilution power of this herbicide and its toxicity, its use was prohibited in the country in June 2017. This contamination obliged the AyA to supply drinking water to the population with tankers and to build a new aqueduct for them, capturing more distant sources of water without risk of contamination from the cultivation of pineapple.

For The State of the Nation report, Ruepert (2011) compiled the existing information on the incidence of pesticides in surface water until 2010, all in the Caribbean zone of the country. According to this study, in a project on the quality of surface water and sediments in rivers, conducted between 2008 and 2011, the presence of substances such as bromacil, chlorpyrifos, diuron, fenbuconazole and endosulfan, compounds related to the cultivation of the pineapple and banana, was detected. The same report indicated that in monitoring conducted between 2009 and 2011 of the Jiménez River, Limón, the presence of the ametryn and diuron was found in surface waters, both pesticides being linked to pineapple crops, whereas in the Madre de Dios River, also in the Caribbean, between 2010 and 2013, the presence of seven pesticides related to the cultivation of pineapple, rice and bananas was identified. Their incidence was also recorded in several parts of the country (Matina, Bagaces, Puntarenas, and Caletas-Ario), where the mortality of aquatic organisms or intoxication of humans was demonstrated, all of which are related to the presence of pesticides. The information compiled by Ruepert (2011) was subsequently added to by Castillo and collaborators (2012), since more data from other studies was presented in which the presence of a large amount of pesticides in various bodies of surface water in the country was identified.

In June 2018, within the framework of the Good Agricultural Practices in Pineapple Production in the North Zone project, implemented by the Center for Research in Environmental Pollution (CICA) of the University of Costa Rica (UCR) and the Phytosanitary Service of the State (SFE) of the Ministry of Agriculture and Livestock (MAG), the presence of pesticides was reported in the Pital, Aguas Zarcas and Venecia de San Carlos water sources. In this project, 22 surface water samples and 10 well water samples were collected between 2015 and 2017. Bromacil, ametryne and diuron were the most frequently reported substances, although metalaxyl, carbendazim and hexazinone were also detected (O'neal Coto, 2018). Through CICA, that same university had detected the presence of bromacil and ametryne residue in the waters and sediment of Térraba-Sierpe Wetland, an area strongly influenced by the cultivation of pineapple and rice (O'neal Coto, 2017).

Problems related to the presence of pesticides in both surface and groundwater sources are exacerbated by the fact that many of the substances remain in the environment for a very short time, making it difficult to determine them by conventional analytics, which are based on the collection of samples that do not reflect the immediate or specific situation, but rather the cumulative nature of some of these chemical substances. Another factor that conspires against an adequate response to the presence of these substances is that there is no state entity that systematically quantifies all these products. The technology used to identify it is extremely costly and it is only as a result of the collaboration between the state and public universities that these important findings have come to light.

3.7 Emerging contaminants

Emerging contaminants are defined as such because of the recent interest they have elicited in the international scientific community. They are mostly substances on which research had not focused, because they exist in very low concentrations, below micrograms or even nanograms per liter. It is only the advance of analytical techniques that has made it possible to focus on them. This analytical interest has been accompanied by the interest in determining their effect on human health and other organisms that are in contact with them, mainly aquatic organisms.

These substances comprise a broad spectrum of chemical compounds: personal care products, disinfectants, perfumes, hormones, bactericides, surfactants, fire retardants and antibiotics. There are no regulations in the country on the presence of these substances in water bodies. Moreover, their detection is expensive and their identification has been due to initiatives in academia, since state entities lack the technological capacity to quantify them, even though they are a substance that is widely distributed in the environment.

There are very few publications in Costa Rica on this subject. In a study by Spongberg *et al*. (2011) 86 samples of surface water, both fresh and brackish, were collected throughout the country. Doxycycline was found in 77% of the samples, sulfadimethoxine in 43%, acetylsalicylic acid in 41%, triclosan in 34% and caffeine in 29%. Caffeine was the substance found was in the highest concentration (1.1 milligram per liter), followed by doxycycline, ibuprofen, gemfibrosil, acetaminophen and ketoprofen, in order of micrograms per liter. The highest incidence of these substances occurred in effluents near the Golfito Hospital, the treatment plant in Liberia, near the Manuel Antonio National Park and the Río Grande de Tárcoles. The actual effect of these substances on human health and whether they are also present in drinking water is still unknown in the country. What is known is that academic initiatives exist to increase the number of sampling sites, substances and regions in the country, in order to have a clearer picture of what is really happening with these chemical compounds that are discharged into water bodies.

3.8 Groundwater pollution

In Costa Rica, as in other parts of the world, groundwater is used for different purposes, such as public water supply, crop irrigation, tourism and industry. According to the MINAE, 80% of the water used for human consumption in the country is groundwater, obtained from springs and wells.

The study of groundwater quality in the country has focused mainly on determining the potability of water intended for human consumption. This work is undertaken by the entities that administer public supply systems. AyA is the entity that supplies 50% of the national population, ASADASs cover 30%, municipalities 15% and the ESPH 5%. Although it is true that Decree 33903, MINAE-S, 2007 for monitoring water quality in surface water bodies seeks to establish a baseline in different parts of the country, a legal loophole exists regarding the monitoring of groundwater quality. There has been very little research on this issue due to the high cost of chemical analysis. The relationship between surface and groundwater should be studied in detail, because pollution in rivers is increasing on a daily basis due to the inadequate disposal of solid and liquid waste, which can reach aquifers when rivers are influent (hydraulically connected to groundwater). The study by SENARA-BGS (1985) notes that there are influent sectors of the Virilla River, a condition that encourages the vertical migration of pollutants into groundwater, which calls for permanent control of the possible adverse effects this could cause. Although efforts are being made to collect wastewater in the metropolitan area through the sanitary sewer system and to improve its treatment, its disposal remains inadequate.

Sources of groundwater contamination are both point and non-point. Pollution by type of compound can be classified as follows:

1. Bacteriological contamination: total and fecal coliforms have been detected in excavated or artisanal wells that capture shallow aquifers in rural areas, since these are often located near the septic tanks of houses, in addition to being prone to flooding, and are often abandoned and used as dumps.
2. Contamination from inorganic substances: nitrates have been reported in the La Libertad spring by SENARA-BGS (1988) and by Losilla *et al*. (2001), and in the Barva aquifer (Reynolds *et al*., 2006). Pesticides in agricultural areas of the Atlantic zone (Ruepert *et al*., 2005) and the North zone of the country are undoubtedly one of the most common non-point sources, while bromacil is one of the main compounds in Cairo and Milano in Siquirres, in Veracruz in Pital de San Carlos and in Río Cuarto de Grecia. All these pollutants are associated with anthropogenic activities. Certain other chemical elements have been reported as anomalous in groundwater, such as manganese and iron, mainly occurring on the Caribbean slope and northern subslope; these elements appear naturally due to the reducing conditions found in the aquifers of these regions.

   Mollinedo (2013) and Araya (2018) determined the origin of arsenic from hydrogeochemical and hydrogeological information in the Aguas Zarcas and Los Chiles, Alajuela regions respectively. Arsenic in the areas of Bagaces and Cañas, in Guanacaste, has been studied by Ramos *et al*. (2014). Other types of contamination have been reported since the early 21st century, such as salinization due to saline intrusion problems in several North Pacific beaches (Arellano and Vargas, 2001, Arias-Salguero and Vargas, 2003). Another case is Tamarindo, Guanacaste, where increases in electrical conductivity and chloride levels in water have been detected, due to excessive extraction of groundwater by pumping wells near the coast (Astorga, 2018, personal communication).
3. Contamination by organic compounds: Point pollution by hydrocarbons has also been found in two places; the AB-1089 well, belonging to the ESPH, located in Barrial de Heredia near a gas station that had had a spill, which is why the well was disconnected from the system in 2005. Another case is the Moín aquifer, in the RECOPE site in Limón studied by Guzmán (2006). Both sites have had to be intervened with remediation processes. Although it is impossible to rule out the existence of other contaminated sites in the country, they have not been detected due to the lack of groundwater monitoring. Studies

on the chemical composition of water in specific aquifers, include the SENARA-BGS study (1985) undertaken in Valle Central, where the waters of the Barva and Colima aquifers were characterized chemically and isotopically. Gómez and Arredondo (1994) and Vargas (2015) studied the hydrogeochemical characteristics of the Tempisque aquifer; while Vargas (2017) explored the hydrogeochemical features of groundwater in the Rio Grande basin. The quality of the groundwater in other aquifers has been sporadically studied through graduate and postgraduate theses on geology. However, more research is required and projects for the adequate instrumentation and permanent monitoring of groundwater quality must be considered at the country level to prevent and detect contamination that may affect the groundwater sources used in public supply in an early stage.

SENARA is currently developing Sustainable Supply Plans (PAS), in which users requests support from to conduct research on selected aquifers and begin a continuous process for water resource management. Two projects of this nature have already been carried out: one in the Parrita region in the Central Pacific and another in Santa Cruz Guanacaste, in which the quality of groundwater is characterized (Ramírez, 2018, personal communication).

4. Social and economic aspects

4.1 Health

The World Health Organization (WHO) has suggested that diarrhea is a symptom of infectious diseases, usually spread by water pollution (WHO, 2000). Factors that can contribute to reducing the number of diarrhea cases include access to water for human consumption, improvements in the health system, good personal and food hygiene, and health education on how diseases are transmitted (WHO, 2000). Diarrhea deaths are common among the poor, especially in developing countries. Every year, there are approximately four billion cases of diarrhea in the world (WHO, 2000).

Costa Rica has achieved extremely satisfactory levels in terms of drainking water coverage, reaching 98% coverage of water from indoor pipes and 99% with improved drinking water sources in 2012 (Hidalgo-León *et al*., 2015). One of the most pressing problems in terms of water quality in Costa Rica, identified in previous studies (Hidalgo-León *et al*., 2015), is the problem of low coverage of sanitary systems for sewage and gray water treatment in metropolitan areas. It is worth noting that in 2016, a positive step was achieved in sanitary sewer coverage, with wastewater treatment increasing from 4.2% in 2014 to 14.4% in 2018 (AyA, 2018).

Although wastewater treatment coverage must be greatly improved, good coverage in terms of access to drinking water and the basic health system mean that the incidence of diarrheal diseases, particularly of diarrhea-related mortality, is still relatively low with respect to other countries in the region (Hidalgo-León *et al*., 2015). The percentage of causes of death in infants due to infectious and parasitic diseases is 1.6%, while for respiratory causes it is 4.3% (INEC, 2013). It should be noted that diseases of the digestive system in Costa Rica are rarely fatal in childhood. For example, in 2011, the percentage of deaths of children under 5 from these causes was 0.01 per thousand, compared with the death rate of 2.21 per thousand obtained by adding all the causes of death for this age range (Ministry of Health, 2011, Hidalgo-León *et al*., 2015). In fact, neither diarrhea nor hepatitis feature among the ten leading causes of death in children under 5 in any of the years from 2012 to 2015 evaluated in INEC (2015, see Table 7.12). The incidence of other types of diseases associated with water is shown in Hidalgo-León *et al*. (2015). In Costa Rica, the mortality rates of the first five sources of death have remained relatively constant over time. Deaths from diseases of the digestive system (a fraction of which may be related to water quality) amount to a third of the diseases due to the leading cause of death in the country (problems of the circulatory system). For reference, the average mortality rate for those years due to certain infectious and parasitic diseases is 0.81 deaths per 10 000 inhabitants (INEC, 2015) and it does not figure among the ten leading causes of death in the country. For the case of diarrhea in particular, the average mortality rate from 2008 to 2015 is 0.1 deaths per 10 000 inhabitants, the great majority of whom are over 75 (Ministry of Health, 2016).

4.2 Poverty

In terms of poverty, the average percentages for the period 2012-2015 of the population living in non extreme, extreme and total poverty are 16.4%, 7.3% and 23.7% respectively (INEC, 2015). This in itself poses a social challenge in many respects, but although the country faces an increasing number of challenges to maintain its basic services, no study has shown that the limitations of the lowest socioeconomic group regarding access to drinking water, basic hygiene education or basic health systems have been sufficiently influential to clearly identify correlations between social stratum and the prevalence of disease outbreaks related to water quality. For example, in the case of diarrhea, there does not seem to be a correlation between the index of social development and the rate of diarrhea (Table 19 of the Ministry of Health, 2016). Other diseases related to the quantity of water available and the presence of breeding grounds for vectors transmitting diseases such as Dengue, Zika and Chikunguña, do seem to have a tendency to produce significant outbreaks in rural municipalities (Ministry of Health, 2018). In these communities, the quality of support services is usually more limited and the population living in poverty may be more socially vulnerable. With respect to indigenous populations (accounting for 2.4% of the total population of the country in the 2011 census), according to the Unsatisfied Basic Needs method, "*only 7.6% of indigenous people have no shortcomings. The main shortcomings are related to productive development, food security, marketing possibilities, access to drinking water, basic services and all kinds of infrastructure development (health, education, production and social). In indigenous populations, the concepts of poverty and vulnerability differ substantially from those use for the non-indigenous population*" (PND, 2014)

4.3 Educational attainment in communities. Education programs and curricula

The National Development Plan (NDP) 2015-2018 includes, among many other goals, the strengthening of community water management, as well as the increase in wastewater collection and treatment (PND, 2014). The need to address the vulnerability of the road, energy and public service systems (water, sanitation, health) to natural, socio-natural and industrial threats is also mentioned. In order to achieve sustainable development, the country needs to improve many aspects, such as the following: the conservation of water resources, the rational exploitation of marine resources, waste management, adaptation and mitigation mechanisms in the face of climate change, land use planning, clean energy use to reduce dependence on fossil fuels and strengthen culture and environmental education (PND, 2014). "*It will also be a major challenge to enforce the Law and ensure that the institutional framework achieves better environmental management, in which the link between environmental sustainability and economic and social development is a central aspect*" (PND, 2014). Environmental education has been mentioned among other priority services that must be evaluated at schools so that they can be improved and thus promote better education and the permanence of students in educational centers. In fact, environmental education (from elementary school to diversified education) is regarded as the core of the curriculum and institutional management to strengthen education for life that will encourage creativity and innovation to enhance human development (PND , 2014).

4.4 Gender

Gender issues have been associated with water supply in certain cases. For example, Rico (1998) notes that women in Costa Rica have traditionally participated in the construction of aqueducts, yet are relegated in terms of the percentage who participate in project administration. The health statistics related to various diseases are differentiated by sex in the information provided by the Ministry of Health, but to our knowledge, no statistical analysis has been undertaken of the incidence of all kinds of diseases for men and women separately in order to determine the causes of the possible differences (there is an analysis of the incidence of hepatitis B, dengue and malaria by sex in INEC *et al*., 2010). In Costa Rica, the National Institute for Women (INAMU) is responsible for ensuring equal conditions for women, although significant gaps exist in some respects, such as access to employment (INEC *et al*., 2010).

4.5 Rural and urban areas

In Costa Rica, excreta disposal systems are based on the use of septic tanks (76.9%) and treated and untreated sewage (21.1%). Most urban services are provided by the AyA (although it is also present in rural regions) and to a lesser extent by the ESPH and municipalities, while ASADAS usually serve rural regions. Of the 21 wastewater treatment systems administered by AyA, nine fail to comply with the Wastewater Discharge and Reuse Regulations, specifically in the determination of total BOD. For its part, the ESPH administers five treatment systems, four of which comply with the total BOD. Information is unavailable on the 32 systems operated by municipalities and ASADAS (Mora-Alvarado *et al*., 2016). Information for the period from November 1, 2012 to October 31, 2015, indicates that urban treatment systems for water supply have an average of 5.4% of treatment compared to 1.3% in rural systems. Likewise, urban systems have 94% of installations with disinfection compared to 38.8% in rural systems (Mora-Alvarado *et al*., 2016). Within the episodes of contamination in the country, there have been cases of anthropic chemical contamination (especially with hydrocarbons) and natural chemical contamination (particularly arsenic). A list of the occurrence of these incidents is available in Mora-Alvarado *et al*. (2016).

4.6 Investment in water quality programs

For over 90 years, basic sanitation has managed to separate fecal matter from direct contact with people. However, although the basic system reached rates of 97% in 2017, approximately 70% are covered by septic tanks which in many regions is unsuitable and creates an enormous risk of contamination of surface waters and underground layers (AyA, 2017a). As a result, many rivers and streams carry soapy or wastewater, due to direct disposal from nearby houses or the poor drainage of septic tanks (AyA, 2017a).

In Costa Rica, wastewater treatment and project implementation is the responsibility of following operators: AyA, ESPH, ASADAS and municipalities. However, the high design and investment costs of the sanitary sewer infrastructure and wastewater treatment plants, mean that they must be covered by the central government budget. The cost of maintenance and operation of these systems is covered by utility rates (AyA, 2017a). Accordingly, the country created a National Investment Plan in the short and medium term, in response to the Public Policy for Wastewater Sanitation, which will allow the development of the improvement projects and new systems required. "*The AyA has spent nearly eight years investing in the environmental improvement of the cantons in the Greater Metropolitan Area, through a loan of more than $300 million USD from the central government, the Japanese Bank and the Inter-American Development Bank*" (AyA, 2017a). The goals are as follows: by 2036 it is hoped to have urban sanitary sewage and wastewater treatment in the priority cities covered and by 2045, rural sanitation and wastewater treatment in the remainder of the urban area (AyA, 2017a). By 2030 it is hoped to invest $1082 million to benefit more than 580 000 people in the Greater Metropolitan Area, $127 million will be invested in the coastal tourism region, benefiting more than 69 000 people, while $435 million will be invested to repair current systems to benefit more than 235 000 people (AyA, 2017a). The entire national investment plan for 2045 will total $6.224 billion, including $3.654 billion for wastewater treatment in urban areas and $2.569 billion for the expansion and implementation of wastewater treatment in rural areas (AyA, 2017a).

5. Meeting Sustainable Development Goals (Goal 6: Ensure water availability and its sustainable management and sanitation for all)

5.1 Compliance with SDG

Costa Rica has made significant efforts to meet not only the Millennium Development Goals (MDGs), but also the Sustainable Development Goals (SDGs). Targets 6.1 and 6.2 of Goal 6 refer to drinking water provision, sanitation and hygiene, with the SDGs being much more precise and having more variables. SDGs promote universal, equitable access for all, promoting the elimination of inequalities in service levels. Hygiene is also included, which had not been considered in the MDGs, while drinking water supply service is conceptualized as safe, affordable water and sanitation is conceptualized as adequate, eliminating open fecalism and paying particular attention to the needs of women and girls and people in situations of vulnerability.

The processes and systems to monitor and review SDG6 trends are being coordinated by the Secretariat of Sectoral Planning of the Environment, in which the National Center for Geoenvironmental Information (CENIGA) and the National Institute of Statistics and Censuses (INEC) provide the inputs. This Secretariat has the technical support of the MINAE Water Directorate, the Ministry of Health, the AyA and the Interinstitutional Technical Committee comprising MINAE, AyA and SENARA.

5.2 Drinking water supply

In Costa Rica, drinking water has been defined as the priority use among other uses, in addition to the recognition of access to drinking water and sanitation as a Fundamental Human Right, as stipulated by the United Nations in 2010. Since 1961, the water supply service as a public rather than a private service has been conceptualized and framed in various laws and, above all, in the constitution of the AyA, which has been given the authority and responsibility to "provide the inhabitants of the country with drinking water, and sewage and liquid industrial waste collection and disposal services". This mission complements it for the entire national population with the work of the ASADAS, the ESPH and the Municipalities.

The Law Establishing the AyA stipulates that, "Rate setting should be based on distributive social justice criteria, taking into account the social strata and the area to which users belong, so that those with the greatest capacity to pay subsidize those with less capacity". Moreover, the service must be at cost through an affordable rate for families.

This public service model implemented in Costa Rica achieved the universalization of water supply services, increasing coverage from 70% in 2000 to 94.5% in 2017. The AyA covers 47%, ASADAS 29% , Municipalities 14%, ESPH 5% and other entities 5%. Indoor coverage is 97.6%, corresponding to 91.8% of the population that receives totally safe drinking water, free of microorganisms and dangerous chemical elements (AyA, 2018).

Water supply service in Costa Rica has generally high coverage, with continuous equitable service. In order to ensure this management model of public water supply services, the National Policy for the Potable Water Sub-sector 2017-2030 (AyA *et al*., 2018) was constructed and launched, with the aim of "achieving access to drinking water through the protection of water resources and the strengthening of the capacities of the actors related to the provision of the service, to contribute to the health, welfare and development of the country". The strategic axes of this Policy are: water culture, governance of the potable water sector, investment in infrastructure and service and environmental management in the drinking water sector. A National Program for the Improvement of the Quality of Drinking Water Services 2017-2030 (AyA/MINAE/MS, 2018) is also in place.

5.3 Basic sanitation

Basic sanitation in the country was promoted through the 1973 General Health Law. By 2017, 70% of the population had a septic tank, 14.4% with sanitary sewerage and a water treatment plant, 13.4% with sanitary sewage without treatment plants, 1.6% with latrines and just 0.5% without toilets. This means that the country has achieve Goal 6 of the SDGs, where the proportion of people who practice open fecalism is almost nil (AyA/MINAE/MS, 2016).

Moreover, in order to promote advanced sanitation for major cities and coastal areas with a high influx of tourists, the National Wastewater Sanitation Policy was constructed in a participatory manner (AyA/MINAE/MS, 2016), with five axes: 1. Institutional and regulatory strengthening, 2. Integrated sanitation management, 3. Infrastructure and investment, 4. Financial sustainability and tariff model and 5. Citizen participation. This policy is complemented by the National Plan of Investments in Sanitation for the period 2017-2045, in which an investment of $6.224.000.000 has been calculated to capture and treat wastewater from cities through sewerage and treatment plants, and wastewater in rural areas through septic tanks or another type of alternative technology.

The Communal Associations for water supply and sanitation are official organizations, which have the AyA delegation to provide these services. In order to strengthen these organizations, the Policy for the Organization and Strengthening of Community Management of Drinking Water and Sanitation Services was launched, which has a digital unified instrument (ASADAS-SAGA Management Support System), which is collecting information on the status of ASADAS aqueducts, as well as the risk level of the systems and sources used. ASADAS capacities are being built by the National Continuous Training Plan.

Integrated Water Resource Management is also reflected in the National Water Policy and the National Water Strategy, launched in 2009, derived from the Political Constitution, which states that, "The State shall seek the greatest welfare for all inhabitants of the country, by organizing and stimulating production and the most appropriate distribution of wealth," where, "everyone has the right to a healthy, ecologically balanced environment". The Minister of Environment and Energy is responsible for the political leadership and stewardship of water resources.

5.4 Legal Framework

With regard to the general legal-regulatory framework for integrated water management and intersectoral action in Costa Rica, there are over 15 organizations including Ministries, Autonomous Institutions and Local Governments with authority over Water Resources. Thus, there is a Water Law dating from 1942 and over 100 instruments among other laws and decrees that govern water in Costa Rica. This is why, since 2001, a bill for Integrated Water Resource Management has been promoted, which is an integrative law with a clear definition of spheres of authority. This bill has yet to be approved by the National Congress.

Water is defined as a good in the public domain, an inalienable good, which must be managed in a sustainable fashion, considering the hydrological and hydrosocial cycle. It is the responsibility of the state to use concessions or permits to authorize the use of water, which is charged through the Environmentally Adjusted Use Free by surface or ground source, according to the volume and type of use: commercial, industrial, tourist, irrigation, human consumption or hydroelectric. It also has a discharge rate which is calculated according to the volume and pollutant load discharged into a surface waterbody.

For wetland ecosystems, there is a National Wetland Policy 2017-2030, with the aim of integrally managing the wetland ecosystems of Costa Rica, in order to contribute to national development. Wetland ecosystems account for seven per cent of the country (Mora-Rodríguez, 2017).

Three of the institutions with competence in water resources comprise the Institutional Technical Committee (CTI), which conducts hydrogeological studies and monitors the country's aquifers. The aim is to determine the amount of water available and to have scientific data on the permissible volumes to be exploited, thus ensuring the sustainable management of groundwater bodies.

Although Costa Rica has undoubtedly made progress in complying with SDGs, it has yet to improve the indicators related to sanitation. The main hurdles to maintaining and even improving SDG 6 involve investing in water treatment and purification systems with chemical elements for human consumption, the protection of water sources, sustainable watershed management using participatory processes and continuing to invest in wastewater collection and treatment.

6. Recurrent Problems and Successful Experiences in Improving Water Quality

Box 1: Sustainable management of the Nimboyores aquifer, Santa Cruz, Guanacaste

By Yamileth Astorga Espeleta

As a result of a crisis caused by a project designed to capture water from the Nimboyores aquifer to supply coastal areas, there is a need to promote a participatory process with various strategic socio-institutional actors to ensure sustainable groundwater management in the Nimboyores area. This process was coordinated by institutions responsible for water resource management, such as the Costa Rican Institute of Aqueducts and Sewers (AyA), the Water Directorate of the Ministry of Environment and Energy (MINAE), the National Groundwater, Irrigation and Drainage Service (SENARA), supported by the Ministry of Health (MS), the Ministry of Agriculture and Livestock (MAG), the Institute of Rural Development (INDER), the Associations of Communal Aqueducts (ASADAS), the Integral Development Associations, local government, academia (National University) and the private sector.

The first step was to win the trust of the various actors and invite them to be part of a participatory process, since the image of public institutions has been severely discredited for various reasons. It was therefore decided to work together on several fronts, such as the measurement and monitoring of the status of the aquifer, the analysis of water balance data, the development of a sustainable management plan for the aquifer and the conceptualization of an infrastructure project to supply water to various communities. This effort culminated with the consolidation of an organization called “Commission for the Sustainable Management of the Nimboyores Aquifer and Coastal Aquifers of Santa Cruz (CONIMBOCO)”, formalized by Executive Decree No. 41094-MINAE.

In this experience, the AyA signed the first public-community agreement with ASADASs on the coastal zone of Santa Cruz, where the AyA built an aqueduct using water from the Nimboyores aquifer and transporting it to 16 communities all supplied by 14 ASADAS. Water is delivered to each ASADA through a macro-meter and charged on the basis of a new tariff defined by the Public Services Regulatory Authority (ARESEP), called block water, calculated on the basis of the average cost of the service provided by each operator, while ensuring the economic sustainability of each ASADA. The commitment of each ASADAS is to ensure efficient, quality service.

CONIMBOCO seeks to restore coastal aquifers that have undergone salinization processes, by reducing or eliminating the extraction of their waters and consuming water from the Nimboyores aquifer, a non-coastal aquifer. This inter-organizational body is also responsible for implementing the management plan for the Nimboyores aquifer, where the extraction of water is limited to the flow established by the water balance study, ensuring that 60% of the water will be reserved in the aquifer, and controlling land use in areas with the greatest water recharge. This guarantees the quantity and quality of the aquifer water.

Box 2. Integrated Water Resource Management at the level of the Purires River Microbasin, El Guarco, Cartago

By Yamileth Astorga Espeleta

The University of Costa Rica promoted the Dialogue of Knowledge Project for the use of Integrated Water Resource Management as a strategy for water sustainability at the level of the Purires River Hydrographic Basin in Cartago, Costa Rica. The objective of this initiative was to contribute to the collective use of integrated water resource management as an integrating strategy for actors and communities based on the Purires River microbasin, through a process of exchanging knowledge, experiences and sustainable water use and management practices.

This project is the continuation of an earlier process, based on the mapping of strategic actors in the microbasin and the promotion and consolidation of a platform, with the representation of local actors, community organizations, and public Costa Rican state and local government institutions. The project incorporated the building of the organizational and integrated water resource management capacities of the Commission for the Purires River Microbasin (ComPurires), culminating in a formally constituted Association with legal status designed to lead and maintain the integral management process of water resources in the micro-basin.

The project also included the assessment of the vulnerability of water resources in production areas, the sources used and the discharge of wastewater from various users, such as the Administrative Associations of Aqueduct and Rural Sewerage Systems (ASADAS), household and agricultural users and, in general, the ecosystem of the Purires River and its main tributaries in the Purires River microbasin, with the active participation of members of ComPurires.

Local actors in the Commission, elementary and middle school students, were trained to take water samples from the river for the evaluation of the physical-chemical quality and macroinvertebrate samples for evaluation through biological indicators of the quality of the aquatic ecosystem. To this end, they also produced maps, guidelines and other types of educational material to continue monitoring water quality in the microbasin.

The project also incorporated continuous monitoring for approximately seven years at six points along the course of the microbasin, in keeping with the provisions of the Regulation of the Evaluation and Classification of Surface Waterbody Quality, Executive Decree No. 33903. Twice a year, samples were taken for the analysis of the physical-chemical quality of the water and the Water Quality Index (WQI) was used, which includes the percentage of oxygen saturation, Biochemical Oxygen Demand and Ammoniacal Nitrogen, in addition to other physical-chemical parameters. Macroinvertebrate samples were taken to use the BMWP-CR biological index.

In order to reduce the vulnerability of the water resources in the micro-watershed, solution strategies were implemented, such as the installation of collectors to harvest rain at education centers, dry leach fields and bio-digesters for wastewater treatment, the production of organic fertilizer using agricultural waste, reforestation in the areas of water recharge and riparian protection areas, solid waste collection in the river bed, environmental education, educational fairs and the use of the Ecological Blue Flag Award V Hydrographic Micro-watershed Category.

Box 3: Water problems affecting the Río Grande de Tárcoles Basin: Seeking solutions

By Édgar Meléndez

The Río Grande de Tárcoles Basin (RGT) covers five of the seven provinces in the, including the upper part of the Greater Metropolitan Area (GAM). The RGT flows into the Pacific Ocean and has been considered the most polluted river in Central America (State of the Nation, 2017).

The RGT Watershed Management Program, undertaken by the Abt Associates Inc. consultancy firm in 1999 (Abt Associates Inc. *et al.*, 1999), declared that, "*This Basin has entered a downward spiral of degradation that threatens not only the sustainability of the natural resources present in it, but also the quality of life of its inhabitants and that of future generations. The logical causes of this problem include rapid, disorderly urbanization as well as the opening up of areas for agricultural and industrial purposes, which are the source of deforestation and the loss of plant cover, which reduces infiltration, thereby increasing run-off, the risk of floods and the dragging of sediment. It states that liquid [sic] effluent from sewerage is discharged untreated into the river, since only 45% of the basin population have untreated sewerage, which leads to the deterioration of the quality of the surface and groundwater in the basin, creating unhealthy conditions and contaminating the water sources. It states that this problem is a result of unplanned growth, deforestation, lack of foresight regarding the impacts of urban use and ignorance of the capacity of the storm sewer system*".

The Resolution of the (Court) Constitutional Chamber, Vote 5894-2007 of April 27, 2007 ordered that, "*the necessary actions be taken immediately to comprehensively eliminate the sources of contamination that exist throughout the basin of the Río Grande de Tárcoles*". Fulfilling this mandate required the joint efforts of a significant number of actors, in both the public and private sectors, a combination of wills aware of the severity of the problem and the continuity of long-term actions. Reversal and repair processes for the damages caused to the Basin must be initiated, through integral environmental management that emphasizes participatory and sustainability aspects. From this perspective, Integral Management of the RGT Basin must be framed in integrality, at least in two respects: 1) by encompassing the geographical totality of the Basin, in other words, the 37 cantons; 2) through Integral Management that contemplates the inclusion of all anthropic factors that generate changes or disturbances in the natural environment, whether positively or negatively.

Once the excess pollution affecting the river was determined, as a direct consequence of inadequate solid and liquid waste treatment, the implementation of all corrective measures contemplated by current laws and decrees becomes indispensable and impossible to postpone. The most obvious method for solving the problem is Integral Waste Management (IWM). Article 6 of Law 8839 defines its nature as "the coordinated, inter-related set of regulatory, operational, financial, administrative, educational, planning, monitoring and evaluation actions for waste management, from its production to final disposal". IWM means that the geographical integration with its actors as well as the different uses of the water factor must be considered with an overall vision, because they are interdependent. As pointed out, the administration of water resources will require a long time to reduce the causes of the severe pollution affecting the river and its tributaries. There are still conditions to initiate processes of reversion and repair of the damages caused to the Basin, with an integral environmental management that establishes an emphasis on participatory and sustainability aspects, which is essentially confined to the municipal sphere in terms of solid waste.

With regard to the production of sewage that affects the RGT Basin, the San José, Heredia and Alajuela sewers in the Great Metropolitan Area (GAM) have systems which only collect sewage and, in practice, dispose effluents without treatment in the rivers of the basin. It should be noted that the Los Tajos AyA Wastewater Treatment Plant, west of San José, involves primary treatment with complete sludge treatment. The recent establishment of this plant will at least partly reduce the high existing contamination rate and the deterioration of water resources in the RGT Basin.

Proposed recommendations for solving the problem include the following: 1) IWM Plans at the municipal level will be successful if these local governments ensure accurate, prompt compliance with the obligations established in Article 8 of the Law for Integral Waste Management; 2) It is advisable to explore whether, through public works concession contracts, sewage and wastewater treatment systems can be built. The costs of these works should be seen as investments rather than merely expenses because from an economic perspective, with the collection of fees for services rendered, compensation is guaranteed; 3) it is important to raise awareness to reflect on the imminent problem of water pollution, which overwhelms us today and could have serious consequences for future generations.

7. Conclusions and Recommendations

Costa Rica has historically made significant progress related to the supply of drinking water, to excreta disposal to a lesser degree and only in recent years has it made progress in the field of wastewater treatment. However, much remains be done. One of the problems is obviously the cost of investing in the infrastructure required to treat wastewater, but there is also very little environmental awareness among a certain sector of the population. Although in recent years many of us have learned to value drinking water more and avoid the waste of clean water, we are usually unconcerned about what happens to wastewater, which is why there is still a high degree of contamination by solid and liquid waste in rivers (particularly in urban basins). Awareness could be raised by the Integrated Water Resource Management in the communal committees around the basins, where the problems of specific regions are addressed. It is essential to create more of these committees throughout the country and strengthen existing ones.

The country requires more research on the subject of surface and underground water quality, so studies focused on monitoring water quality should be strengthened, for which rivers and aquifers should be equipped with devices to measure levels of water and electrical conductivity, fecal coliforms and nitrates as indicators of anthropogenic pollution.

The institutions of the national water sector must join forces to carry out studies in areas where demand has been growing and/or is expected to occur in the future. Research should be increased on issues linked to the physico-chemical characterization of water, while plans to prevent pollution should also be drawn up.

A modern Water Law is required that will adapt to the needs of the management and responsible use of water resources. New legislation should place greater importance on water and guarantee its supply, protection and quality. But a law alone is not enough to guarantee a significant change in management of water resources, since it must be accompanied by suitable mechanisms and financing for its implementation and supervision. A change is required in the way water has been managed in recent years, especially with regard to the time horizons needed for proper planning. Increases in demand, associated with population aspects, changes in household use, industries and agriculture, as well as climate variability and change, have the potential to impose restrictions and create challenges regarding the availability and quality of water resources in the short, medium and long terms. There is also a need to establish an effective mechanism to transfer technical/scientific information to decision makers. To this end, universities should include degree courses to train professional "managers" who will serve as a link between physical and social fields. Effective coordination between the various institutions related to water is also required, particularly as water becomes increasingly scarce.

8. References

Abt Associates Inc., CONCESA, CATIE, FUNDACIÓN NEOTRÓPICA (1999). *Programa de Manejo de la Cuenca del Río Grande de Tárcoles", Estudio de Factibilidad.* Diagnóstico Integrado. BID ATN/JF-5622-CR. San José, Costa Rica.

Acuña, J., Vargas, J., Gómez, E. & García, J. (2004). Hidrocarburos de petróleo disueltos y dispersos en cuatro ambientes costeros de Costa Rica. *Revista de Biología Tropical,* 52 (Suppl. 2), 43–50.

Alpízar, M. & Vargas, I. (2017). *Caracterización hidrogeoquímica y determinación del origen del arsénico en aguas de consumo humano en sitios seleccionados de Costa Rica.* Informe final del proyecto 802-B3-515, Vicer. Investigación Universidad de Costa Rica. CICA-Escuela Centroamericana de Geología, San Pedro Montes de Oca, Costa Rica.

Araya, Á., Barboza, R., Ramírez, W. & Rodríguez, A. (2009). *Informe técnico sobre la inspección tramo fecal del Emisario de Limón.* San José, Costa Rica: Instituto Costarricense de Acueductos y Alcantarillados.

Araya, M. (2018). *Mecanismos de movilización del arsénico hacia el agua subterránea, en la zona de Cañas, Guanacaste.* Tesis inédita. Maestría Académica en Hidrogeología y Manejo de Recursos Hídricos. Posgrado en Geología. Universidad de Costa Rica.

Arellano, F. & Vargas, A. (2001). Casos de contaminación por intrusión salina en acuíferos costeros de la Península de Nicoya (Costa Rica). *Revista Geológica de América Central,* 25, 77–84.

Arias-Salguero, M.E. & Vargas, A. (2003). Geofísica aplicada al problema de la intrusión salina en los acuíferos costeros de Costa Rica. In J.A. López-Geta, J. de Dios Gómez, J.A. de la Orden, G. Ramos & L. Rodríguez (Eds.), *Tecnología de la intrusión de agua de mar en acuíferos costeros: países mediterráneos,* pp. 163–167. Madrid: Instituto Geológico y Minero de España.

AyA (2017a). *AyA invierte en Saneamiento de Aguas Residuales y Mejoramiento Ambiental.* Suplemento AyA, Junio de 2017. San José, Costa Rica: Instituto Costarricense de Acueductos y Alcantarillados. Retrieved from: https://www.aya.go.cr/Noticias/Documents/Suplemento%20Saneamiento%20y%20Mejoramiento%20Ambiental.pdf

AyA (2017b). *Plan Nacional de Inversiones en Saneamiento 2017-2045.* Créditos: Y. Astorga Espeleta, J. Phillips Ávila, I. Sáenz Aguilar, A. Araya García, N. Aguilar Monge, D. Fernández. San José, Costa Rica: Instituto Costarricense de Acueductos y Alcantarillados. Retrieved from: https://www.aya.go.cr/Noticias/Documents/Plan%20Nacional%20de%20Inversiones%20en%20Saneamiento%20marzo%202017.pdf

AyA (2018). *Informe de Gestión de la Presidencia del AyA, 2014-2018.* Yamileth Astorga Espeleta, Directora Ejecutiva. Presidencia Ejecutiva. San José, Costa Rica: Instituto Costarricense de Acueductos y Alcantarillados. Retrieved from: https://www.aya.go.cr/Noticias/Documents/Informe%20final%20de%20Gesti%C3%B3n%20AyA%202014%202018.pdf

AyA, MINAE & MS. (2016). *Política Nacional de Saneamiento en Aguas Residuales 2016-2045.* Primera edición. San José, Costa Rica. Retrieved from: https://www.aya.go.cr/Noticias/Documents/Politica%20Nacional%20de%20Saneamiento%20en%20Aguas%20Residuales%20marzo%202017.pdf

AyA, MINAE & MS. (2018). *Política Nacional de Agua Potable de Costa Rica 2017-2030*. Retrieved from: https://www.aya.go.cr/Noticias/Documents/AyA%20Pol%C3%ADtica%20Nacional%20de%20Agua%20Potable%20de%20Costa%20Rica%202017-2030.pdf

Barrantes, K., Chacón, L.M., Solano, M. & Achí, R. (2013). Contaminación fecal del agua superficial de la microcuenca del río Purires, Costa Rica. *Revista de la Sociedad Venezolana de Microbiología,* 33, 40–45.

Calvo-Brenes, G. & Mora-Molina, J. (2012). Contaminación fecal en varios ríos de la Gran Área Metropolitana y la Península de Osa. *Tecnología en Marcha,* 25 (4), 33–39.

Carazo-Rojas, E., Pérez-Rojas, G., Chinchilla-Soto, C., Chin-Pampillo J.S., Aguilar-Mora, P., Alpízar-Marín, M., Masís-Mora, M., Rodríguez-Rodríguez, C.E. & Vryzas, Z. (2018). Pesticide monitoring and ecotoxicological risk assessment in surface water bodies and sediments of a tropical agro-ecosystem. *Environmental Pollution,* 241, 800–809.

Castillo L.E., Ruepert, C. & Solis, E. (2000). Pesticide residues in the aquatic environment of banana plantation areas in the North Atlantic zone of Costa Rica. *Environmental Toxicology and Chemistry,* 19(8), 1942–1950.

Castillo, L.E., Ruepert, C., Ramírez, F., van Wedel, B., Bravo, V. & de la Cruz, E. (2012). *Plaguicidas y otros contaminantes, Informe Final.* Decimoctavo Informe del Estado de la Nación (2012). Retrieved from: http://www.estadonacion.or.cr/files/biblioteca_virtual/018/Castillo-L-et-al-2012-Plaguicidas-y-otros-contaminantes-1.pdf

Castillo, L.E., Martínez, E., Ruepert, C., Savage, C., Gilek, M., Pinnock, M. & Solis, E. (2006). Water quality and macroinvertebrate community response following pesticide applications in a banana plantation, Limón, Costa Rica. *Science of the Total Environment,* 367, 418–432.

Céspedes-Vargas, E., Umaña-Villalobos, E., & Silva-Benavides, A.M. (2016). Tolerancia de diez especies de diatomeas (*Bacillariophyceae*) a los factores físico-químicos del agua en el Río Sarapiquí, Costa Rica. *Revista de Biología Tropical,* 64(1), 105–115.

Córdoba, J. (ed.) (2017). Agua Potable: un derecho a proteger. 27 de setiembre. Suplemento especial, *Semanario Universidad.* Retrieved from: https://www.aya.go.cr/ASADAS/informeseAqui/Suplemento%20Agua%20Potable%2028%20set.pdf

Echeverría-Sáenz, S., Mena, F., Pinnock, M., Ruepert, C., Solano, K., De la Cruz, E., Campos, B., Sánchez-Ávila, J., Lacorte, S. & Barata, C. (2012). Environmental hazards of pesticides from pineapple crop production in the Río Jiménez watershed (Caribbean Coast, Costa Rica). *Science of the Total Environment,* 440, 106–114.

Estado de la Nación (2017). *Estado de la Nación en Desarrollo Humano Sostenible.* Pavas, Costa Rica.: Programa Estado de la Nación. Recuperado de: www.estadonacion.or.cr

Fernández, L. & Springer, M. (2008). El efecto del beneficiado del café sobre los insectos acuáticos en tres ríos del Valle Central (Alajuela) de Costa Rica. *Revista de Biología Tropical,* 56(Suppl 4), 237–256.

Gómez, A. & Arredondo, S. (1994). *Hidrología isotópica del Valle del río Tempisque, Provincia de Guanacaste, Costa Rica.* Comisión Internacional de Energía Atómica. ARCAL XIII Proyecto. Estudios hidrológicos e hidrogeológicos en América Latina sobre los recursos hídricos y la contaminación de las aguas subterráneas. SENARA, Costa Rica.

Guevara, D. & Herrera, J. (2014). *Informe sobre calidad de Aguas Superficiales.* San José.

Gutiérrez Wa-Chong, T. (2018). Río Torres entre los más sucios del mundo. *La República,* January 26. Retrieved from: www.larepublica.net/noticia/rio-torres-entre-los-mas-sucios-del-mundo

Gutiérrez-Fonseca, P. & Lorion, C.M. (2014). Application of the BMWP-Costa Rica biotic index in aquatic biomonitoring: sensitivity to collection method and sampling intensity. *Revista de Biología Tropical,* 62(2), 275–289.

Guzmán, G. (2006). *Estudio de contaminación por hidrocarburos tipo BTEX, en el plantel de RECOPE, Moín, Limón.* Tesis inédita. Maestría Académica en Hidrogeología y Manejo de Recursos hídricos, Posgrado en Geología. Universidad de Costa Rica.

Herrera, J., Rodríguez, S., Rojas, J.F., Herrera, É. & Chaves, M. (2013). Variación temporal y espacial de la calidad de las aguas superficiales en la subcuenca del río Virilla (Costa Rica) entre 2006 y 2010. *Revista de Ciencias Ambientales,* 45 (1), 51–62.

Hidalgo-León, H.G., Herrero-Madriz, C., Alfaro-Martínez, E.J., Muñoz, A.G., Mora-Sandí, N.P., Mora-Alvarado, D.A. & Chacón-Salazar, V.H. (2015). Las aguas urbanas en Costa Rica. In Interamerican Network of Academies of Sciences (Eds.), *Desafíos del agua urbana en las Américas,* pp. 208-233. México: IANAS y UNESCO. Retrieved from: http://www.kerwa.ucr.ac.cr/bitstream/handle/10669/11370/Hidalgoetal2015LAUes.pdf?sequence=1&isAllowed=y

INEC (2013). *Mortalidad infantil y evolución reciente.* San José, Costa Rica: Instituto Nacional de Estadística y Censos, Boletín Anual, Vol. 2, Year 19. Retrieved from: http://www.inec.go.cr/sites/default/files/documentos/poblacion/mortalidad/publicaciones/repoblacev2013-01_0.pdf

INEC (2015). *Anuario Estadístico 2014-2015, compendio de datos país.* San José, Costa Rica: Instituto Nacional de Estadística y Censos. Retrieved from: http://www.inec.go.cr/sites/default/files/documetos-biblioteca-virtual/reanuario2014-2015.pdf

INEC *et al*. (2010). *Indicadores de Género y Salud, Costa Rica 2010.* San José, Costa Rica: Instituto Nacional de Estadística y Censos. Retrieved from: https://www.paho.org/cor/index.php?option=com_docman&view=download&category_slug=genero-y-salud&alias=199-indicadores-de-genero-y-salud-costa-rica-2010&Itemid=222

Jones, J.R., Lohman, K. & Umaña, G. (1993). Water chemistry and trophic state of eight lakes in Costa Rica. *Verhandlungen des Internationalen Verein Limnologie,* 25(2), 899–905.

Kohlmann, B., Arroyo, A., Springer, M. & Vásquez, D. (2015). Agrorural ecosystem effects on the macroinvertebrate assemblages of a tropical river, chapter 12. In Y.-H. Lo, J.A. Blanco & S. Roy (Eds.). *Biodiversity in Ecosystems – Linking Structure and Function,* pp. 299-333. Intech. Retrieved from: http://www.intechopen.com/books/biodiversity-in-ecosystems-linking-structure-and-function

Losilla, M., Rodríguez, H., Schosinsky, G., Stimson, J. & Bethune, D. (2001). *Los acuíferos volcánicos y el desarrollo sostenible en América Central.* San Pedro Montes de Oca, Costa Rica: Editorial de la Universidad de Costa Rica.

Mafla, M. (2005). *Guía para evaluaciones ecológicas rápidas con indicadores biológicos en ríos de tamaño mediano, Talamanca - Costa Rica.* Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE).

Mena-Rivera, L., Salgado-Silva, V., Benavides-Benavides, C., Coto-Campos, J.M. & Swinscoe, F.HA. (2017). Spatial and seasonal surface water quality assessment in a tropical urban catchment: Burío River, Costa Rica. *Water*, 9, 558, 2–12.

Michels, A., Umaña-Villalobos, G. & Raeder, U. (2006). Epilithic diatom assemblages in rivers draining into Golfo Dulce (Costa Rica) and their relationship to water chemistry, habitat characteristics and land use. *Archiv für Hydrobiologie* 165(2), 167-190.

Ministerio de Ambiente, Energía (MINAE) y Ministerio de Salud (S) (2006). Reglamento de Vertido y Reúso de Aguas Residuales, Decreto Ejecutivo No. 33601. *La Gaceta* No.55, Alcance 8. Retrieved from: http://www.regenciaquimica.ucr.ac.cr/sites/default/files/33601-s-minae.pdf

Ministerio de Ambiente, Energía (MINAE) y Ministerio de Salud (MS) (2007). Reglamento para la Evaluación y Clasificación de Cuerpos de Agua Superficiales, Decreto Ejecutivo No. 33903. *La Gaceta* No.178. Retrieved from: https://www.aya.go.cr/centroDocumetacion/catalogoGeneral/Reglamento%20evaluación%20y%20clasificación%20de%20calidad%20de%20cuerpos%20de%20agua%20superficiales.pdf

Ministerio de Salud (MS) (2011). *Análisis y determinantes sociales de la situación de salud. Memoria institucional,* pp. 26–84. Gobierno de Costa Rica. Retrieved from: https://www.ministeriodesalud.go.cr/sobre_ministerio/memorias/memoria2012/UMI_analisis_determinantes_sociales_2011.pdf

Ministerio de Salud (MS) (2016). *Boletín Estadístico de Mortalidad por Enfermedades de Declaración Obligatoria del año 2015.* Gobierno de Costa Rica. Retrieved from: www.ministeriodesalud.go.cr/index.php/vigilancia-de-la-salud/indicadores-de-salud-boletines/boletin-mortalidad/3173-boletin-de-mortalidad-por-enfermedades-de-declaracion-obligatoria-2015/file

Ministerio de Salud (MS) (2018). *Boletín Epidemiológico* No 16-2018. Enfermedades transmitidas por vectores. Gobierno de Costa Rica. Retrieved from: https://www.ministeriodesalud.go.cr/index.php/vigilancia-de-la-salud/boletines

Mollinedo, N. (2013). *Investigación hidrogeológica para determinar el origen del arsénico en aguas para consumo humano en la región noroeste de Aguas Zarcas, San Carlos, Alajuela, Costa Rica.* Tesis de la Maestría Académica en Hidrogeología y Manejo de Recursos Hídricos. Posgrado en Geología. Universidad de Costa Rica.

Montero Mora, A. & Sandi Morales, J.A. (2009). La contaminación de las aguas mieles en Costa Rica: un conflicto de contenido ambiental (1840–1910). *Diálogos, Revista Electrónica de Historia,* 10 (1), 1–15.

Mora-Alvarado, D. (1992). Evolución y expectativas de la contaminación de la cuenca Virilla-Tárcoles. *Revista Costarricense de Salud Pública,* 2, 18–23.

Mora-Alvarado, D. (2004). Calidad microbiológica de las aguas superficiales de Costa Rica. *Revista Costarricense de Salud Pública,* 13 (24), 15–31.

Mora-Alvarado, D. (2011). *Informe: acciones correctivas para disminuir las concentraciones de arsénico en el acueducto de la comunidad de Cañas.* Laboratorio Nacional de Aguas, Instituto Costarricense de Acueductos y Alcantarillados.

Mora-Alvarado, D.A., Mata-Solano, A. & Portuguez-Barquero, C.F. (2016). *Agua para consumo humano y saneamiento y su relación con los indicadores básicos de salud en Costa Rica: Objetivos de Desarrollo del Milenio y la agenda para el 2030.* Acueductos y Alcantarillados. Gobierno de Costa Rica.

Mora-Alvarado, D.A. & Portuguez-Barquero, C.F. (2016). Cobertura de la disposición de excretas en Costa Rica para el periodo 2000–2014 y expectativas en el 2021. *Tecnología en Marcha,* 29 (2), 43–62.

Mora-Alvarado, D. & Portuguez, C.F. (2010). *Evolución de las coberturas y calidad del agua para consumo humano y disposición de aguas residuales domésticas en Costa Rica al año 2009.* Laboratorio Nacional de Aguas, Instituto Costarricense de Acueductos y Alcantarillados.

Mora-Alvarado, D., Portuguez, C.F. & Brenes, G. (2002). Evaluación de la contaminación fecal de la cuenca del río Tempisque 1997-2000. *Revista Costarricense de Salud Pública,* 11(20), 5–17.

Mora Rodríguez, F. (coordinador) (2017). *Política Nacional de Humedales 2017-2030.* Viceministerio de Agua, Mares, Costas y Humedales. San José, Costa Rica: Ministerio de Ambiente y Energía. Retrieved from: http://www.minae.go.cr/recursos/2017/pdf/consulta-linea-politica-nacional-humedal.pdf

O´neal Coto, K. (2017). UCR advirtió presencia de plaguicida usado en piña en Humedal Térraba-Sierpe. *Semanario Universidad,* May 15. Retrieved from: https://www.ucr.ac.cr/noticias/2017/05/15.html

O´neal Coto, K. (2018). UCR detecta residuos de plaguicidas en fuentes de agua en la Zona Norte. *Semanario Universidad,* June 14. Retrieved from: www.ucr.ac.cr/noticias/2018/06/14.html

OMS (Organización Mundial de la Salud). (2000). *Global Water Supply and Sanitation Assessment. World Health Organization.* Geneva. Retrieved from: http://www.who.int/water_sanitation_health/monitoring/jmp2000.pdf

Pérez-Castillo, A.G., Barboza-Mora, R. & Ramos-Matarrita, F. (2013). Calidad del agua del Refugio Mata Redonda y los arrozales colindantes, Guanacaste, Costa Rica. *Agronomía Mesoamericana,* 24(2), 379–392.

Picado Twight, C. (1915). *Análisis sanitario de las aguas que se consumen en San José.* En colaboración con F. Sancho. San José, Costa Rica: Imprenta Alcina.

PND (2014). *Plan Nacional de Desarrollo 2015-2018 "Alberto Cañas Escalante".* San José, Costa Rica: Ministerio de Planificación Nacional y Política Económica. Gobierno de Costa Rica. Retrieved from: http://www.infoagro.go.cr/Documents/PND%202015-2018%20Alberto%20Ca%C3%B1as%20Escalante%20WEB.pdf

Ramos, V., Corrales, C., Zuñiga, M., Alpízar, M., Vargas, I., Ramírez, R. & Barrantes, A. (2014). Investigación geológica hidrogeológica, e hidrogeoquímica sobre el origen del arsénico en la zona de Cañas-Bagaces y alrededores. Comisión Científica del origen del arsénico. Instituto Costarricense de Acueductos y Alcantarillados (AyA), Escuela Centroamericana de Geología, Centro de Investigaciones en Contaminación Ambiental (CICA), Servicio Nacional de Aguas Subterráneas, Riego y Avenamiento (SENARA), Dirección de Aguas (DA-MINAE). Informe interno.

Rasmussen, J.J., Reiler, E.M., Carazo, E., Matarrita, J., Muñoz, A., & Cedergreenb, N. (2016). Influence of rice field agrochemicals on the ecological status of a tropical stream. *Science of the Total Environment,* 542 (Part A) 15, 12–21.

Reynolds, J., Fraile Marino, J. & Hirata, R. (2006). *Tendencias en las concentraciones de nitratos y determinación de sus orígenes usando isótopos estables (18O y 15N) en el agua subterránea de la parte oeste del Valle Central, Costa Rica.* Universidad Nacional: Heredia. Retrieved from: http://www.observatorioambiental.una.ac.cr/index.php/indicadores-ambientales/115-tendencias-en-concentraciones-de-nitratos-y-determinacion-de-sus-origenes-usando-isotopos-estables-18o-y-15n-en-agua-subterranea-oeste-valle-central

Reynolds, K. (2002). *Tratamiento de Aguas Residuales en Latinoamérica.* Retrieved from: http://www.agualatinoamerica.com/docs/pdf/DeLaLaveSepOct02.pdf

Rico M.N. (1998). *Las mujeres en los procesos asociados al agua en América Latina. Estado de situación, propuestas de investigación y de políticas.* 8th Stockholm Water Symposium. Workshop n°8: "Contributions of women in the field of water resources" held on August 8-12 1998. Estocolmo, Suecia. Retrieved from: https://www.cepal.org/publicaciones/xml/7/4337/indice.htm

Rizo-Patrón, F., Kumar, A., McCoy Colton, M., Springer, M. & Trama, F.A. (2013). Macroinvertebrate communities as bioindicators of water quality in conventional and organic irrigated rice fields in Guanacaste, Costa Rica. *Ecological Indicators,* 29, 68–78.

Ruepert, C. (2011). *Plaguicidas y otros contaminantes, Informe Final.* Decimoséptimo Informe del Estado de la Nación. Retrieved from: https://estadonacion.or.cr/files/biblioteca_virtual/017/Ponencia-Clemens-Plaguicidas-y-otros-contaminantes.pdf

Ruepert, C., Castillo, L.E., Bravo, V. & Fallas, J. (2005). *Vulnerabilidad de las aguas subterráneas a la contaminación por plaguicidas en Costa Rica. Estudio preliminar.* (Informe ejecutivo). Heredia, Costa Rica: Universidad Nacional.

Sedeño-Días, J.E., Kohlmann, B. & López-López, E. (2012). Benthic macroinvertebrates as indicators of water quality in streams of Costa Rica: using an adaptation of the BMWP Score. *Transylvanian Review of Systematical and Ecological Research,* 14, 177–188.

SENARA-BGS (1985). *Mapa hidrogeológico del Valle Central, Costa Rica.* Servicio Nacional de Aguas Subterráneas, Riego y Avenamiento. Servicio Geológico Británico.

SENARA-BGS (1988). *Continuación de las investigaciones hidrogeológicas en el Valle Central de Costa Rica.* Servicio Nacional de Aguas Subterráneas, Riego y Avenamiento. Servicio Geológico Británico. Informe final.

Soto, M. (2012). Contaminación fecal y basura ahogan al río Torres. *La Nación,* December 29. Retrieved from: https://www.nacion.com/archivo/contaminacion-fecal-y-basura-ahogan-al-rio-torres/4PS4YFA3FJCBXIFF2LDDZLLKFU/story/

Spongberg, S., Witter, J., Acuña, J., Vargas, J., Murillo, M., Umaña, G., Gómez, E. & Pérez, G. (2011). Reconnaissance of selected PPCP compounds in Costa Rican surface waters. *Water Research,* 45, 6709–6717.

Stein, H., Springer, M. & Kohlmann, B. (2008). Comparison of two sampling methods for biomonitoring using aquatic macroinvertebrates in the Dos Novillos Watershed, Costa Rica. Ecological Management and sustainable development in the humid tropics of Costa Rica. *Ecological Engineering,* 34(4), 267–275.

Svensson, O., Sanderson Bellamy, A., Van den Brink, P.J. & Gunnarsson, J.S. (2017). Assessing the ecological impact of banana farms on water quality using aquatic macroinvertebrate community composition. *Environmental Science and Pollution Research,* 25(14), 1–9.

Umaña-Villalobos, G. (2014). Ten years of limnological monitoring of a modified natural lake in the tropics: Cote Lake, Costa Rica. *Revista de Biología Tropical,* 62(2), 567–578.

Umaña-Villalobos, G. & Farah-Pérez, A. (2018). Revisiting the limnology of Lake Río Cuarto, Costa Rica, thirty-five years later. *Revista de Biología Tropical,* 66(1), S42-S52.

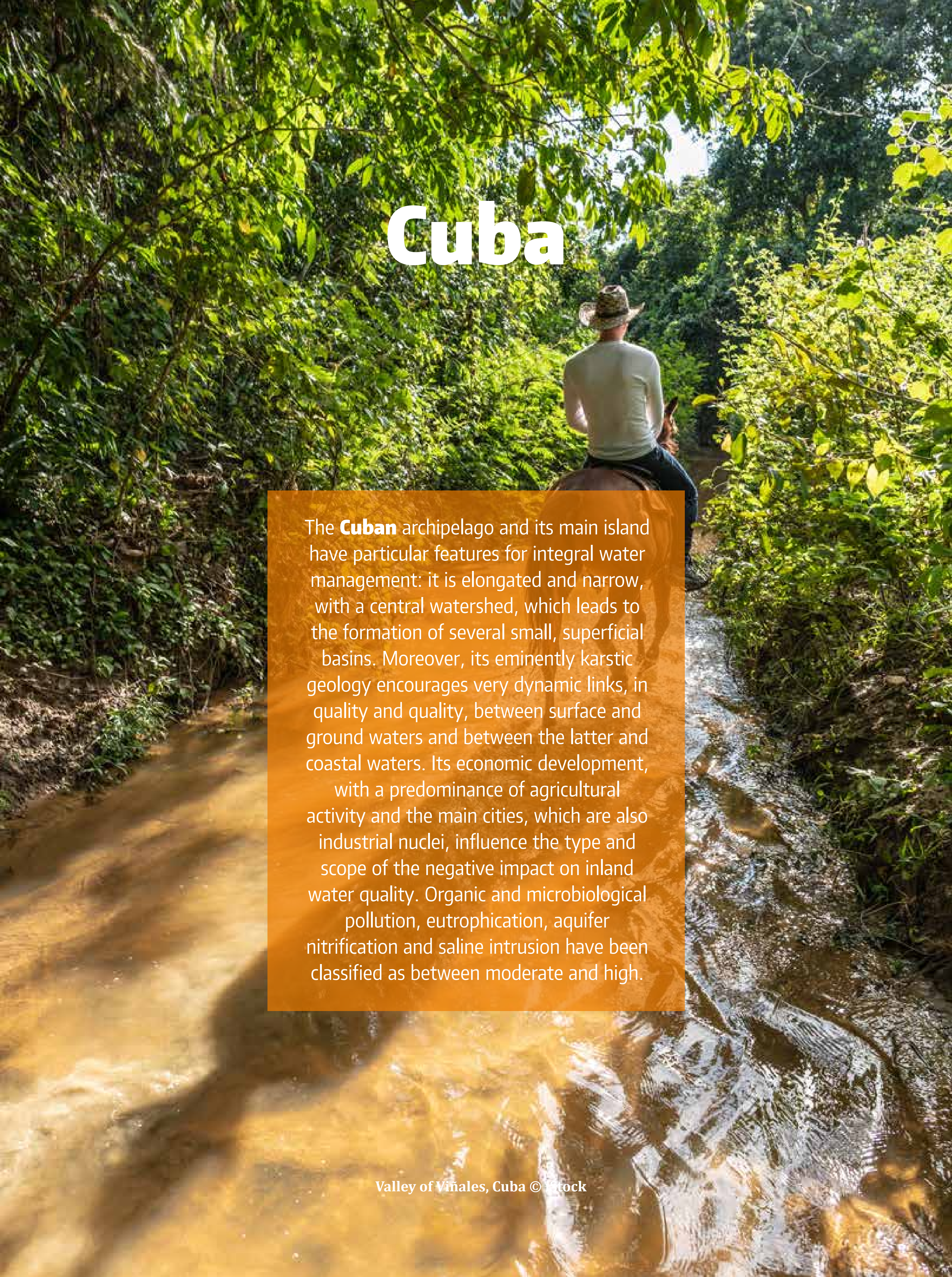
Umaña, G., Haberyan, K.A. & Horn, S.P. (1999). Limnology in Costa Rica. In R.G. Wetzel & B. Gopal (Eds.), *Limnology in Developing Countries 2,* pp. 33-62. International Association of Theoretical and Applied Limnology (SIL). New Delhi: International Scientific Publications.

UNICEF (Fondo de las Naciones Unidas para la Infancia) & OMS (Organización Mundial de la Salud) (2006). *Progreso para la Infancia: un balance sobre agua y saneamiento.* New York, USA.

Vargas Sanabria, A. (2001). El manejo histórico de los recursos hídricos en Costa Rica con énfasis en el período indígena y en los siglos XVI, XVII, XVIII y XIX. Anuario de Estudios Centroamericanos, 27(1), 59–81.

Vargas, I. (Ed.) (2015). *Manejo sostenible de la zona norte del acuífero Tempisque.* Informe final del Proyecto 802-BO-513 Vicerrectoría de Investigación. CICA, Escuela Centroamericana de Geología, SENARA, Costa Rica.

Vargas, I. (Ed.) (2017). *Propuesta del modelo hidrogeológico conceptual para la estimación de la disponibilidad de agua subterránea y análisis de la vulnerabilidad de los acuíferos en la zona oeste del Valle Central, cuenca del río Grande, Alajuela.* Informe final del Proyecto 113-B2-515 Vicerrectoría de Investigación. Escuela Centroamericana de Geología, CICA, SENARA, Costa Rica.



Cuba

The **Cuban** archipelago and its main island have particular features for integral water management: it is elongated and narrow, with a central watershed, which leads to the formation of several small, superficial basins. Moreover, its eminently karstic geology encourages very dynamic links, in quality and quality, between surface and ground waters and between the latter and coastal waters. Its economic development, with a predominance of agricultural activity and the main cities, which are also industrial nuclei, influence the type and scope of the negative impact on inland water quality. Organic and microbiological pollution, eutrophication, aquifer nitrification and saline intrusion have been classified as between moderate and high.

Valley of Viñales, Cuba © iStock

Water Quality in Cuba

Joaquín B. Gutiérrez Díaz and Jorge Mario García Fernández

1. General introduction[1]

Cuba, located between 19°49' and 23°16' N and 74°08 'and 84°57' W, placing it north of the Caribbean Sea and south of the Tropic of Cancer, is the largest island in the Antilles. Cuba is an archipelago comprising over 1,600 islands, islets and cays, with an area of 109,¿ 884.01 km^2, with the mainland accounting for 106,757.60 km^2, and adjacent cays in 3 126.41 km^2. The Island of Cuba is the largest, with 107,465 km^2, followed by Isla de La Juventud, with 2420 km^2.

In 2011, a new Political-Administrative Division was established in Cuba, organizing it into 15 provinces and 168 municipalities, including Isla de La Juventud. It has a resident population of approximately 11 239 000 inhabitants, according to data from the last census taken in 2015. Its capital is Havana, with a population of 2 125 320 inhabitants, the largest on the island, which is followed in importance by the provincial and municipal capitals.

It has complex geology, mainly on the Island of Cuba, with ancient rocks from the Jurassic and Cretaceous periods, especially in the mountainous areas, and from the Paleogene to the Quaternary eras in the rest of the territory. Carbonate rocks predominate in over 60% of the territory, influenced by climate action and topography, where karstic features are common. The relief is both complex and diverse, consisting of mountains, heights and plains accounting for two thirds of the territory.

In most of Cuba, the climate is predominantly warm and tropical, with a rainy season in the summer. In general, climate is tropical and seasonally humid, with a maritime influence and semi-continental features.

2. Overview of the water cycle and water resources

In the case of Cuba, it is essential to consider certain premises determining the strategies to be adopted to guarantee a water supply with sufficient quantity and quality for various uses, in the context of integrated water resource management (IWRM): (i) the vulnerability of the archipelago, (ii) the central watershed along the main island that delimits the formation of numerous small basins, and the predominance of karst in underground aquifers, (iii)

1. Cf. Anuario Estadístico de Cuba 2015 in ONEI, 2016.

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the dependence of water resources on the behavior of rainfall, (iv) the predominance of farming and the agri-food industry, (v) climate change and adaptation and mitigation measures, and (vi) the natural variability of the weather.

Since Cuba is an island system, the water cycle is governed by rainfall, the archipelago's only source of annual renewable water. It is a limited, finite strategic resource, essential for the sustainable development of the country.

The hydrological regime is heavily influenced by the location and physical-geographical characteristics of the archipelago, with a relief characterized by a succession of broad plains and mountain systems, which, as a result of their position, block the passage of humid air masses and the regulatory action of karst on surface runoff, mainly in the Western and Central regions of the country.

The average temperature is approximately 25°C. During the summer, daytime temperatures can exceed 30°C, whereas in winter, the weather cools to an average of approximately 21°C. Solar radiation is high, ranging from 5.16 to 5.96 kW/h/m^2, varying very little due to the elongated shape of the land. The highest values are registered in the eastern region of the country. The island enjoys between 10 and 12 hours of sunshine a day, depending on the time of year. Given these conditions, the ranges of annual average evaporation, from a free surface, vary from the western to the eastern region, from 1600 to 2400 mm/year.

2.1 Water basins and underground aquifers

The long, narrow shape of the land, together with the layout and structure of the relief, create a central watershed along the main island in the direction of its longitudinal axis, with two slopes: the northern slope and the southern slope.

The fact that rainfall is the main factor determining runoff, together with the extraordinary extent and intensity of the karstic phenomena present in Cuba, explains the predominance of relatively small catchment areas. In the archipelago, 642 surface basins with an area of over 5 km^2 have been identified, 10 of which correspond to closed basins or internal drainage (endorheic).

Aquifers are generally located in karstic formations and mostly in a hydraulic relation with the sea, leading to saline intrusion, which is sometimes intensified by the inadequate exploitation and administration of these sources. Due to the above, there is also an intense quantitative and qualitative relationship between surface water and aquifers, which results in an underground recharge through sinkholes, hollows and other means.

2.2 Rainfall and available water resources

Rain is the element with the greatest variability, both spatial and seasonal, in the Cuban climate. There are two clearly defined seasons: rainy, from May to October, when 75-80% of the annual total occurs, and mostly dry, from November to April, when the remaining precipitation takes place. Spatially, various regions have been defined with different types of rainfall, as shown in Figure 1.

According to studies published in previous years (INRH, 2002), Potential Water Resources (PWR) from rainfall have been estimated at 38 100 million m^3; comprising 6.4 billion m^3 of groundwater in 165 hydrogeological units and 31.7 billion m^3 of surface water, located in 642 hydrographic basins. Average annual rainfall amounted to 1375 mm/year. However, results from the most recent study on rainfall in Cuba, covering the period 1961-2000 (National Hydrological Service, 2006), show that the average annual rainfall is 1335 mm/year, less than the previous figure, meaning that current figures could potentially be lower. Updated figures are included in the actions linked to the passage of the National Water Policy in December 2012 (INRH, 2012).

The Water Availability Index from the RHP – an index based on rainfall and the number of inhabitants - is approximately 3400 m^3 per inhabitant per year for all uses and is evaluated as low (between 1000 and 5000 m^3 per inhabitant per year), ranking 105th out of a list of 182 countries (Allan, 1993).

The development of hydraulic infrastructure has made approximately 57% of the RHP available to meet economic, social and environmental demands. The Available Hydraulic Resources (AHR), from the hydraulic infrastructure created, amount to 13 667 million m^3, of which about 9150 million m^3 are surface and the remainder groundwater. The actual (average) Water Availability Index per inhabitant per year for all uses, on the basis of the built hydraulic infrastructure, is approximately 1220 m^3 (INRH, 2002).

Box 1. The Law of Inland Waters was passed by the National Assembly of Popular Power (ANPP) - Unicameral Parliament of Cuba

In 2012, the National Water Policy was approved by the Council of Ministers, providing a suitable framework for updating and prioritizing existing legal instruments. Prior to this, an extensive consultation process was carried out by all the social actors and citizens in general, through meetings, electronic media, workshops, mass media and other means, with the aim of updating, extending and expanding the scope and hierarchy of inland waters to raise their legal status to that of Law of the Nation. It was eventually passed by the 9th Period of Sessions of the VIII Legislature of the ANPP, held on July 13 and 14, 2017 (Law No. 124, 2017).

2.3 Water use

Inland waters in Cuba are governed by the National Institute of Hydraulic Resources (INRH), which, through a rigorous and concerted process with the main users, draws up an annual Water Use Plan, taking into account the forecasts for the availability of this resource. The Plan is divided into provinces, territories and also into river basins, and is one of the guidelines of the National Economy Plan (**Figure 1**).

Until 2013, water demands for the economy maintained an upward trend and, after the National Water Policy was approved in 2012, a process of adjustment and compliance with consumption regulations has taken place, meaning that the total figure for recent years has been approximately 7 billion m^3.

Between 2014 and 2017, the presence of an intense drought event, with unfavorable hydrological aspects, negatively affected the physical availability of both surface and groundwater.

3. Authorities and governance

3.1 Water governance and legal framework

Article 27 of the Cuban Constitution recognizes the close connection between water and the sustainable economic and social development of the country, together with the duty of citizens to contribute to its protection. Other legal instruments complement and extend the current legal basis regarding water, such as Law No. 81 on the Environment (1997). Decree Law No. 138 of Inland Waters, in force from 1993 to 2017, has since been repealed.

The INRH, founded in 1962, was ratified by Decree-Law 114 (1989) and subsequently confirmed by Decree-Law 280 (2011), with the level of the Central State Administration body responsible for directing, implementing and controlling the application of state and government policy related to the integrated, sustainable management of inland waters, understood as the coordinated evaluation, planning, use and protection of this element, the land and its resources, to maximize economic and social well-being, without compromising the health or conservation of vital ecosystems.

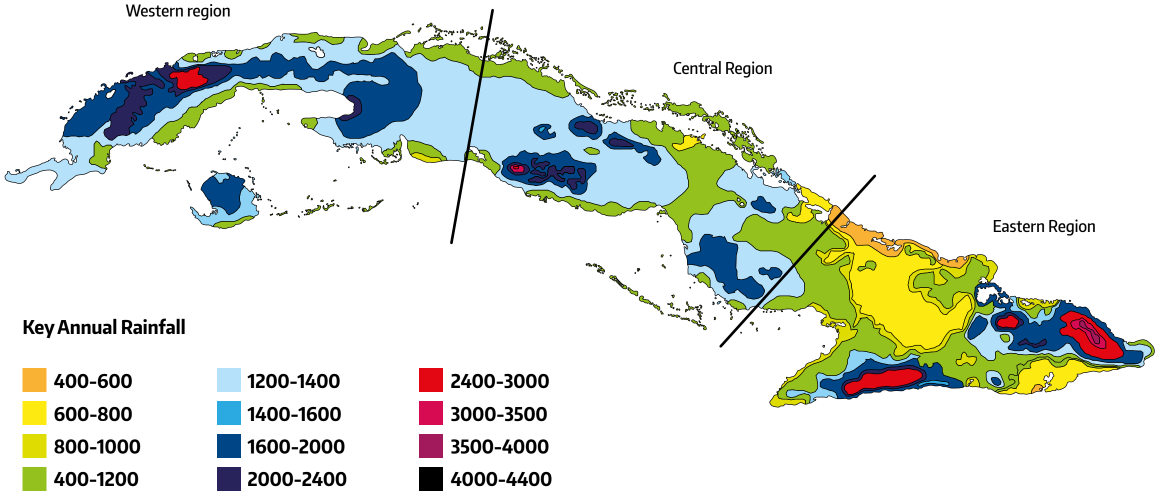
There is a system of Cuban Standards that are closely linked to the assessment of the quality of inland waters for different uses, which have gradually become key legal instruments for materializing what is contained in the Constitution, laws and decree-laws.

The aforementioned Law contains 12 titles, 36 chapters, 17 sections, three provisions and a total of 127 articles (ANPP, 2016). Its content includes articles closely linked to the protection of the quality of inland waters; maintaining their quality; drawing up and perfecting the corresponding norms according to their use or provisions; regulating and controlling their use and management; dumping waste; reusing water; encouraging the use of clean production technologies; establishing protection zones around water bodies, underground sources and recharge areas which, due to their importance, require this and adopting measures to protect natural stream channels, lake beds, lagoons and reservoirs from the dangers of excessive siltation due to erosion.

3.2 Institutional organization

The existing institutional structure for the exercise of water governance mechanisms in Cuba is based on the INRH system. Its work is closely linked to the environmental (Ministry of Science, Technology and Environment, CITMA) and public health (Ministry of Public Health, MINSAP) authorities, the Ministry of Agriculture (MINAG), and the Institute of Physical Planning (IPF), among other key insti-

Figure 1. Isohyet map 1961-2000 (mm/year)



Source: National Hydrological Service, 2006. Annual Rainfall Period 1961-2000

tutions and agencies, as well as the provincial and municipal governments in the country.

INRH has a system of provincial delegations, national and territorial companies and laboratories, which implement and control what is established in the National Water Policy, as well as the annual performance objectives and indicators, which fulfill its mission. At the same time, together with the remaining institutions and instances, it promotes, encourages and controls the fulfillment of the responsibilities related to rational, efficient water use, based on its protection and good management.

3.3 Relations with non-governmental organizations, universities and other institutions

Since its inception, the Cuban institutional organization responsible for governing inland waters, the INRH, has been characterized by establishing, developing and promoting close relationships and working links with non-governmental organizations, scientific and technical societies, universities, civil society organizations, and both provincial and municipal territorial governments.

There has been an understanding that the fulfillment of the mission of the Institute to ensure the quantity and quality of water for the sustainable development of the country, requires facilitating and enhancing the participation of all actors to achieve that end, without replacing the specific responsibilities of each institution, and creating synergies and spaces for coordination and integration.

Thus, in a perfectible process that could achieve greater results, for many years, INRH has participated in cooperation programs with the Technical University of Havana (CUJAE), particularly with the Center for Hydraulic Research (CIH), which has borne fruit in terms of water management. Since the early 1980s, it has promoted, encouraged and supported the strengthening and development of the activities of the Hydraulic Engineering Society (SIH) of the National Union of Architects and Construction Engineers of Cuba (UNAICC). It also directs and develops national and international actions through the Cuban Committee of the UNESCO International Hydrological Program (IHP-UNESCO).

Likewise, it has expanded its collaboration in training issues with the national system of universities, which offers a degree course in hydraulic engineering and others related to water management, such geography, chemistry, biology and meteorology, to mention some of the most important ones.

It also maintains extensive links with other organizations in the United Nations system, including: the United Nations Development Program (UNDP), the United Nations Children's Fund (UNICEF) and the United Nations Environment Programme (UNEP).

4. Main quality problems of inland waters

From a general point of view, the insufficient number of sewage and treatment systems in communities, cities and towns, coupled with the existence of industries without proper treatment of their wastewater and other causes, has led to a situation in which the flow and load of the wastewater that enters inland waters has compromised their use. Most of the hydrographic networks that cross our main cities and towns are used as receiving bodies for raw or partially treated wastewater, creating unfavorable hygienic-sanitary situations for the normal development of economic and social activities, with a potentially negative impact on health (INRH, 2002).

In the Cuban national context, there is a predominance of domestic sewage, industrial sewage from the agri-food sector (agriculture, livestock, food, sugar, fishing), industrial chemicals from the chemical and mining sector and mixed sewage (usually a combination of domestic and other types of waste). These discharges produce the following negative effects in the receiving bodies: a decrease in the saturation concentrations of dissolved oxygen, an increase in organic, dissolved and suspended matter, reflected in a rise in the Biological Oxygen Demand over five days (BOD5); an increase in turbidity, color and suspended solids, an increase in the concentration of nitrogen and phosphate and therefore problems of eutrophication, a greater presence of bacteria of fecal origin, an increase in salinity, nitrification of aquifers, and the presence of metals and organic compounds, among others.

4.1 Eutrophication

The term "eutrophication" is used to characterize the biological effects caused in natural aquatic ecosystems by increasing nutrient concentrations, typically phosphorus (P) and nitrogen (N). Since the mid-20th century, it has been recognized as a phenomenon induced by man, and has been registered as a problem in water bodies in various countries.

Eutrophication in Cuba is caused by the increase of nutrients P and N in water bodies, mainly reservoirs, which contribute domestic or mixed waste, agricultural waste and drainage from intensive agriculture (use of inorganic fertilizers).

Most of the hydrobiological studies that resulted in methodologies for classifying the trophic levels of reservoirs were developed in temperate climates. In order to offset the differences in the methodologies used, the former Pan American Center for Health Engineering and Environmental Sciences (CEPIS), together with several Latin American countries, developed a simplified methodology for the evaluation of eutrophication in tropical hot lakes between 1981-1990, also used for reservoirs, adapted to the conditions of the Latin American climate. Its final version, published in 2001 and known by its acronym LACAT (Salas and Martino, 2016), is the one that has been applied in Cuba for this type of studies.

The application of this model in some reservoirs (Laiz *et al.*, 1979) in the central and western region of Cuba -Lebrije (Le), Higuanojo (Hi), Zaza (Za), Tuinucú (Tu), Avilés (Av), Abreus (Ab), Paso Bonito (Pb) and Pedroso (Pe), the latter in the province of Mayabeque, in the west of the country-revealed that according to the average P, the reservoirs studied have trophic levels ranging from oligotrophic, mesotrophic to eutrophic, where a single reservoir, Pedroso, obtained a hypertrophic evaluation (see **Figure 2**).

Reservoirs with trophic classifications (eutrophic and hypertrophic) have obvious signs of eutrophication, which are associated with the presence and abnormal growth of aquatic vegetation, especially water hyacinth, *Eichhornia crassipes*.

4.2 Agrochemicals and nitrification of aquifers

Cuban soil has characteristics that encourage the intensive use of fertilizers, pesticides and herbicides. Data corroborating this use have been obtained from the Ministry of Agriculture (MINAG) and its Institute of Soils (IS). The agricultural area of Cuba is approximately 6.7 million hectares (ha). Cuban agricultural soils have a variety of conditions limiting their use and productivity. In particular, 70% have very low organic content while 45% have low fertility, meaning that extensive agriculture requires the use of fertilizers, linked to pesticide and herbicide use, as well as soil improvement and conservation measures.

Data and estimates of fertilizer use in Cuba (Rodríguez, 2015), during the period 1960-2010, indicate that the intensity of the use of fertilizers in the agricultural area increased steadily between 1980-1990, reaching an estimated maximum of 190 -220 kg/ha; approximately 60% of which were nitrogen fertilizers, decreasing sharply until the beginning of 2000, after which it began to rise again (**Figure 3**).

The excessive concentration of nitrates in the groundwater of Cuba is associated with diffuse and point sources of contamination. Diffuse sources are mainly due to the application of fertilizers, chemicals and organic to agriculture, this being the main cause of the increase in nitrate concentrations in groundwater. Point sources are the contributions to the soil of: raw domestic waste, effluents from treatment systems, agricultural waste and industries with discharges rich in nitrogen compounds.

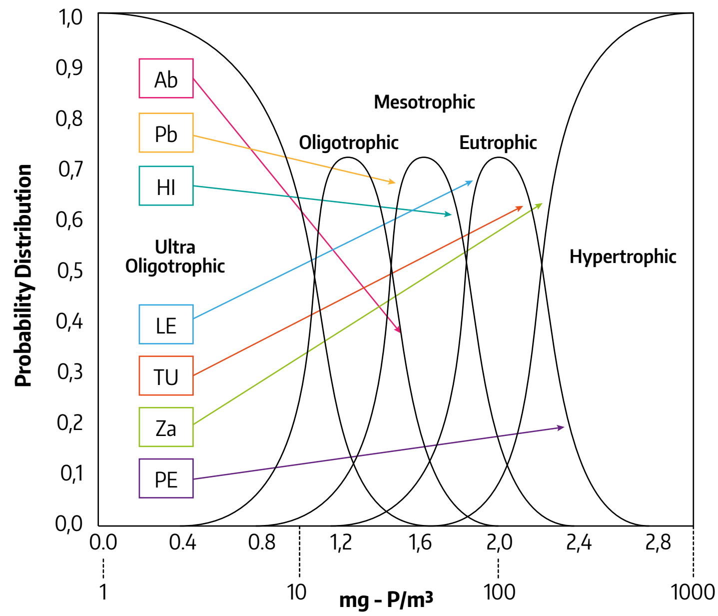
Groundwater is predominantly linked to karst systems, which are vulnerable to pollution. An analysis of the period 1960-1990 shows that nitrogen fertilizer applications nationwide were between 40-100 kg/ha, reaching high values from 1980 to 1990 of approximately 100 kg/ha (**Figure 3**), comparable to figures in developed countries. These application rates obviously changed the dynamics of the nitrogen cycle in the soil and raised the concentration of nitrates in aquifers by increasing it in percolated waters.

The presence of nitrate is considered a priority in terms of defining the quality of drinking water in Cuba, particularly in terms of health. The maximum permitted concentration of nitrates according to the current potability regulations is 45 mg/l (National Standardization Office, 2012).

The National Water Quality Control Network (RedCal) monitors the concentration of nitrates in groundwater. The results obtained indicate that since the 1980s, variations in nitrate concentration in groundwater have evolved, as can be seen from the behavior of the 1983, 1991, 2010 and 2014 data. As a trend, in the years analyzed, the nitrate concentration range between 0 and 10 mg/l decreased, increasing slightly between 10 and 20 mg/l and 20 and 40 mg/l. Seasons with values over 45 mg/l have remained virtually unchanged (URA-INRH, undated).

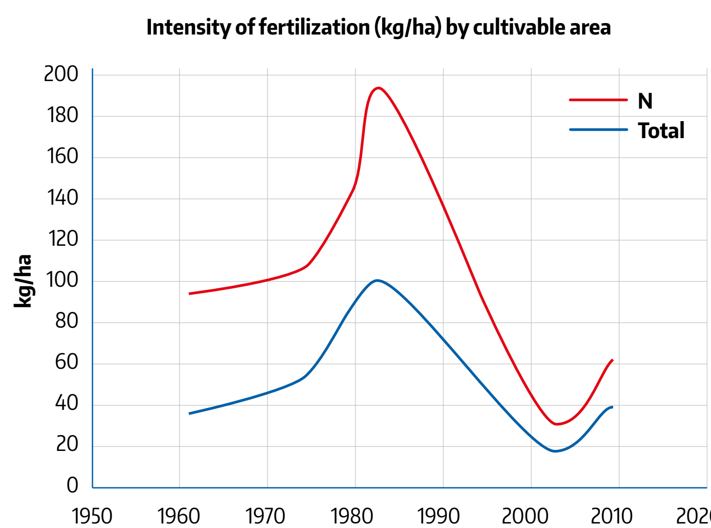
The highest applications of nitrogen fertilizers occurred between 1985 and 1995. The increase in the nitrate concentration of aquifers occurred gradually and in terms of tens of years. In general terms, a rapid reduction of nitrates has not been observed

Figure 2. Trophic levels in Cuban reservoirs according to LACAT



Source: Laiz *et al.*, 1979.

Figure 3. Trends in the intensity of fertilizer application in Cuba



Source: Prepared by D. Rodríguez, 2015.

since the decrease in nitrogen fertilization applied from the 1990s onwards.

With the disappearance of European socialist countries, together with the resurgence of the commercial, economic and financial blockade imposed by the US government against Cuba, which is still in force, as can be seen in **Figure 3**, since the 1990s, Cuban agriculture has undergone an intense, far-reaching change in fertilizer use due to the limited financial and technological resources available.

An intense search was conducted for sustainable, organic and other alternatives and technologies to ensure food sustainability in the country. New sources of nutrients were developed and applied on the basis of agricultural production, such as compost, earthworm humus, biofertilizers and biopesticides.

Demonstration Polygons for Soil, Water and Forest Improvement and Conservation were also developed (Rodríguez, 2017). They are conceived as sites designed to implement integrated technologies for soil, water and forest resource management, through intervention in plant health and other means. The main objective of these sites is to build capacities in communities, productive sectors and local governments to address the effects of climate change, through a sustainable agricultural approach, in which farms are considered the basic management unit and watersheds a geographical physical space to be protected. The use of polygons as priority areas for soil, water and forest conservation lent a new dimension to the work being carried out in Cuba through the National Soil Improvement and Conservation Program (Spanish acronym PNMCS).

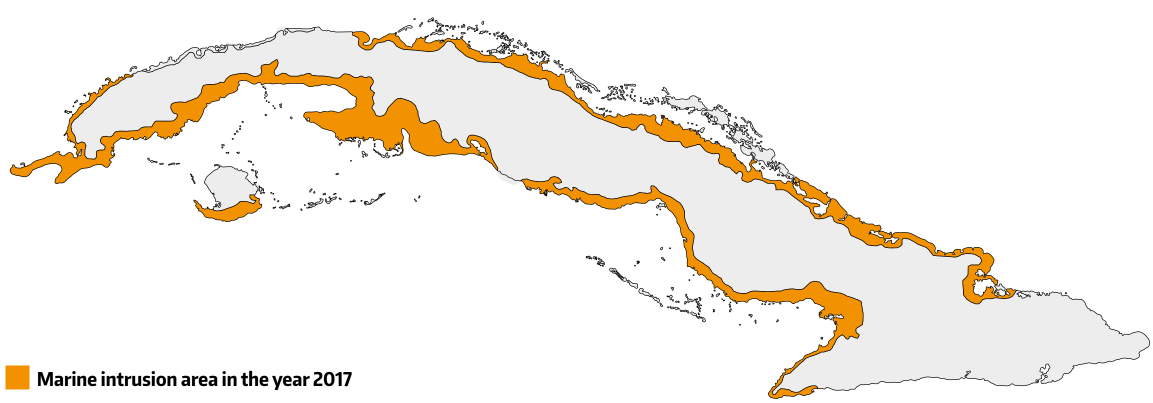
4.3 Marine intrusion and soil salinization

Marine intrusion is a phenomenon that occurs in coastal aquifers. It is a dynamic process, whereby saltwater moves inland during periods when there is a lower recharge of the aquifer and retreats towards the sea when the recharge increases. This mechanism attempts to strike a balance between freshwater and saltwater, which depends on several hydrogeological conditions, among which the volume of fresh water contributed to the sea is usually the most important. When groundwater extraction increases, sometimes reaching overexploitation levels, the volume of fresh water discharged into the sea is reduced, allowing a significant increase in the entry of seawater into coastal areas. In these cases, the freshwater-saltwater interface tends to achieve a new equilibrium. If the volume of extraction is greater than the natural recharge of the aquifer, the process of saltwater intrusion is continuous and sustained. Within a certain time, wells close to the affected area will increase their salinity, due to the mixture of freshwater and seawater, as a result of exploitation.

Marine intrusion in Cuba, mainly induced by poor groundwater management and exploitation practices, is present to a greater or lesser degree in coastal karst aquifers subjected to intense use, especially irrigation and potable water supply. Among climate change effects, rising sea levels will lead to the penetration of the sea inland, which in turn will cause a significant change in the dynamics of saltwater intrusion in Cuba.

Project 13 “Estimation of the impact of climate change on the possible advance of marine saline intrusion in coastal aquifers of Cuba”, is part of the “Coastal Hazard and Vulnerability (2050-2100)”

Figure 4. Map (1:250000) of 2009-2010 saline intrusion



Source: INRH (GEIPI, GEARH y EIPH, 2011).

Macroproject implemented by CITMA. As part of the project, INRH specialists produced a model and map of the curve of total soluble salts (TSS) of 1 g/l, on a scale of 1:250 000 (GEIPI, GEARH and EIPH, 2011). This result is shown in **Figure 4**. Work continues on estimates for the 2050 and 2100 scenarios.

4.4 Heavy metals

Studies on metals in water were developed at the same time as the analytical capacity for their detection grew, with the advent of the atomic absorption spectrometer and its subsequent development: the graphite furnace and new generations of ICP equipment. This high-cost technology is a constraint for developing countries that do not have access due to the availability of funds or the development of specialized personnel.

Cuba was not exempt from these constraints and in the 1970s, it was possible to use atomic absorption spectrometry and initiate large-scale studies of heavy metals in natural waters. In 2012, the Cuban Standard NC-827:2012 (National Standardization Office, 2012) came into effect, establishing the concentrations to be met by the supply sources, in other words, the maximum admissible limit (MAL).

The RedCal conducted two special metal assessments. The first specific study to monitor and evaluate metals in the main groundwater sources, in both the dry and rainy season, was undertaken in 2003 (Mora *et al*., 2003). It included the use of a relatively large number of stations located in the western, central and eastern regions of the country. The metals identified were: cadmium (Cd), cobalt (Co), manganese (Mn), copper (Cu), zinc (Zn), lead (Pb), iron (Fe) and nickel (Ni). Only 5% of the results yielded values above the expected range, according to the established standard, which were attributed to problems of sampling or contact with metal agents (pipes, connections), since there were no nearby sources of contamination.

The second study, which was extremely important since it included the sampling of both surface and underground water supply sources for the population, was conducted in 2016 (GEARH, 2016). A total of 2620 sources were examined during the first stage and 310 in the second to re-sample suspicious results. The following metals were identified: cadmium (Cd), chromium (Cr), manganese (Mn), copper (Cu), zinc (Zn), lead (Pb), iron (Fe) and nickel (Ni). Only 9% of results showed values above the expected range, which was attributed to the contact between water and metals in the water pipes. No contamination sources, whether natural or anthropic, were identified in the vicinity of these sources.

These studies indicate that Cuban surface and underground water supply sources are not affected by metal pollution, and that their natural level is relatively free of the metals considered.

5. Programs designed to control negative effects on inland water quality

5.1 Water quality monitoring network

To control the quality of inland waters and the impact of wastewater discharge into surface and groundwater basins, the INRH designed and operates the National Network of Water Quality Observations (RedCal).

Its main purpose is to: i) collect basic data on water quality in order to categorize the country's water resources; ii) determine, by monitoring water quality, the suitability of the sources intended for various purposes, especially those used in the public water supply, iii) classify the country's water resources by quality in order to optimize their use and efficiently manage them; iv) specify and quantify the negative influence of the pollution of water bodies in order to identify current dangers and future risks, and therefore take the appropriate actions, v) determine the effectiveness of wastewater control and treatment measures, vi) identify water quality trends and implement the appropriate alarm and action system and vii) prepare and operate a national information system on water quality.

RedCal has more than 30 years of systematic observation to date and its number of stations has fluctuated between 2400 and 3500 per year. In the past 10 years, the number of stations per year has been approximately 2700, including approximately 75% basic stations and 25% monitoring stations. Between 75% and 80% of the basic stations are for groundwater and the remainder for surface water. Most monitoring stations are for surface water, including wastewater discharges.

INRH has 14 water laboratories at the provincial level. The national laboratory undertook more complex analyses requiring specialized equipment to determine metals and organic compounds. The results of its operation, especially the data and information generated, constitute an official source for the entire country.

INRH functional directorates, in conjunction with the provincial delegations and the business system in charge, prepare annual bulletins and hydrological reports at the end of the dry (November to April) and rainy (May to October) seasons, used for making decisions and evaluating their behavior over time.

5.2 Water quality assessment

The main water quality assessment tools used by the INRH are the systematic determinations of the quality parameters monitored at the stations and their comparison with the provisions of current legal regulations. Water Quality Indices (WQI) are also used (García and Gutiérrez, 2015) together with other instruments, such as self-purification models of currents, and the trophic classification of reservoirs, albeit to a lesser extent and less frequently. Water quality bulletins are systematically developed.

5.3 Forest cover

The world community is increasingly aware of the importance of the goods and services provided by forests. Forest-soil-water relationships are crucial to the health of productive and conservation ecosystems. One of the first programs of the Revolution, launched in 1959, was the National Reforestation Program. It was a response to the status of the country's forests. Estimates indicate that, at the time of the Spaniards' arrival in Cuba in the 15th century, forest cover amounted to approximately 90%, which had declined to 50% in 1900, as a result of the development of sugarcane agriculture. In 1959, it was no greater than 14% (Herrero, 2017).

In 1979, the reforestation program was perfected and developed through a Government Agreement (Agreement 509/1979), oriented towards the reforestation of watersheds and the establishment of forest strips to protect water bodies. In 1998, the National Assembly of People's Power of Cuba, the highest body in the country, approved Law No. 85 (Forestry Law), which raised these actions in a hierarchical, executive manner. In 1999, the Cuban Standard NC-23 "Forestry Belts of Protection Zones for Reservoirs and River Channels" was adopted.

As a result of all these actions, by the end of 2015, forests in Cuba occupied an area of 3 184 000 ha, 2 656 000 of which correspond to natural forests

Table 1. Woodland Indices in Basins of National Interest (2015)

Basins of National Interest	Basin Area	WI %	WI %	WI %	WI %	WI %	Potential WI
Name	(ha)	2011	2012	2013	2014	2015	(%)
Cuyaguateje	79 500	69,1	69,6	70,3	70,1	70,3	87,0
Almendares-Vento	40 200	19,3	20,4	21,2	22,1	22,8	33,2
Ariguanabo	29 500	17,7	18,2	18,7	18,7	19,1	35,6
Ciénaga de Zapata	500 000	55,8	55,9	56,1	56,1	56,2	57,0
Sagua la Grande	218 416				7,20	7,70	10,3
Hanabanilla	28 747	40,5	40,8	40,9	41	41,0	41,9
Zaza	241 300	8,3	8,7	8,3	9,1	9,5	11,7
Cauto	954 020	17,3	17,6	18,3	18,6	19,5	21,0
Mayarí	126 40	34,6	35,0	36,4	37,3	38,0	43,3
Toa	106 100	92,2	92,4	92,6	93	93,0	94,4
Guantánamo-Guaso	234 700	24,7	24,8	25,2	25,4	25,5	28,6

Source: Herrero, 2017.

and 528 000 to plantations (Herrero, 2017). In the distribution by categories, Water and Soil Protecting Forests account for 30% of the total.

This category includes natural and planted forests on the banks of water bodies known as gallery forests, those located at the headwaters of the rivers, water recharge zones and lands with steep slopes located mostly in the upper section of the basins.

Expanding the area of soil and water protective forests is important in that it decreases erosion and sediment transport, and nutrient concentrations, while at the same time, it will increase sunlight penetration, dissolved oxygen and the self-purifying capacity of rivers, all of which improve water quality.

Table 1 shows the increase in the Woodland Index (WI) in the basins of national interest. Comparing the WI with the potential WI shows the effort that remains to be made.

5.4 Inventory of polluting sources of inland waters

Pollution source inventories are used as a reference for control and inspection, the location of financial and technical resources, monitoring and follow-up, among other activities, at the level of provinces, municipalities, watersheds or any other unit selected. This working instrument has been institutionalized and perfected in the country, by both the entity responsible for the Cuban environment, CITMA, and the National Institute of Hydraulic Resources (INRH), responsible for controlling inland

The characterization and physical-chemical and bacteriological monitoring of wastewater is, above all, a responsibility of the entity that generates it, according to the legal instruments in force. This characterization is an essential activity for determining the impact of wastewater discharge and its probable effect on the receiving body, in terms of concentration units and pollutant load. The environmental authorities are responsible for granting environmental licenses, with the participation of the water and health authorities, and other agencies. The license has a specific point referring to the quality requirement for discharges and the corresponding monitoring for carrying this out. Both the characterization of wastewater and the entire process of granting environmental licenses, in relation to water pollution, is contemplated in the NC-27 "Wastewater discharge into inland waters and sewerage. Specifications" (National Standardization Office, 2012).

Box 2. Inventory of polluting sources of inland waters, a tool for monitoring and controlling their quality

INRH records of recent years show that approximately 2,260 main pollutant sources of inland waters have been identified, particularly water supply sources for the population, of which approximately 72% of the wastewater produced is treated. The main polluting sources are agrifoods, accounting for nearly 700, followed by mixed and household waste with 254 and 712, respectively, and industry with 594.

According to data presented in the Statistical Yearbook of the National Bureau of Statistics and Information of Cuba (ONEI) (2016), provided by CITMA, in 2015, the pollutant load of organic origin discharged into the environment, mainly inland waters, and in relation to the main polluting sources considered in the inventory, was 157 547 tonnes of BOD5/year.

5.5 Wastewater treatment

There are no records of the design, construction and operation of wastewater treatment systems in the country before 1959. As a result of the concern of the Cuban government and specialized institutions, a process began in the early years of the triumph of the Revolution to train human resources and build wastewater treatment systems to protect the quality of inland waters, in the context of the economic and social development the country experienced.

In the period 1971-1976, Cuba was among the first countries in Latin America and the Caribbean to adopt and build stabilization ponds, initially for household waste treatment, and subsequently for the treatment of livestock, sugar mill and food industry waste. In late 1997, there were approximately 1800 ponds operating in the country, administered by the INRH (300), other organisms and communities, mainly intended for household waste treatment.

In 2014, there were approximately 3000 of these ponds (Gutiérrez and García, 2015). ONEI (2016) reports that there are 561 localities in Cuba benefiting from sewerage systems, with a total of 787 wastewater treatment systems administered by INRH.

In 2017, 15 compact waste treatment plants were operating, most associated with tourist centers and the remainder in urban areas of the country's capital. Total treatment capacity of the plants is roughly 70,000 m^3/d. In general, approximately 55% of the wastewater produced in the country is properly treated.

From a general point of view, wastewater from the tourism industry, not linked to sewage systems, is treated in compact plants, most of which use the activated sludge process, with final polish depending on their reuse. Pig breeding and fattening facilities have conventional wastewater treatment systems: bar racks, grit chambers, anaerobic digesters and lagoon systems.

In sugarcane agriculture, for years, the controlled fertigation of its fields has been carried out with the wastewater generated in sugar mills, sugar refineries and distilleries, disposing of them through lagoon systems, and preventing high pollution loads from affecting rivers and estuaries.

6. Investments in water quality programs

Data from ONEI indicate that environmental investments oscillated annually in the 2011-2015 period, from 482 to 562 million pesos. Of the components shown in **Table 2**, water has been the largest recipient, with a percentage contribution of approximately 50% of total environmental investments per year, enabling actions and programs to be implemented that improve water quality at the national and local levels, whether directly or indirectly.

In addition to the above, for example, the actual spending of investments allocated for environmental protection in the 11 Basins of National Interest in the period 2011-2015 amounted to approximately 799.8 million pesos, oscillating annually between 118 and 229 million, with an annual average of approximately 160 million pesos (an average of 32,4% of total annual investment for the environment). In 2016, it amounted to 184.84 million in investment expenses and 12.3 million in current expenses

As a trend, approximately 85% was allocated to water management annually throughout the country (sewerage networks, wastewater treatment and equipment for quality control and water pollution in the basins).

Table 2 lists the expenditure for environmental protection between 2011 and 2016, including integral watershed management expenses.

7. Millennium Development Goals. Sustainable Development Goals

In September 2002, the United Nations General Assembly approved the Millennium Declaration, which comprehensively addresses and expands on the agreements signed at the United Nations world summits in the 1990s.

Through the National Institute of Economic Research (INIE), in close collaboration with ONEI, Cuba submitted periodic reports to the United Nations system on the development of millennium indicators, available for consultation on the ONEI

Table 2. Investment expenses for environmental protection (units in thousands of pesos)

Environmental Sectors	2011	2012	2013	2014	2015
Total	**482 454,8**	**488 452,6**	**517 267,0**	**562 621,3**	**534 820,6**
Water	309 354,1	240 948,6	230 435,8	258 398,4	298 054,3
Land	18 146,9	18 473,6	23 61,0	32 172,5	11 233,5
Atmosphere	10 253,4	123 262,5	127 300,0	55 961,3	36 723,8
Forest resources	74 661,6	71 445,0	122 140,5	126 590,6	91 667,5
Solid waste	13 924,9	12 307,3	10 484,8	24 862,1	17 425,2
Remainder	20 073,9	1 957,2	3 295,1	64 646,4	79 716,2

Source: ONEI, 2016.

Table 3. Millennium Development Goals 2014 (Goal 7C)

Indicator Goal Official Indicators	2011	2012	2013	2014	2015
7.8 Proportion of the population with access to improved drinking water supply sources (%)					
Urban Zone	81,90	96,30	96,30	98,30	93,90
Rural Zone	68,80	72,20	77,20	75,70	74,70
7.9 Proportion of the population with access to improved sewerage services (%)					
Urban Zone	96,10	97,00	97,90	98,40	94,60
Rural Zone	68,20	83,20	86,00	82,50	81,10

Source: ONEI, Objetivos de Desarrollo del Milenio (2015).

website (www.one.cu). INRH was in charge of the information on Goal 7C: "To halve the percentage of people without sustainable access to drinking water and basic sanitation services by 2015".

The high figures and coverage reached by Cuba have been achieved in difficult economic circumstances due to the financial, commercial and economic blockade of the US Government and without collaboration from international financial organizations.

According to the *Anuario Estadístico de Cuba 2016* (ONEI, 2017), chapter 2 "Environment", the population with access to drinking water in the urban area reached 98.3% (household connection 85.6%, public service[2] 2.9% and easy access[3] 9.8%. Similar percentages of 40.4%, 10.7% and 35.4% were reported in the rural area), while sewerage in the urban area reached 98.4% (sewerage 46.3%, pits and latrines 52, 1%) and 92.2% in the rural area (sewerage 3.5%, pits and latrines 88.7%), supporting the priority placed by the country on the disinfection of water intended for human consumption.

7.1 2030 Agenda for Sustainable Development

In September 2015, the 2030 Agenda for Sustainable Development was adopted at the United Nations, conceived as a new, more comprehensive plan of action. This new 2015-2030 vision transformed the Millennium Development Goals: it has 17 Sustainable Development Goals (SDGs).

2. Public service involves water service by water trucks, and users have to haul water inside and outside the home.

3. Easy access: requires fetching water from distances of up to 300 meters. Both definitions appear in the reference cited.

INRH, the institution responsible for organizing, planning and supplying information on goal 6, "Ensure availability and sustainable management of water and sanitation for all" and its eight targets, is working on this to offer national data and information, in keeping with the commitments already adopted.

8. Successful experiences

8.1 Environmental management in watersheds

Based on articles 110 and 111 of the Environmental Law 81 of 1997, the Executive Committee of the Council of Ministers of Cuba (CECM) adopted Agreement 3139 that same year and created the National, Territorial and Specific Councils of Hydrographic Basins. The Regulations of the Councils came into effect in August 2007. Eleven basins of national interest distributed throughout the country have been approved, on the basis of their economic, social and environmental importance, together with 50 basins of provincial interest, adopted by agreements of the respective provincial governments.

From the outset, through concrete work programs, indicators for integrated basin management in the basins have enabled their permanent evaluation. They include: (i) environmental protection investments in the Basins of National Interest, (ii) water resources (quantitative and qualitative networks, potable water and sanitation coverage, maintenance of hydraulic infrastructure, (iii) water use planning by watershed, (iv) soil improvement and conservation, (v) reforestation (total cover, forest belts and forest farms), (vi) fire control and management,

(vii) cooperative surveillance of natural resources, (viii) the fight against pollution and reduction of the pollution load, (ix) studies and sustainable use of biological diversity, (x) environmental education and participation, (xi) science and technological innovation, and (xii) Territorial Management plans.

The passage of Law 124/2017 on Inland Waters mentioned above (see **Box 1**) and the adoption of its Regulations has strengthened the role and responsibilities of the Boards. Now, with greater scope and hierarchy, everything related to water management and its quality in the basin will continue to develop.

8.2 Education and public awareness. "Water is Children's Friend" Project

In order to increase knowledge and develop a culture of water care as a natural resource for Cuban children, in 1999, the INRI formed the National Water is Children's Friend Group, which has had the support of the United Nations Children's Fund (UNICEF), the Hydraulic Engineering Society of the National Union of Architects and Construction Engineers of Cuba (UNAICC), the Cuban Committee of the International Hydrological Program (IHP), the Cuban United Nations Association (ACNU), the Country Association Program in Support of the Fight against Desertification and Drought (OP15), coordinated by the Environment Agency of Cuba, and other institutions, as well as local governments in each province.

The central mission of this group has been to develop work initiatives with the population ages 5 to 24, to strengthen the health education of children, adolescents and young people from all the provinces in the country, in aspects related to water –such as its importance for hygiene and health- with a view to developing a sense of duty towards this resource, as regards its proper use, saving and protection, emphasizing the need to develop the necessary hygienic habits.

The activities carried out include the growing participation of children, adolescents and young people in the TRAZAGUAS contest, which achieved its XVIII annual edition in 2017. Its extensive national dissemination meant that that year, a total of 5789 contributions were received in the different modalities (drawings, stories, poetry). In each edition, the organizers of the contest have printed posters with the awarded works. In addition to reflecting the efforts of the children and young participants, this dissemination is a means of conveying experiences to others. In particular, the publication of seven books with the stories, poetry and experiences of the winners, has achieved an enormous impact.

The steady work of TRAZAGUAS has led to a sustained increase in the number of circles of interest dedicated to water throughout the country. In 2016, there were 173 of these circles, bringing together a total of 2876 children and adolescents enrolled in elementary, middle and high school and special education, who receive the technical attention and guidance of specialists in the various INRH entities and other institutions linked to water management.

9. Conclusions and Recommendations

Now that the status of water quality in Cuba has been described, **Table 4** shows a causal chain of the main problems identified, proposed by the authors.

In the past 50 years, the government, through the corresponding national authorities, particularly the authorities responsible for inland waters, have systematically promoted the tasks related to the diagnosis, detection, evaluation, legal instruments and institutional arrangements to assess the quality of the waters in the country. There is a profound knowledge of these fundamental characteristics and others, as already described, which not only ensure the safe supply of the proper quantity of water, but also its quality.

This has been achieved in a specific, complex context marked by a variety of causes, such as:

- Island status, vulnerability and negative impacts of climate change on water resources. Cuban hydraulic development is an important achievement of the Revolution.
- Stiffening of the US Government's financial, economic and commercial blockade against Cuba.
- Decision by the government to annually spend millions of dollars on investment in and maintenance of water management and hydraulic infrastructure in the country.
- Development and implementation of plans and programs directly and indirectly designed to improve the quality of inland waters, such as:
    - National Hydraulic Plan;
    - Plan to Combat the Contamination of Inland Waters;

Table 4. Causal chain of water quality problems

Pollution problems	Sectors	Immediate cause	Impact Assessment	Root cause
Eutrophication	Agriculture	Increase in nitrate concentrations in groundwater.	Moderate-High	High use of nitrogen fertilizers.
Nitrification of aquifers	Agriculture	Increase in nitrate concentrations in groundwater.	Moderate-High	High use of nitrogen fertilizers.
Urban pollution	City planning	Loss of quality in surface currents, especially rivers that cross large urban centers.	High	Lack of sewage infrastructure and wastewater treatment.
Industrial and agro-food contamination	Industry	Loss of quality in surface streams that receive wastewater discharges.	Low-moderate	Absent or deficient wastewater treatment.
Pollution related to the erosion of soils and channels	Agriculture (soils and forest)	Increase in transport rates of suspended solids in surface streams and reservoirs.	Moderate	Poor soil and forest management.
Saltwater intrusion pollution	Agriculture	Increase in salinity in groundwater.	Moderate	Overexploitation of aquifers. Poor control of extractions.
Heavy metal pollution	Mining and Geology	Increase in metal concentrations	Low	Mining Activity Natural pollution

Source: INRH, prepared by the authors of this chapter.

- Investment and Maintenance Program, for the relative increase in water availability for the economy, society and the environment, increased coverage of drinking water and sanitation;
- Hydrometry program in drinking water networks and pipes and channels and water transfers between basins;
- Program for increasing efficiency in water use and reducing losses from pipes;
- Improvement of RedCal with an increase in the number of identifications, especially of metals and organic compounds;
- Rehabilitation program of the Hydrogeological Network to evaluate and control Saltwater Intrusion;
- Soil Conservation and Improvement Program, which includes the development of water, soil and forest polygons;
- National Reforestation Program, especially in hydrographic basins and hydro-regulatory fringes.

In this respect, it is recommended that continued efforts should be made to:

- Extend the monitoring of sediments in areas affected by industrial discharges, and increase the number of parameters to be detected systematically, especially organic compounds linked to their use in agriculture.
- Increase the frequency of monitoring in sections of rivers affected by wastewater discharges and incorporate hydrobiological variables, in order to study the status of the most important aquatic ecosystems.
- Strengthen existing cooperation relationships with national scientific and educational institutions, which undertake specific studies or research related to water quality, and take into account their results with a view to adopting pertinent actions.

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Bibliographical references

Allan J.A. (1993). Fortunately, there are substitutes for water otherwise our hydropolitical futures would be impossible. In: *Priorities for water resources allocation and management.* London: ODA. pp. 13-26.

García, J. M. y Gutiérrez, J. (2015). Un índice para evaluar la calidad de los recursos hídricos superficiales en cuencas hidrográficas (ICA sp 2014). *Revista Voluntad Hidráulica* No. 113 de 2015. ISSN 0505-9461.

GEIPI / GEARH / EIPH (2011). *Exposición sobre los trabajos relacionados con el cumplimiento a los proyectos 13 y 9, del Megaproyecto sobre el Cambio Climático en la República de Cuba. Presentación.* La Habana: INRH.

Grupo Empresarial de Aprovechamiento de los Recursos Hidráulicos (GEARH) (2016). *Resumen del pesquisaje de metales pesados en las aguas de las fuentes de abasto para consumo humano. Informe preliminar.* Documento interno. La Habana: INRH.

Gutiérrez, J. y García, J.M. (2015). *Manual de lagunas de estabilización.* La Habana: Instituto Nacional de Recursos Hidráulicos (INRH). ISBN 978-959-300-115-1.

Herrero, J.A. (2017). *Bosques en cuencas hidrográficas de interés nacional. Situación actual y perspectivas.* 1er. Taller de Gestión Integrada de Cuencas Hidrográficas. La Habana: Dirección Forestal, Flora y de Fauna Silvestre / Ministerio de la Agricultura. ISBN 978-959-247-156-6.

Instituto Nacional de Recursos Hidráulicos (INRH) (2002). Los recursos hidráulicos en cifras. Edición Especial 40 Aniversario INRH. *Revista Voluntad Hidráulica,* Año 2002. ISSN 0505-9461.

Instituto Nacional de Recursos Hidráulicos (INRH) (2012). *Política Nacional del Agua* La Habana: INRH.

Laiz, O.; Quintana, I.; Blomqvist. P.; Broberg, A.; Infante, A. (1979). Comparative limnology of four Cuban reservoirs. *Int. Rev. Hidrobiology* 79 (1) 17-45.

Ministerio de Justicia. *Gaceta Oficial de la República de Cuba.* GO No. 51 Extraordinaria del 16 de noviembre de 2017. Ley 124/2017 (GOC -2017-715-Ex51). ISSN-1862-7511.

Mora, I.; Muñoz, M.; Hernández, S.; Matos, A. (2003). *Estudio del contenido de metales en las principales fuentes de abasto de Cuba.* La Habana: Centro Nacional de Hidrología y Calidad de las Aguas, Rama 1003.

Oficina Nacional de Estadísticas e Información (ONEI) (2015). *Los Objetivos de Desarrollo del Milenio – Cuba.* La Habana: ONEI Edición.

Oficina Nacional de Estadísticas e Información (ONEI) (2016). *Anuario Estadístico de Cuba 2015.* ISBN: 978-959-7119-62-3.

Oficina Nacional de Estadísticas e Información (ONEI) (2017). *Anuario Estadístico de Cuba 2016.* Capítulo 2. Medio Ambiente.

Oficina Nacional de Normalización (2012). *NC 27-2012. Vertimiento de Aguas Residuales a las Aguas Terrestres y al Alcantarillado. Especificaciones.*

Oficina Nacional de Normalización (2012). *NC 827-2012. Agua potable requisitos sanitarios.*

Rodríguez, D. (2015). *Taller de Alianza Regional para Centro América, México y el Caribe. Prioridades hacia un Manejo Sostenible del Suelo.* La Habana: FAO.

Rodríguez, D. (2017). La función de los polígonos de suelos, aguas y bosques en la protección y conservación de cuencas. Logros alcanzados. 1er. Taller de Gestión Integrada de Cuencas Hidrográficas. CUBAGUA 2017. La Habana: Ministerio de la Agricultura. ISBN 978-959-247-156-6.

Salas, H. y Martino, O. (2001). *Metodología simplificada para la evaluación de lagos cálidos tropicales.* La Habana: CEPIS.

Servicio Hidrológico Nacional (2006). Nuevos Logros en el Estudio de la Pluviosidad en Cuba. Mapa Isoyético para el periodo 1961-2000. *Revista Voluntad Hidráulica* No. 98, pp. 2-14.

Dominican Republic

The quality of **Dominican** waters today negatively impacts on health, as well as creating extreme climatic incidents, overcrowding and marginality. Food production is compromised by the salinization of soils, eutrophication due to the use of agrochemicals, the irresponsible use of antibiotics in veterinary science and the biodiversity of the island. The population consumes an excessive amount of bottled water due to its distrust of water from the aqueducts. The current legal framework suffers from serious deficiencies and requires a new institutional reorganization to optimize the quality of water as both a resource and a service.

El Limón Waterfall, Dominican Republic © iStock

Water Quality in the Dominican Republic

Eleuterio Martínez, Roberto Castillo Tió, Luis Reyes Tatis, Pedro de León and Luis Salcedo

1. Introduction

Water quality is a priority concern for the Dominican Republic, amply reflected in its current legal system, from the Constitution (2015), to adjective laws; as well as the National Development Strategy (2010-2030), the Regulation for Water Quality for Human Consumption, Decree No. 42-05 of 2005 and several Environmental Norms on surface (2012), ground (2004), coastal (2012) and wastewater (2004) quality.

Although the legal texts show that the greatest interest in water quality lies in the supply for human consumption, as will be seen below, given the diversity of uses of this resource, there is an enormous demand to sustain the development activities the country requires and the natural mechanisms to guarantee its permanent natural recovery. This variable must therefore be approached using the same regulatory frameworks designed to counteract the influence exerted by the powerful agricultural and mining sector, which results in the salinization of agricultural soils, the effects of return water in certain regions, eutrophication of water bodies and deforestation in the middle slopes and high mountains of the country.

1.1 Problem of water quality

Water quality is the main challenge for its different uses, not only because of the alteration of its composition, but also because of the type of management used in water preservation -which warrants an institutional rearrangement-, water management and water service provision for human consumption and public health. At present, the quality of Dominican waters reflects substantial direct and recurrent health impacts (epidemic and emerging diseases), extreme climate incidents, overcrowding, marginalization, food production (soil salinization, degradation, eutrophication due to the use of agrochemicals in horticulture and floriculture), intensive livestock farming (bovine, poultry, swine, irresponsible use of antibiotics in veterinary medicine) as well as effects on the island's biodiversity. Another aspect related to quality is aqueduct management, which creates distrust in the water supplied by them, expressed in the intensive use of bottled water (78% of the population) for human consumption. The current legal framework -described later- reflects the overlapping of in-

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stitutional competencies, lack of definition of roles (mainly in the management of pollutants), social aspects and obstacles to achieving optimization in the quality of national waters, raising the need for a new institutional reorganization of the water sector as a resource and water as a service.

2. Institutional authority and water quality governance

2.1 Legal framework

The Constitution contains three articles on water (15, 67 and 75 section 11), which establishes its patrimonial and strategic nature for public use, and the fact that it is inalienable, indefeasible and cannot be encumbered. It also states that it is essential for life, that human consumption has priority over any other use, and that it is the duty of the state to guarantee its quality and quantity.

In the Framework or General Law on Environment and Natural Resources, Chapter III, devoted to Water, contains ten articles (from 126 to 135), in which special emphasis is placed on preserving its quality, particularly articles 127 and 130. They establish the right of every person to use this resource to satisfy their vital food and hygiene needs, avoiding activities that may damage, diminish or alter its quality, or preclude the same use by third parties.

In view of the fact that the Dominican Constitution obliges the State to guarantee compliance with the Human Right to Water and Sanitation, the National Development Strategy (END) 2010-2030 defines water resources as a strategic national heritage, taking into account the Sustainable Development Goals (SDGs), particularly SDG-6 (Water and Sanitation), the overarching aim of which is "to ensure availability and sustainable management of water and sanitation for all" by 2030".

Both the current Water Law and the new Law in the legislative chambers establish specific mandates and provisions designed to preserve water quality. Law 5852 of 1962 on the Domain of Terrestrial Waters and Distribution of Public Waters devotes articles 42, 43, 107 and 122 to establishing provisions that prevent contamination and encourage remediation, the creation of a Water Police Force, and the definition of offenses and the establishment of the respective sanctions.

Article 2 of the new Sectoral Law on Water currently in the legislative chambers (National Congress) establishes the goal of: "Guaranteeing water security in the Dominican Republic, through the availability of water in sufficient quality and quantity and at the time it is required" and in Article 4 it clearly establishes that "Access to Water (quality and quantity)" is a human right, as established in the Constitution.

The same occurs with Law N° 5994 of 1962, which established the National Institute of Drinking Water and Sewerage (INAPA), an institution that provides service to 25 of the 32 territorial demarcations of the Dominican Republic, while the remaining seven are served by the following laws: Law 498 of 1973, which created the Corporation of the Aqueduct and Sewer System of Santo Domingo (CAASD), Law 582 of 1977, which established the Corporation of the Aqueduct and Sewer System of Santiago (CORAASAN), Law 89 of 1997, which set up the Corporation of the Aqueduct and Sewer System of Moca (CORAAMOCA), Law 142 of 1997 which created the Aqueduct and Sewerage Corporation of Puerto Plata (CORAAPLATA), Law 385 of 1999, which established the Aqueduct and Sewerage Corporation of La Romana (COAAROM) and lastly, Law 428 of 2006, which set up the Aqueduct and Sewerage Corporation of Boca Chica (CORAABO). The following coverage map by territorial demarcation shows the domains of INAPA and each of the CORAS.

All these legal entities share the goal of guaranteeing the quality of water supplied to their respective cities.

2.2 Water quality governance

Judging by the profusion of mandates in legal texts, regulations, rules and administrative provisions, the issue of water quality in the country would appear to have an excess of goals and to be inefficient in reality, because of the overlapping of competencies, as can be seen in **Table 1**.

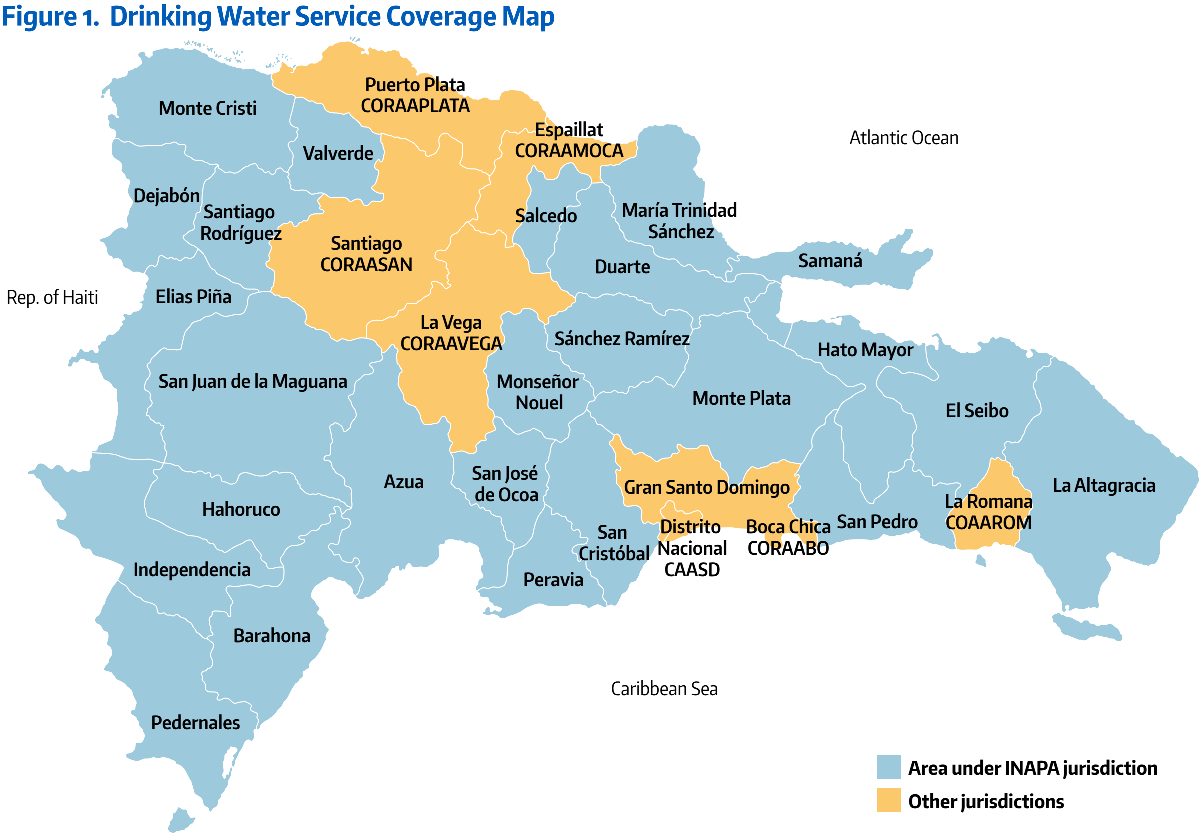
Faced with this framework of dispersion and overlapping of functions, the Executive Branch created the Water Board (Decree 265-16), chaired by the Minister of the Economy, Planning and Development, as an inter-institutional coordination body for the water sector and related to the integrated management of water basins, until the structural modifications discussed in the preliminary draft of the Sectoral Law on Water as a resource and the Law of the Drinking Water and Sanitation Service came into force. Institutions that form part of the Water Board include: the Ministry of Public Health (MSP), the Ministry of Environment and Natural Resources (MARENA), the National Institute of Hydraulic Resources (INDRHI), the National Institute of Drinking Water and Sewerage (INAPA), the Ministry of Agriculture, the Ministry of Energy and Mines, the Aqueducts and Sewers Corporation of Santo Domingo, the Aqueduct and Sewer Corporation of Santiago, and the corporations of the City of Moca, Province of Puerto Plata, of the Municipality of Boca Chica, the provinces of La Romana and La Vega, the Dominican Federation of Municipalities, the Dominican Municipal League, the National Council for Climate Change and the Hydroelectricity Generation Company.

In short, water quality in the Dominican Republic is governed by three environmental standards, the series of Dominican Standards of Quality, which establish the parameters of analysis and a regulation which defines the concept of 'water quality' in the following terms:

Set of water characteristics, primarily determined by the values established in the present regulation of maximum admissible concentrations and those established in quality guides, which ensure the non-existence of a certain kind of risk or danger involving sanitation; as well as proper service, operation and maintenance throughout the supply system, thereby achieving the basic needs and rights of users and consumers.

As can be seen in the preceding table, Law No. 42 of 2001 grants the MSP the function of "stewardship and surveillance" of water quality at the national level, a function it fulfills through the application of Decree No. 42-2005, which establishes the Regulation of Water Quality for Human Consumption and also regulates any activity that may affect water quality in the watersheds, its use for agricultural irrigation, as well as the implementation of

Figure 1. Drinking Water Service Coverage Map



Source: INAPA-BANCO MUNDIAL, 2016.

Table 1: Diagram of water quality competencies

Institution	Function	Legal framework	Nature	Overlapping and clashes with:
Ministry of Public Health (MSP)	Stewardship, regulation, surveillance. Health system.	Law n.º 42-01	State (Central Government)	»INDOCAL, in regulations and surveillance of drinking water quality. »Min. of the Environment, in regulations and wastewater management surveillance. »INAPA, in the control, design, authorization and implementation of sewage works.
Ministry of Environment and Natural Resources (MARENA)	Stewardship, management, regulation, monitoring of the environment and natural resources.	Law n.º 64-00	State (Central Government)	»INDRHI, in water management. »INDOCAL, in regulations on wastewater discharges. »MSP, in excreta management.
Ministry of Economy, Planning and Development (2017)	Governing body of planning and formulation of public development policies.	Law n.º 496-06	State (Central Government)	»INAPA and CORA, in the implementation of the Water and Sanitation Project in Tourist Centers (PASCT).
National Institute of Hydraulic Resources (INDRHI)	Control and regulation of water use. Watershed protection.	Law n.º 6-1965	Autonomous state public; attached to the Ministry of the Environment	»MARENA, due to INAPA water control, in aqueducts and well water management.
Dominican Quality Institute (INDOCAL)	Official standardization body, provides support to ministries for creating technical regulations.	Law n.º 166-12	Technical entity of the Dominican Quality Council of (Affiliated to MEPYD)	»MSP, in regulation and quality control of bottled drinking water.
Ministry of Tourism (MITUR)	Supervision, design and construction of infrastructure works for tourist complexes through CEIZTUR.	Law n.º 84-79	State (Central Government)	»INAPA and CORAS, in the implementation of sewerage projects in tourist centers.
Town Halls	Local government. Political-administrative coordination.	Law n.º 176-07	Autonomous Basic Political-Administrative Unit of the State.	»INAPA, due to the implementation of APS systems.
National Drinking Water and Sewerage Institute (INAPA)	Stewardship, regulation and operation of APS services.	Law n.º 5994 year 1962	Autonomous State. Attached to the MSP	»MSP, in control, design and authorization of implementation of projects. »INDRHI, in the construction of aqueducts and control of water wells for human consumption.
Aqueducts and Sewerage Corporations (CORAS)	Stewardship, regulation and operation of APS services in the DN, six provinces and one municipality.	Laws n.º 498- 73 582-77 142-97 89-98 385-98 512-05 428-06	Autonomous State.	»MSP, in the control, design and authorization of the implementation of projects. »MEPYD, in the implementation of sanitation projects.

Fuente: MAPAS – II – D (BM, INAPA, WSP, APS), 2016.

the rules established in this respect by service providers to the population.

The environmental standards established by mandate of the General Law on Environment and Natural Resources (No. 64-00) are: 1. Water quality and discharge control standard, 2003; 2. Environmental standard on groundwater quality and discharges into the subsoil, 2004, and Environmental quality standard for surface and coastal waters, 2012.

The Dominican Quality Institute has established 14 national standards of procedure for water quality analysis, 11 of which are already in force, and three of which are in the preparation phase.

2.3 Proposal for institutional reorganization

Fresh water is a limited resource that must be managed according to the water cycle, taking into account the concepts of river basins and hydrological basins leading to the sustainable development of the country. In this context, the concept of "quality" is one of the factors that contributes to water insecurity, since it limits the use of water for different uses. Accordingly, there is a regulation for the quality of water, when it is a source for aqueducts (supply systems) and another type of quality for rivers and surface runoff in its exploitation for other uses, with separate, taxative functions.

The Water as a Resource Bill proposes the separation of roles at three levels:

1. Stewardship: This would be under the direction of MARENA, responsible for the policies, water planning and financing of the sector.
2. Sectoral organizations: to. Drinking water and sanitation, b. Agricultural development, c. Production of hydroelectricity, d. Industrial sector, e. Mining, f. Tourism and g. Waterworks.
3. Organizing body of the waters in the country, which would be the highest technical authority, responsible for enforcing the Water Law as a resource and for monitoring compliance with the guidelines laid down by the stewardship.

The Drinking Water and Sanitation Law (PSA) will be the responsibility of the ministerial body of public health, with a structure similar to the second level (public or private service providers), while the National Institute of Drinking Water and Sewerage (INAPA) would be transformed into a regulating body and the highest technical authority in the sector, excluding constructive (building) functions.

3. Status of Water in the Dominican Republic

3.1 Water availability

The country has six hydrographic regions with 97 main basins and 556 secondary basins, as established in the National Hydrological Plan (INDRHI, 2012), which indicates that the surface water availability of the Dominican Republic is 23,497.69 million m^3 (Mm^3) year.

Current (2018) availability of water in the country is 25,966.69 million m^3 (Mm^3) (see **Table 2**). If 23.497.69 million m^3 (Mm^3) or runoff (rivers and

Table 2. Water availability in the Dominican Republic (Calculated in millions of cubic meters per hydrographic region)

N°	Hydrographic Region	Surface Water (millions of m^3)	Usable Groundwater (millions of m^3)	Actual availability (Million m^3)
1	Yaque del Norte	2,905.46	181	3,086.46
2	Atlantic	4,634.73	216	4,850.73
3	Yuna	3,600.96	236	3,836.96
4	Este	3,125.95	758	3,883.95
5	Ozama/Nizao	4,459.08	457	4,916.08
6	Yaque del Sur	4,771.51	621	5,392.51
	Total available	**23,497.69**	**2,469**	**25,966.69**

Source: Compiled on the basis of PHN-INDRHI (2012) and Fany Vargas (2014).

Cuadro 3. Situación de los recursos hídricos del país (principales Indicadores)

N°	Características Generales	Rep. Dominicana
1	Superficie	48,670 km^2
2	Población 2017	10,169,172 habitantes
3	Precipitación media	1,500 mm/año
4	Volumen precipitación	73 km^3
5	Volumen evaporado	51 km^3
6	Volumen disponible	23.497.69 km^3
7	Volumen per cápita	2,310 m^3/h
8	Índice de déficit hídrico (OMM)	1,000 m^3/h
9	Índice del grado de competencia	Problemas generales
10	Grado de competencia en sequías	Tensión hídrica

Fuente: Elaboración propia con base en informaciones de Héctor Rodríguez (2006) y ONE (2017).

minor currents) are added to underground water availability, which is 2,469 million m^3, these 25,966 million m^3 of total availability are equivalent to approximately 823 m^3/s (cubic meters per second). It is estimated that average annual rainfall in the country is 1,410 millimeters and that nearly 70% is lost naturally (through direct evaporation and evapotranspiration), according to calculations by Reynoso (2017).

If we only take into account the surface water moving through rivers and other sources, the availability of easily accessible water would be 2,310 m^3 per inhabitant, considering that the Dominican Republic had a population of 10,169,172 inhabitants at the end of 2017, according to projections by the National Bureau of Statistics. But if we add the availability of groundwater to the availability of running water, actual availability would be 2,553 m^3 per inhabitant.

On the basis of the same information, FAO (2015) points out the following: "*Groundwater resources are estimated at 4.161 million m^3/year, all considered as base flow or superposition between surface water and groundwater. The availability of usable groundwater has been estimated at 2.469 million m^3/year*".

The INDRHI National Water Plan (2012) also establishes that the 35 dams and reservoirs have the capacity to store approximately 2,144 million m^3, which considerably increases overall water availability to approximately 32,740 million m^3, although in practical terms this does not happen, because this information is only valid in theoretical conditions. However, the information is valid in crisis situations, since efficient water use could considerably increase through saving policies and responsible national water resource management.

FAO (2015) states that the maximum capacity of the reservoirs is 2,301 million mm^3, of which large reservoirs (those with over 100 million mm^3 in storage capacity) store 85% of total capacity. For the most part, these are multi-purpose reservoirs (supply to the population, flood control, irrigation and hydroelectric power), except for a few small reservoirs used only for electricity generation.

The highest capacity reservoirs are Hatillo (441 million mm^3) in the Yuna River, Sabana Yegua (401 million mm^3) in the Yaque del Sur River, Monción (360 million mm^3) in the Mao River, Bao (244 million mm^3) in the Bao and Valdesia rivers (185 million mm^3) and Jigüey (167 million mm^3), both in the Nizao river.

Groundwater accounts for 60% of available water resources in the country. Seventy-seven per cent of groundwater comes from the direct recharge of rain or infiltration from river channels, 15% from irrigation water returns or infiltration and the remaining 8% from lateral connections with contiguous zones.

When all these data are analyzed and contrasted with the reality of the country at this times, they show that the Dominican Republic has enough water to supply drinking water for its population and sustain the main activities that currently serve as the basis for its development.

The current status of water in the Dominican Republic is reflected in the **Table 3** that detail the prevailing reality in the country.

3.2 Current status of water use

3.2.1 Supply deficit

At the end of 2017 and beginning of 2018, the main Dominican cities were experiencing a marked deficit in the supply of drinking water. This was the case of the city of Santo Domingo, the Dominican capital, where continuity of service does not exceed 10% of households (CAASD, 2017). Santiago de los Caballeros (CORAASAN, 2017), the second most populated city in the country, has a similar situation according to reports the Academy of Sciences of the Dominican Republic received from the National Institute of Drinking Water and Sewage. There are very few cities in the interior where service is more efficient.

With only slight variations, in the two largest cities in the country - Santo Domingo and Santiago - which currently have a population of 4.5 million people out of the 10,266,149 inhabitants of the Dominican Republic, water consumption per capita exceeds 112 gallons per day, amounting to approximately 425 liters/person/day. However, Article 65 of Regulation 42-05 of water for human consumption of the MSP establishes the minimum levels for cases where there are no specific or regional studies. Guidelines vary in warm climates and areas with a population of over 150,000 inhabitants to 350 liters/person/day.

3.2.2 Consumption status

In other words, although the country apparently exceeds the water consumption of developed nations by a factor of two or three, this data includes the large volume of water lost due to leaks and waste: over 50% None of the APS institutions has a Leak Correction Plan as part of a Loss Control Program.

Irrigated agriculture, which has a higher water demand than all the other sectors together, requires a supply of 5 m^3 per second, of which it wastes four (blue ecological footprint) and uses one (footprint) ecological green) for practically all crops under irrigation. In other words, water efficiency in irrigation agriculture varies between 20 and 25%, and only in exceptional cases has 32% been reached, with the remainder being wasted.

3.2.3 Demand by sector

a. Agricultural

The most recent study on water consumption in the Dominican Republic, "Contrast of Water Availability and Demand by Province" (2017), by water specialist Gilberto Reynoso, establishes that water demand for agriculture in the country amounts to 80%, while 12% is assigned for human consumption and the remaining 8% for tourism, industry and other uses. This situation contrasts with global availability and demand, where 20% is assigned for agriculture, another 20% for other sectors and 60% for human consumption.

b. Tourism

Water demand for the tourism sector will grow considerably in the next few years, if the rate of influx of foreign visitors continues. At present, tourism in the Dominican Republic exceeds 7 million visitors per year, according to statistical data from the Central Bank of the Dominican Republic (2017) and it is

Table 4. Projected water demand by sectors (Million m³/año)

Sector	2005	2010	2015	2020	2025
Drinking Water	679.86	760.76	843.80	928.50	1,013.08
Irrigation	6,429.85	4,878.90	3,327.95	2,894.43	2,460.90
Livestock	538.24	835.80	1,133.35	1,430.91	1,728.47
Ecological	3,675.60	3,675.60	3,675.60	3,675.60	3,675.60
Industrial	259.10	586.07	659.88	716.80	793.02
Tourism	43.71	94.29	124.80	165.98	221.57
Total	**11,626.36**	**10,831.42**	**9,765.38**	**9,812.22**	**9,892.64**

Source: INDRHI (2012): National Hydrological Plan.

Table 5. Water Demand in Mining (2005-2030)

Hydrographic Region	Water demand for Mining Subsector 2005-2030 (million m³ / año)					
	2005	2010	2015	2020	2025	2030
Yaque del Norte	1.22	3.40	3.79	4.06	4.46	13.55
Yuna	0.92	1.11	1.31	1.53	1.75	1.62
Ozama – Nizao	3.59	9.91	11.03	11.77	12.89	1.80
Este	0.75	0.90	1.07	1.25	1.43	1.98
Atlantic	0.48	1.27	1.43	1.54	1.70	1.76
Yaque del Sur	0.82	0.99	1.17	1.36	1.56	4.71
Total	**7.77**	**17.58**	**19.80**	**21.50**	**23.79**	**25.41**

Source: United Nations-INDRHI.

Table 6. Water Demand by sector (Million m³/year)

Sector	2015	%	2020	%	2025	%
Drinking Water	843.80	7	928.50	7	1013.08	7
Irrigation	6429.85	50	6429.84	49	6429.84	47
Livestock	1133.35	9	1430.91	11	1728.47	13
Ecological	3675.60	29	3675.60	28	3675.60	27
Industrial	659.88	5	716.80	5	793.01	6
Tourism	34.62	0.3	48.91	0.4	84.85	1
Total	**12,777.99**	**100**	**13,230.56**	**100**	**13,724.85**	**100**

Source: MAPAS-RD. Monitoring of the Country's Progress in Drinking Water and Sanitation II.

projected that the influx of tourists to the country will be much higher when 2018 is calculated.

The drinking water deficit in the Eastern Region, where the main hotel areas of this tourist resort are located, is much more evident and since the only supply comes from underground sources (aquifers), overexploitation has caused the advance of the salt wedge due to saline intrusion, which has advanced more than 11 kilometers inland, and created another set of associated problems.

That is, a drinking water supply crisis for this sector, currently the main pillar of the Dominican economy, is rapidly approaching, which is why the Dominican Government will have to create the necessary infrastructure for the use of surface water resources , which are fairly abundant, yet still untapped due to the lack of planning and the almost spontaneous and unusual tourist development that has taken place in this region. If this trend continues, supply sources are likely to collapse in the short to medium term.

c. Mining

Mining is a key sector of the Dominican economy as regards the gross domestic product and warrants particular attention due to the volumes of water estimated as a percentage of industrial consumption (period 2005-2030) for the extraction of gold and silver, ferronickel and other metallic goods (see **Table 5**).

The water demand for mining (2020-2030) is projected at 23.57 million cubic meters per year and in the regions where mining activity takes place, water should be prioritized as a human right for the surrounding populations.

d. Fresh water demand by productive sector

In the Dominican Republic, six (6) major water uses have been identified (see **Table 6**), of which potable water is the priority, accounting for 7% of the total demand for all uses. In the case of irrigation, water demand was estimated at 50% in 2015, with a slight decrease for 2020 of 49% and 47% for 2025. Conversely, livestock will increase its share of water demand from 9% in 2015 to 13% in 2025. Ecological water consumption is expected to remain virtually constant at approximately 28%.

3.2.4 Water demand in the Dominican capital

Existing potable water supply systems contribute an approximate daily flow rate of between 18.0 and 22.0 m^3 to the National District and the province of Santo Domingo, to supply a population of over 3.5 million inhabitants, which wastes between 54% and 60%, including leaks due to obsolescence in distribution network lines, in addition to the lack of real macro and micro measurement systems (CAASD, 2018).

However, the amount actually used by citizens varies between 9.0 and 12.0 million cubic meters per day (Salcedo, 2018). All this indicates that, if Santo Domingo had a permanent policy of citizen education oriented towards the saving and responsible use of its waters, associated with an effective leak correction program, we would not be talking about shortages, as is the case today, even in the worst scenarios (see **Table 7**).

3.2.5 The Specter of scarcity

In other words, provided water availability at the national level remains above 2,000 m^3 per person per year, it is not possible to speak of scarcity, because the critical state occurs when availability drops below 1,600 m^3/inhabitant/year. If this situation is projected to 2020, availability would be 2,485 m^3/inhab/year and even 10 years later (2030), it would remain in normal conditions, above 2,300 m^3/inhab/year.

Although the National Institute of Water Resources presents more critical scenarios, its estimates are based on a much larger population than the one calculated by the National Bureau of Statistics. It will be necessary to wait for the 2020 census data to see which one provides a more accurate reflection of the situation.

Table 7 shows the current and projected water demand by sectors with the highest consumption in the country, according to the INAPA-WORLD BANK (2016) studies, based on the fact that total water demand for all uses in 2015 was 12,778 m^3/year, which will be 13,230.56 m^3/year BY 2020 and 13,725 m^3/year by 2025.

3.2.6 National strategy en route to the SDGs

The same source conducts a specific analysis for the same period (2005-2015) of supply (availability), with respect to specific consumption (demand) for drinking water, contrasting it with production capacity at the national level, as detailed below (See **Table 8**).

Table 7. Water availability and demand in the Dominican Republic

Year	Availability (Million m³)	Demand (Million m³)	Population Projected (inhabitants)	Availability (Million m³/ inhabitants/year)
2015	25,996.7	12,777	9,980,243	2,602
2020	25,996.7	13,231	10,448,499	2,485
2025	25,996.7	13,315	10,878,277	2,387
2030	25,996.7		11,253,284	2,308

Source: Compiled using data from WB-INAPA Maps -II- RD.

Table 8. Water supply and demand and production capacity

Year	Potential freshwater supply for all uses (m³/s)	Drinking water demand (m³/s)	Production capacity (m³/s)
2015	745.08	26.76	62.27
2020	745.08	29.44	65.02*
2025	745.08	32.12	68.76*

Source: MAPAS-RD. Monitoreo de los Avances del País en Agua Potable y Saneamiento II. * Projected.

Although several scenarios can be drawn from the preceding table and multiple considerations can be made, it is clear that the freshwater supply is far higher than the demand the country has for this natural resource and that the capacity to produce it using the current water use systems is also twice as high as demand at this time, and albeit to a lesser extent, this situation is expected to remain constant in the following years.

These data are very important for the analysis of the current scenario and future situations that may arise in the country in terms of drinking water supply for the population, which much be the starting point to comply with the projections of the National Development Strategy and for compliance with the goals set for the SDGs, particularly SDG -6, concerning drinking water access and availability and sanitation.

4. Main problems impacting water quality in the country

4.1 Service Coverage and Social Participation

4.1.1 National coverage

According to the 2010 national census, there were 1,272 aqueducts in the country, 420 of which were public (34%) and 852 of which were community-run (66%). Of that universe, 170 aqueducts were urban and 1,102 were rural, with an installed production capacity of 62.27 m^3 /s, although they actually produced about 46.30 m^3/s, enough to supply almost twice the actual population demand, estimated at 26.26 m^3/s, according to the 2012 National Water Plan.

However, the supply of drinking water was deficient in 2014 due to the fact that average water loss in the water supply systems was 54% nationwide, according to the INAPA-World Bank study on Water Supply and Sanitation Monitoring (2016), which drew on the final diagnostic report of wastewater and excreta by Leonardo Mercedes (2016).

The 2010 census determined that national potable water service coverage was 84%, with 67% in urban areas and 17% in rural areas, while 16% of the Dominican population lacked this service (7.9% in cities and 8.1% in rural areas).

4.1.2 Millennium objective achievement

According to the latest report from the Ministry of Economy, Planning and Development (MEPYD) on compliance with the United Nations Millennium Development Goals (MDGs), released in 2015, the country achieved the goal of halving the proportion of the population lacking access to potable water in 1991 (33.6%), which involved raising access coverage from 66.4% to 83.2%, contemplated for 2015.

In this document, the MEPyD states that in 2014, the population with access to drinking water service was estimated at 90.2%, and was expected to rise to 92.6% by 2015. This proportion exceeds the original MDGs (83.2%) by 9.4 percentage points, which was subsequently increased to 92.2%, on the basis of the review and updating of the methodology for calculating the indicator of access to improved drinking water sources, according to UN criteria. It also exceeded the proportion projected for 2015 by 0.4 percentage points, reflecting an upward trend in drinking water access.

4.1.3 Water Quality Monitoring

Water quality monitoring in the Dominican Republic is the primary responsibility of the MSP, as established by its legal system, which fulfills its mission through the implementation of the National Water Quality Regulation, for which it has the support of the Pan American Health Organization (PAHO), the World Health Organization (WHO) and the United Nations International Children's Emergency Fund (UNICEF).

4.1.4 Social participation

The greatest social participation in the Potable Water and Sanitation System occurs at the local level, in the operation of rural aqueducts, where 65% of existing systems are run by the Community Association of Rural Aqueducts (ASOCAR) and Community Water Committees (CAC), as a result, among other causes, of the lack of public attention and the decentralization of rural aqueducts begun in 1997 by INAPA.

Citizens' participation in the planning, study, design, construction and management of drinking water and sanitation projects is not legally contemplated, nor is it widespread. All social participation occurs, as has been indicated, as a result of local initiatives, sometimes institutional and, sometimes –

in most cases- as a result of grassroots community organizations.

There is civil society representation on the boards of five of the seven CORAS, but the institutional and management model which establishes the legal framework on which the Potable Water and Sanitation System is based does not institute social participation at any of its decision levels or in the operation of PHC services, which are conceived as an exclusive function of the state through public institutions.

4.2 Water quality and main pollutants

Drinking water contaminants alter the quality of water for human use (drinking, personal hygiene, domestic chores) and may vary from region to region, according to the characteristics of the aqueducts, type of management, geological and soil conditions. However, the most important ones include total and fecal coliforms, pH, temperature and nitrates. Regulation 42.05 defines the parameters and analytical methods applicable to water for human consumption:

A: *Organoleptic parameters.* B: *Physico-Chemical Parameters* C: *Chemical Parameters.* D: *Parameters regarding unwanted substances.* E: *Parameters related to toxic substances.* F: *Microbiological parameters.* In total, there are 69 components without systematic accountability.

4.2.1 Monitoring parameters

What elements are taken into account to evaluate water quality in the country?

Water quality as a non-standard variable in the country is estimated at 98%, determined by sampling the basic parameters:

- Social acceptability index: The Potabilization Index in aqueducts controlled by decentralized service companies is variable, with an acceptable record and is accepted by 22% of the population.
- Level of rejection or social distrust: A total of 78% of the population distrusts the potability of water from the aqueducts and, instead, consumes bottled water (ENDESA 2013).
- Key health indicators: Color, smell, total coliforms, fecal coliforms.
- The continuity, quantity and pressure of the water service are discontinuous, forcing the poorest people to have to store water in containers, which in turn obliges the MSP to engage in an annual campaign of cleaning, disinfection and "covered tanks" to prevent the development of the Aedes aegypti mosquito.
- Management indicator: The service is not sustainable in the long term.

4.2.2 Waste water quality

According to data from the 2010 national population census, information on coverage and treated water in domestic wastewater treatment plants indicates that 70% of the Dominican population uses toilets, 24% utilize latrines or toilets and 6% still defecate in the open air.

The 70% with access to the health service were distributed among the 27% of the population with access to sewer networks, while 43% used septic tanks, with discharges into caved wells.

The status of wastewater in 2015, according to the drinking water produced, is recorded in **Table 9**.

- Drinking water flow: installed capacity: 62.27 m^3/s

Table 9. Wastewater Treatment Summary

Parameters	Q (m^3/s)	%
Theoretical Wastewater Flow reported	31,00	100
Flow Captured in Sewage Networks	8,76	28
Flow treated at 104 WWTP* until 2015	3,32	38
Untreated Flow Captured in Networks	5,44	62
Nominal capacity of 104 WWTP	9,41	
Restoration of existing WWTP Treatment Capacity	6,09	65
Flow to be Captured in New Networks and Treated at New WWTP	22.24	72

Table 10: Status of country's treatment plants

No.	Region	Amount	Nominal Q (lps)*
1	Ozama Region	24	740.75
2	North Cibao Region	29	2,784.20
3	South Cibao Region	11	1,243.06
4	Northeast Region	4	1,073.00
5	Northwest Region	4	76.00
6	Valdesia Region	5	974.85
7	Enriquillo Region	7	261.39
8	El Valle Region	3	500.00
9	Yuma Region	10	406.08
10	Higuamo Region	7	1,350.00
	Total	**104**	**9,409**

*lps: Liters per second.

- Drinking Water Flow Produced: 45 m^3/ s
- Nominal Wastewater Flow: 36 m^3/ s
- Wastewater treatment: 38% of the volume captured in networks (8.76 m^3/s)

Table 10 shows the WWTPs for each of the regions comprising the Dominican Republic, as well as the nominal flow, in other words, the design flow rate in lps. There are 104 wastewater treatment plants with a nominal flow of 9,409 lps.

Fifteen key parameters are identified in the typical composition of domestic wastewater, on the basis of which three types of wastewater are established: strong, medium and weak. Its characteristics are given in **Table 11**.

Wastewater in the Dominican Republic can be assumed to have medium concentration and for each parameter there are regulations prepared and supervised by MARENA, which limits concentrations when no studies are available on the receiving body. There are other parameters, such as temperature, pH, COD/BOD ratio, treatability indicators and others for biological processes.

Biodegradability index (IBD). This index, determined by the COD/BOD ratio, makes it possible to define when biological treatment is applicable and when there is a risk in the process, as can be seen in **Table 12**.

These measurements of the receiving body are not shown in the designs of the Wastewater Treatment Plants (WWTP) of the operating entities, which are guided by the thresholds specified in the regulations and by the designer's criterion.

4.3 Detail of sewage treatment nationwide

According to the information received at the Academy of Sciences and the National Hydrological Plan, INAPA is responsible for operating 58 wastewater treatment plants throughout the country, 16 of which are currently out of service, while the CAASD operates other 23 in the city of Santo Domingo, CORAASAN operates eight in Santiago de los Caballeros, CORAAMOCA operates one in the city of Moca and CORAAROM one in La Romana.

These 91 wastewater treatment plants nationwide have been reinforced by several sanitation projects undertaken in Santo Domingo and the interior of the country, such as: Cañada Guaijimía, La Castellana Ecological Park and several streams cleaned up by the European collaboration project SABAMAR and the World Bank. Other projects have been undertaken in San Pedro de Macoris, Las Terrenas-Samana, San Francisco de Macoris, as well as the Guaymate and Cayetano Germosén plants, the latter two jointly operated by INAPA and CAASD.

Although tourist centers in the country operate individualized, collective treatment systems, there is no fully documented definition of efficiency and coverage. In rural areas, households usually dispose of excreta individually through the use of latrines. According to the study entitled “Capacity

Building Project for the Safe Use of Sewerage in Agriculture" undertaken by FAO, WHO, UNEP, UNU-INWEH, UNW-DPC, IWMI and ICID (2015), 59.8% of rural households use latrines, 33.1% toilets and 7.1% of households have no system for excreta disposal.

This same study reveals that the National District and the Province of Santo Domingo produce a total of 1,169,152.02 m^3 per day of wastewater, representing 80% of the total; 113,040.78 m^3/d of this amount are collected. The installed capacity of the

Table 11. Classification of domestic wastewater

Other pollutants	Concentration (mg/l)*		
	Strong	Medium	Weak
Total solids (TS)	1200	700	350
Total dissolved solids (TDS)	850	500	250
Fixed	525	300	145
Volatile	325	200	105
Suspended solids (SS)	350	220	100
Fixed	75	55	20
Volatile	275	165	80
Sedimentable solids	20	10	5
(DBO_5, 20°C)	400	220	110
Total organic carbon (TOC)	290	160	80
COD	1,000	500	250
Organic nitrogen	35	15	8
Phosphorus (total in P form)	15	8	4
Organic	5	3	1
Inorganic	10	5	3
Chlorides	100	50	30
Sulfates	50	30	20
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50
Total coliforms (in no./100 ml)	107 - 109	107 – 108	106 – 107
Volatile organic compounds (VOCs), in µg/ l	>400	100-400	<100

*mg/l: milligrams per liter. Source: Metcalf and Eddy (1996).

Table 12. Index of biodegradability, nutrients, nitrogen and potassium

Parameter	Ratio	Result
COD / BOD	Equal to 1.5	Highly biodegradable
COD / BOD	Equal to 2	Moderately biodegradable
COD / BOD	Equal to 10	Not very biodegradable
BOD / COD	Less than 0.2	Not biodegradable
BOD / COD	Over 0.6	Biodegradable
Total nitrogen	1 to 15	Population under 100,000 / population over 100,000
Phosphorous	1 to 2	Population under 100,000 / population over 100,000

Source: PAHO/WHO. Virtual Health Library. www.bsvdepho.org/bvsaidis/chile

Table 13. Biodegradability index of wastewater in the WWTP* of the INAPA

N°	INAPA WWTP	COD/BOD
1	Bayahíbe	2.6
2	Pimentel	2.9
3	San Juan	4.3
4	Las Terrenas	1.3
5	San Francisco de Macorís	2.6

Source: Prepared using data from INAPA. * Wastewater Treatment Plant. Note: The WWTP of Terrenas and San Francisco de Macorís comply with the physical-chemical parameters indicated in the discharge regulations. The others do not.

CAASD for treatment is 64,960 m^3/d, but due to the deterioration of the plants, only 21,960 m^3/d are actually treated.

4.3.1 National Institute of Drinking Water and Sewerage (INAPA)

The INAPA submits quality control reports for five of the 19 WWTPs in operation, which correspond to effluents from the Canoa-Bayahíbe, Pimentel, San Juan de la Maguana, Samaná, Las Terrenas and San Francisco de Macorís plants; all of which involve biological treatment.

The first criterion is to determine the rate of biodegradability of the water for each WWTP, which ranges from 1.3 and 4.3, in other words, from extremely biodegradable to moderately biodegradable.

4.3.2 Santo Domingo Aqueduct and Sewerage Corporation (CAASD)

The CAASD reports partial and limited analyses of the effluent quality of three of the ten plants it claims to operate (Los Jardines, La Ciénega and Los Tres Brazos) and only in two of ten parameters: BOD / COD.

When the COD/BOD indicator was established, they were between 2.45 and 2.99, which classifies them as wastewater that has hardly been biodegraded by biological processes. None of the effluents comply with having a COD of less than 150 ppm. As for the BOD, only the Los Tres Brazos plant complies with this parameter.

The data show that there was no traceability study and, if it exists, surveillance management is extremely poor, affecting the quality of the process. It is important to note that the receiving body for this effluent is the Ozama River.

Figure 2. La Zurza Treatment Plant (model)

In order for the PTARs to operate well, it is necessary to detect the discharges that reduce biodegradability, which suggests that the CAASD should install individual treatment systems for discharge into sewers.

4.3.2.1 La Zurza Wastewater Treatment

This is the largest of the seven treatment plants contemplated in the Sanitary Sewer Master Plan of Greater Santo Domingo, which is 97% complete and scheduled to begin operating (October 2018).

During the first stage, the aim is to treat 1.2 m^3/sec of wastewater. Treatment will involve conventional trickling filters (biological filters), with a sludge treatment line by anaerobic digestion. The plant will purify the industrial and waste waters of sectors in the northern margin of the National District and Santo Domingo Norte municipality. This is one of the most important public works, which will contribute to the recovery of the Ozama and Isabela rivers.

The project is implemented through financing with Deutsche Bank, and during the first phase, three stages of investments are to be undertaken with an extension period every 10 years, according to the Master Plan schedule, which has an environmental license for its construction and operation. The work will benefit the sectors of Cristo Rey, Villas Agrícolas, Villa Juana, Villa Consuelo, Ensanche La Fe, La Agustina, Miraflores, San Juan Bosco, 24 de abril, Simón Bolívar, Capotillo, Los Jardines del Norte, Isabel Villas, Cuesta Hermosa I and II, Cerros of Arroyo Hondo, Arroyo Hondo Viejo, Altos de Arroyo Hondo I and II, Barrio La Zurza and La Cañita, as well as the extensions and Espaillat, Luperón, in Santo Domingo Norte, which will benefit Villa Mella, Los Guaricanos and Sabana Perdida.

4.3.3 Santiago Water and Sewerage Corporation (CORAASAN)

In the CORAASAN case, seven WWTPs are analyzed using laboratory analysis reports. Three Extended Aeration WWTPs (a variant of activated sludge), one involving Activated Sludge, two Septic ones and an IMHOFF Tank with a total flow of Q=1,627 lps.

The biodegradability indicator (COD/BOD) for activated sludge processes was between 2.24 and 2.26. In the case of IMHOFF,[1] the index was 2.43. In the Septic WWTP, it was between 2.2 and 2.31 and in the Aereation Tank, the index was 7.76. The first three qualify as moderately biodegradable and the last as scarecly biodegradable.

The discharges corresponding to the effluents from extended aeration systems comply with the parameters for solids, BOD and COD, with the exception of plant No.7, which fails to comply with the COD. Activated sludge plants only meet the standards for COD. Effluent from IMHOFF complies with all the parameters, unlike septic effluents, which only meet the standards for suspended solids.

In fact, there is not enough systematized information to evaluate the quality of WWTP effluents. The reported samples indicate effluents that do not comply with the regulations and there is poor management, while recognizing that CORAASAN shows promising signs of good wastewater management in the identification of discharges that could affect the treatment process.

There is no evidence of the use of laboratory models for the design of Biological Treatment Systems and there is a lack of national parameters characterizing the quality of effluents from Wastewater Treatment Plants (WWTP) at the provincial and regional level.

4.4 Quantity and quality of return water

It is estimated that return water represents a flow of 40 m^3/s and transports part of the insecticides and chemicals used in agricultural practices. This flow affects the quality of surface and groundwater. In reality, return waters represent one of the main sources of diffuse contamination to be evaluated.

In water statistics, the volume of return water is recorded by river basin, values that are transcribed below, with a range of 26 to 46% efficiency.

Return water in conjunction due to drag-outs from rainwater runoff from the livestock sector is crucial when considering the equivalent population (**Table 15**).

4.5 Water quality of principal Dominican rivers

The main causes of pollution of river waters include erosion, return water (agriculture) and domestic effluents, the quality of which depends on the different uses of the river and season of the year.

4.5.1 Río San Juan

The San Juan River is the strategic axis for agricultural production, associated with land uses in eight micro-basins, modifying the quality of the water along its 202 km journey, and requiring controls through instruments for different types of use according to the particular stretch of the river, such as

a. Physical and technological methods, such as: modernization of stations, relocation, new stations, definition of parameters to be measured.
b. Definition of indicators. Among the first, it is recommended that two of the existing stations be located, 17 new hydrometric stations be built and 30 water quality stations be activated, with new technology instruments.

1. Wastewater treatment system named after the German professor and doctor in engineering Karl Imhoff.

Table 14. Return Water in the Dominican Republic

Region	Irrigation Volume in million m³ (Mm³)	Flow (m³/s)
Yaque del Sur	527.5	16.73
Yaque del Norte	492.9	15.63
Atlantic	30.6	0.97
Yuna	92.3	2.93
Ozama-Nizao	70.1	2.22
Este	36.4	1.15
Total	**1,249.8**	**39.63**

*1 Mm3 = 0,03171 m^3/s. Source: Compiled using data from PHIN, INDRHI 2012.

Table 15. Pollution expressed in terms of equivalent population

Name	Weight (kg)	Equivalent
Confined cow	500	12-15 inhab. Equivalent
Confined pig	60	2-5 inhab. Equivalent
Hen	1-2	0.1-0.2 inhab. Equivalent

Source: Compiled using data from PHIN, INDRHI 2012.

4.5.2 Quality of the Yaque del Norte River

In its passage through the City of Santiago, the Yaque del Norte river has physical-chemical and bacteriological characteristics classified as Class B Water - for surface water - as shown below:

a. The percentage of oxygen saturation is greater than 70% in 10 sampling stations, ranging between 76.5% and 94%.
b. Levels for Oxygen Biochemical Demand, with a maximum permissible limit of 5 ppm, are exceeded in 8 out of 10 monitoring stations within a range of 7.3 ppm to 20 ppm.
c. Fecal Coliforms (FC). In this parameter, the regulation establishes a limit of 1000 NMP /200 ml and the values measured in 10 monitoring stations in the urban area of Santiago range from 2,500 to 86,000 NMP/100ml in the CORAASAN reports for the period 2013-2017. In the case of Total Coliforms (TC), the range is greater than for FC, varying from 2,600 to 94,000 MPN/100 ml.

4.5.3 Quality of Ozama and Isabela rivers

The quality of the Isabela and Ozama rivers is affected by erosion and the dragging of organic matter, which in turn encourages the growth of the water hyacinth, causing recurrent impacts every year, and limiting their use and increasing risks for human settlements and tourism. The Isabela River is a tributary of the Ozama River and 15 km from its confluence lies a development area for the water hyacinths dragged there annually in the rainy season. This section is one of the most polluted areas in the country.

Key factors of pollution in the Ozama and Isabela rivers include:

a. Erosion in the upper basin, general and lateral scour in the channel, sedimentation/deposition in the middle and lower basins.
b. Emergence, development and disappearance of water hyacinths (*Eichhornia crassipes*) as a result of organic matter sedimented in the middle and lower basins rich in NPK, creating more damage than good, promoting the development of the *Aedes aegypti* mosquito, a transmitter of dengue, the roots of which can serve as a habitat for cholera bacteria.
c. Floods due to changes in rainfall, increasing the river flow and causing variations in the hydraulic section: minimum water level (NAMI), maximum ordinary water level (NAMO) and extraordinary maximum water level (NAME), affecting existing human settlements.

d. Physical, chemical and biological pollution: solid waste, industrial, domestic, agricultural and livestock discharges.

4.5.3.1 Sedimentation and eutrophication processes

The Ozama River has one of the most densely populated, highly polluted basins in the country. There is no integral management study of this basin considering river hydraulics, which would make it possible to define hydraulic and channeling works. The current solution to the rapid processes of sedimentation, eutrophication and contamination that occur at the mouth of the river are resolved by dredging, with the sludge being deposited in the sea.

4.6 Water quality and final disposal of solid waste

The surface of open dumps (350 garbage dumps) in the Dominican Republic is approximately 6 km^2, which, as a result of average rainfall of 1,500 mm/a creates an estimated 90 lps of leachate (Swiss method).

4.6.1 Problems affecting water quality

Water supply and sanitation systems, and bodies of water should undergo technical health audits and continuous monitoring. With the participation of society, they should be conducted as part of water management, currently totally absent in the country.

The main problems impacting water quality in the country include:

- An economic model with high carbon consumption, coupled with a lack of vision of the importance of water as an axis of national development.
- Erosive processes in the main mountain ranges of the country.
- Low sanitary control of hydrographic basins, which supply drinking water to nearly 1,300 small and large aqueducts.
- Inappropriate designs without taking appropriate provisions for hydrometeorological effects.
- Limited infrastructure sanitary sewer networks, which leads to the use of isolated treatment systems that cause widespread diffuse contamination in soil and groundwater.
- Only 20% of the water collected in sewer networks is treated.
- Existence of more than 350 open-air dumps throughout the country, which occupy an approximate area of 6 km^2, which, when it comes into contact with rainfall, produce about 90 lps of leachate.
- Water resource management without an integral approach.
- Drinking water service management through aqueducts has low coverage and low pressure and is discontinuous, creating enormous distrust in the population regarding the quality of water for human intake.
- Low proportion of sewage and sewage treatment.
- Lack of regulation of water resource and service, respectively.
- Low investment levels.
- Human resources should be evaluated and reassigned on the basis of academic training.

4.6.2 Social conflict involving mining and the environment

The Dominican Republic has enormous mining potential because of its large deposits of gold (the second largest deposit in America), silver, nickel, bauxite, marble, copper, limestone and granite.

This sector is still governed by the obsolete Mining Law No. 146 of 1971, which establishes in Article 28 that, "It is of primary interest to the Dominican State to explore the national territory, in order to discover deposits of mineral substances for their subsequent use and economic exploitation".

As a result of this paragraph, the country has seen large territorial spaces ruined and countless rivers and aquifers contaminated by the Aluminum Company of America (bauxite), Rosario Maining Company (gold and silver), Falconbridge Dominicana (ferronickel), Dominican Mining Corporation (copper and gold) and CORDE (salt and gypsum), among other companies which, for over 70 years, have developed in the midst of social conflicts due to the damage caused to the environment, particularly, the quality of the water used in their processes.

It is necessary to define a suitable regulation of national territory and regulate land uses for the rational use of mining resources with clear rules, to ensure the well-being of the country.

4.6.3 Relationship between environmental and social mining conflicts in the new millennium

a. After a brief suspension of operations, between 1998 and 2007, the gold mine of Pueblo Viejo, precariously run by the Rosario Dominicana and Placer Dome companies, severely polluted the Margajita River, turning the wate red and crimson water, and creating an extremely acidic pH, with values of between 1 and 3, where no aquatic life could survive. To control the situation, a permanent lime application program was maintained to try to neutralize the pH as much as possible.

b. There was an oil spill due to a break in the pipeline (72 km long) of Falconbridge Dominicana over the Carvajal Stream, a direct tributary of the Haina River and in an area with high rainfall on its way through Villa Altagracia (2002). The cost of damage was estimated at $6.8 million USD, and the local trade union demanded $4.3 million USD in compensation through a legal claim. Damage to the aquatic biodiversity and the river banks was analyzed by the Sciences Commission of the Academy of Sciences of the Dominican Republic and the Environmental Commission of the Autonomous University of Santo Domingo (UASD).

c. Fear and complaints following the oil spill in the Quinto Centenario community of Piedra Blanca, a few meters from the Maimón River, which supplies the Yuna River (second largest basin in the country) and the Hatillo Dam (2008). This case was also documented by the Academy of Sciences and the UASD.

d. The MSP reported that 346 workers and some of the Barrick Gold company personnel suffered from food poisoning as a result of consuming contaminated food and water, although unofficial reports indicate that approximately 600 people received medical assistance and were admitted to clinics and hospitals in Maimon, Cotuí, Bonao, La Vega and San Francisco de Macorís (March 15, 2010); The company resumed operations in 2011.

e. During the 2011-2012 period, a conflict erupted over the exploitation of the nickel deposit Xstrata Níkel planned to carry out in Loma Miranda, the headwaters of 40 springs and rivers studied by the Academy of Sciences of the Dominican Republic and the UASD, with the collaboration of the Vega Real Cooperative and the social support of the Catholic and evangelical churches, town councils and building authorities of the Monseñor Nouel and La Vega provinces, as well as legislators and grassroots communities. To avoid future risks, a proposal for the creation of a National Park was drawn up to protect 98 of the 200 botanical families, on the Island of La Española. The National Park was created unanimously in the National Congress and subsequently postponed by the president until the passage of a Law for the Regulation of National Territory. This conflict was internationalized when the Dominican government requested the assistance of the United Nations Development Program (UNDP), to evaluate the biological attributes and abundance of water Loma Miranda, which confirmed the studies undertaken by the Academy of Sciences and the UASD.

f. According to the MSP study, on the outskirts of the Pueblo Viejo gold mine where Barrick Gold operates, there are about 150 people affected by cyanide and heavy metals due to the pollution of the rivers in the area, including the Mejiíta, Maguaca , Margajita and Colorado (September 25, 2013).

g. Falcondo (Falconbridge Dominicana) was tried at the San Cristóbal Court of Inquiry for polluting the Haina River according to numerous community complaints from Quita Sueño, submitted to the Attorney General's Office during the 2013-2015 period.

h. The Ministry of Energy and Mines closely monitored the El Llagal dam from the Barrick Gold company, built on the channel and headwaters of the Maguaca River, a rainforest area, due to the threat of heavy rains from Hurricane *Matthew* (26 October 2016).

i. The Dominican government announced it will remove Mejita Tailings Dam from the operating center of the Pueblo Viejo Dominicana gold mine, administered by Barrick Gold (60%) and Goldcorp (40%) in order to eliminate the environmental danger it poses to the province of Jan Sánchez Ramírez (March 8, 2016).

j. MARENA fined Falconbridge Dominicana $164,859 through resolution 0273/2017, for the most recent oil spill on the banks of the

Haina River as it passes through the community of Quita Sueño a short distance from the main commercial port in the country (Bajos de Haina), on September 26, 2017.

k. On the occasion of World Wetlands Day, The Academy of Sciences of the Dominican Republic, warns of the danger posed by the mining triangle Barrick Pueblo Viejo (Río Margajita), Minera Maimón (Río Sin) and Falconbridge Dominicana (Río Yuna), for the Health of the Hatillo Dam, the core area of Anianas Vargas National Park (February 2, 2017).

4.7 Economic impacts of water quality

For every dollar invested in water and sanitation, its impact on GDP is $ 4 US. Insofar as the quality of the water in the catchment areas deteriorates, investment in the treatment systems becomes more expensive and the adduction distance increases.

5. Infrastructure and education for water quality management

Sanitary water infrastructure in the aqueduct systems should be increased by 16% so that the population lacking this service has indoor connections installed. Infrastructure in sewage networks should be expanded so that 70% of the population has sewerage by 2030, in other words, 7 million inhabitants.

Investment in construction is important and must be complemented through the continuing education of managers, to understand and accept the separation of roles in the performance of their duties, training in new design criteria, operation and maintenance, to keep unaccounted for water within reasonable limits and without cross connections. Additionally, a vigorous health orientation is required for the population regarding water use and citizen education for payment for drinking water and sanitation services.

The situation described above, together with other elements, constitutes the foundations for the construction of capacities to move towards sustainable development.

5.1 Potabilization

Water as raw material has to be potabilized in order to be transformed into water suitable for human consumption. It is an industrial process subject to good operation and maintenance and, therefore, requires good quality control, with specialized personnel. In the Dominican Republic, slow filtration plants are used for small flows and relatively good raw water, and fast filtration water treatment plants with a high risk of contamination, such as surface water, and disinfection plants for excellent quality water.

5.2 Impact of water quality on health

Quality water in the context of human consumption and sanitation creates benefits at a ratio of 1 to 9. In other words, every dollar invested can generate benefits to the economy of up to $9, beginning with the health of the population.

Good quality water and sanitation in general constitute the main barrier to disease control, since personal hygiene prevents the transmission of diseases. Annex V of Regulation 42-01 of the Health Law 42-01 defines 59 parameters of sanitary importance for possible effects on health, among those related to microbiological parameters and their diseases that can be transmitted by water. According to the MSP report, it is estimated that 60% of diseases in the Dominican Republic are water-related.

5.2.1 Reemergence of cholera

The island of Hispaniola was free of cholera for more than a hundred years, until it was introduced in Haiti in October 2010, from which it spread rapidly to neighboring Dominican Republic three weeks later. The dramatic cholera experience on the Island of Hispaniola has put the response capacity of the health sector in both countries to the test.

In the Dominican Republic, the Vice Ministry of Environmental Health (ex-DIGESA), supported by UNICEF in coordination with PAHO, prepared and coordinated the implementation of an Action Plan against the Cholera Epidemiological Alert, which defines priority lines, as well as the preparatory and response actions of the water, sanitation and hygiene sector, which enabled the epidemic to be contained in its first two years.

5.3 Educational experiences

Whenever citizens become more aware of the importance of water, due to its multiplicity of uses, this is reflected in the empowerment of society, a situation that can be observed as time passes and at all levels or strata of society. The importance of water as a resource and its multiplicity of uses must be transversally incorporated into syllabuses and curricula, both in schools at the basic level and at higher education centers, throughout the country.

Among the multiple tests that conducted throughout the country by different sectors that have become aware of the water quality-health relationship, there are two worth mentioning, which are detailed below in the **Box 1**.

Table 16. Slow filtration plants

No.	Location		Design Flow Rate (lps)
	Aqueduct	Province	
1	La Gorra	Dajabón	10.7
2	Restauración	Dajabón	12.5
3	Vaca Gorda	Dajabón	5.0
4	Arroyo Blanco - El Guanal	Santiago Rodríguez	8.8
5	Villa los Almácigos El Pino	Santiago Rodríguez	15.0
6	Santiago Rodríguez	Santiago Rodríguez	80
7	Vaca Gorda	Dajabón	5
8	Entrada de Mao	Valverde	11.0
9	Peralta	Azua	16.0
10	Magueyal	Azua	22.0
11	Tábara-Abajo	Azua	5.8
12	Villarpando- La Bastida	Azua	22.0
13	La Siembra	Azua	8.8
14	Guayabal	Azua	15.0
15	Juan Santiago	Elías Piña	30.0
16	Sabana Larga - Potroso	Elías Piña	9.0
17	Hondo Valle	Elías Piña	30.0
18	Loma Babor Babor	Elías Piña	8.8
19	Cercado	San Juan	40.0
20	Sabana Alta	San Juan	15.4
21	Guanito	San Juan	8.8
22	La Zanja	San Juan	16.0
23	El Cacheo	San Juan	9.0
24	Jínova	San Juan	30
25	La Maguana	San Juan	30.0
26	El Llano	Elías Piña	26.0
26	El Factor	María Trinidad Sánchez	45
27	San Isidro - Copeyito	María Trinidad Sánchez	30
28	Punta Balandra	Samaná	4.8
29	Majagual	Samaná	8.8
30	Villa Clara - Carenero	Samaná	16.0
31	Guanuma	Distrito Nacional	30.0
32	Centro Boya	Monte Plata	4.0
33	El Cacique	Monte Plata	8.8

34	Sabana De Payabo	Monte Plata	15.0
35	La Gina – Serralle	Monte Plata	10.0
36	Honduras – Matadero	Peravia	5.0
37	Sabana Piedra	Peravia	3.0
38	Yaguarizo	Peravia	14.0
39	La Montería – Las Caobas	Peravia	5.6
40	Paya	Peravia	10.8
41	Medina	San Cristóbal	5.0
42	La Cuaba	San Cristóbal	20.0
43	Los Cacaos	San Cristóbal	10.0
44	Cambita	San Cristóbal	15.0
45	Cambita	San Cristóbal	3.2
46	Medina- La Cuchilla	San Cristóbal	8.8
47	Monte Negro	San José de Ocoa	10.3
48	Monte Negro	San José de Ocoa	4.0
49	Rancho Arriba	San José de Ocoa	10.0
50	Juan Luis	San José de Ocoa	3.2
51	El Pinar	San José de Ocoa	3.0
52	La Peñita	San José de Ocoa	14.6
53	Sonador	Monseñor Nouel	35.0
54	Rincón De Yuboa	Monseñor Nouel	8.8
55	Arroyo Toro	Monseñor Nouel	2.9
56	El Blanco	Monseñor Nouel	8.8
57	Fula – Sabana Del Puerto	Monseñor Nouel	10.0
58	Fula – Los Paleros, Los Quemados	Monseñor Nouel	25.0
59	Juan Adrián	Monseñor Nouel	6.4
60	Los Quemados	Monseñor Nouel	13.0
61	Los Arroces	Monseñor Nouel	16.0
62	Paleros	Monseñor Nouel	35.0
63	Antón Zapemalo	Santiago	60.0
64	Baitoa-La Lima	Santiago	30.0
65	Las Placetas- Esperanza	Santiago	3.5
66	Pedro García	Santiago	9.0
67	Jánico	Santiago	40.0
68	Rincón De Piedra	Santiago	2.5
69	El Cuey	El Seibo	9.0
70	La Cuchilla	El Seibo	12.0
71	La Gina	El Seibo	37.0
72	Pedro Sánchez	El Seibo	16.0
73	Vicentillo	El Seibo	30.0
74	Arroyo Grande	El Seibo	9.0
75	El Cedro	El Seibo	12.5
76	Los Kilómetros	El Seibo	5.0
77	El Valle	Hato Mayor	65.0
78	Hato De Mana	La Altagracia	5.6

79	Otra Banda-Macao	La Altagracia	36.0
80	Sabana De Nisibón	La Altagracia	4.4
81	Los Hatillos	San Pedro de Macorís	80.0
82	El Puerto- Los Llanos	San Pedro de Macorís	8.8
83	Magua	Hato Mayor	8.0
84	Los Hidalgos-Navas	Puerto Plata	4.4
85	Lajas De Yaroa	Puerto Plata	5.5
86	Sabaneta De Yasica	Puerto Plata	5.5
87	Puente Camu	Puerto Plata	4.5
88	Navas- Los Hidalgos	Puerto Plata	30.0
89	El Tamarindo	Bahoruco	12.5
90	Galván	Bahoruco	30.0
91	La Filipina	Barahona	8.0
92	Las Salinas	Barahona	30.0
93	Salinas	Barahona	13.0
94	La Descubierta	Independencia	28.0
95	Pinos del Edén	Independencia	3.2
96	Puerto Escondido	Independencia	4.0
		Total	**1,631.2**

Table 17. Rapid filtration plants (The majority require proper maintenance and remodeling)

No.	Ubicación		Caudal diseño (lps)
	Acueducto	Provincia	
1	Corral Grande	Dajabón	15
2	Dajabón	Dajabón	100
3	Loma de Cabrera	Dajabón	70
4	Partido – La Gorra	Dajabón	70
5	Guayubín	Monte Cristi	100
6	Guayubín	Monte Cristi	200
7	Monte Cristi	Monte Cristi	100
8	Pepillo Salcedo	Monte Cristi	40
9	Monción	Santiago Rodríguez	70
10	La Meseta La Caoba	Santiago Rodríguez	15
11	Santiago Rodríguez	Santiago Rodríguez	120
12	Ac. Línea Noroeste (ALINO)	Valverde	3,000
13	Jaibón	Valverde	100
14	Jicomé	Valverde	70
15	Río Mao	Valverde	450
16	Múltiple Mao	Valverde	500
17	Municipal de Mao	Valverde	125
18	Esperanza (Nueva)	Valverde	100
19	Esperanza (Vieja)	Valverde	125
20	Guatapanal	Valverde	35
21	Azua	Azua	70
22	Canoa – Los Bancos	Azua	40

23	Estebanía – Las Charcas	Azua	70
24	Padre Las Casas	Azua	80
25	Sabana Yegua	Azua	100
26	Elías Piña	Elías Piña	70
27	Pedro Santana – Bánica	Elías Piña	30
28	Carrera de Yegua	San Juan	30
29	Las Charcas de María Nova	San Juan	30
30	Las Matas de Farfán	San Juan	130
31	Punta Caña- Arroyo Loro	San Juan	30
32	San Juan de La Maguana	San Juan	450
33	San Juan de La Maguana	San Juan	500
34	Jorgillo el cercado	San Juan	70
35	Castillo-Hostos	Duarte	35
36	Villa Rivas	Duarte	125
37	San Francisco de Macorís (Cenovi)	Duarte	250
38	San Francisco de Macorís	Duarte	1000
39	Nagua (nueva)	María Trinidad Sánchez	300
40	Río San Juan	María Trinidad Sánchez	200
41	Guayabito, nagua	María Trinidad Sánchez	70
42	Samaná	Samaná	600
43	Nagua (vieja)	María Trinidad Sánchez	200
44	El Pozo-Los Limones	María Trinidad Sánchez	100
45	Salcedo	Hermanas Mirabal	500
46	Juana Vicenta	Samaná	40
47	Las Terrenas	Samaná	260
48	La Lometa Rincón Molinillo	Samaná	160
49	Sánchez	Samaná	70
50	Los Cacaos	Samaná	25
51	Fantino	Sánchez Ramírez	100
52	Cevicos	Sánchez Ramírez	50
53	Cevicos	Sánchez Ramírez	25
54	Las Cuevas, Cevicos	Sánchez Ramírez	30
55	Guanábano Cruce de Maguaca	Sánchez Ramírez	15
56	Guanuma	Monte Plata	70
57	Sierra Prieta	Distrito Nacional	35
58	Yamasá	Monte Plata	50
59	Monte Plata	Monte Plata	75
60	Yamasá	Monte Plata	130
61	Monte Plata	Monte Plata	130
62	Sabana Grande de Boyá	Monte Plata	100
63	Sabana Grande de Boyá	Monte Plata	50
63	Bayaguana	Monte Plata	200
64	Peralvillo	Monte Plata	70
65	Baní (Nueva)	Peravia	1000
66	Sabana Larga	Peravia	30

67	Cañafístol	Peravia	30
68	Baní (vieja)	Peravia	160
69	San Cristóbal	San Cristóbal	1000
70	Villa Altagracia	San Cristóbal	200
71	Los Mogotes	San Cristóbal	15
72	La Colonia	San Cristóbal	10
73	Ramon San Francisco	San Cristóbal	15
74	El Puerto	San Cristóbal	20
75	Piedra Blanca	Monseñor Nouel	50
76	Maimón	Monseñor Nouel	125
77	Bonao	Monseñor Nouel	650
78	Bonao	Monseñor Nouel	250
79	Sabana El Puerto	Monseñor Nouel	35
80	Los Arroces el verde	Monseñor Nouel	40
81	Navarrete	Santiago	80
82	Sabana Iglesia	Santiago	100
83	La Canela	Santiago	105
84	Hato del Yaque	Santiago	80
85	Villa Bao	Santiago	80
86	La Canela	Santiago	22
87	San José de Las Matas	Santiago	50
88	Baitoa la Lima	Santiago	250
89	Villa Trina, José Contreras	Espaillat	40
90	Los Quemados-Los Pedregones	Monseñor Nouel	20
91	El Seibo	El Seibo	200
92	Miches	El Seibo	100
93	Hato Mayor (Yerba Buena)	Hato Mayor	100
94	Sabana de La Mar	Hato Mayor	100
95	Sabana de La Mar	Hato Mayor	150
96	Laguna de Nisibón	La Altagracia	70
97	Higüey	La Altagracia	500
98	Higüey	La Altagracia	150
99	San Pedro de Macorís	San Pedro de Macorís	500
100	Imbert	Puerto Plata	70
101	Neiba	Bahoruco	100
102	Los Ríos-Las Clavellinas	Bahoruco	40
103	Jimaní	Independencia	25
104	Duvergé	Independencia	100
105	Enriquillo	Independencia	70
106	Oviedo	Pedernales	40
107	Quita Coraza - Fondo Negro	Barahona	30
108	Pedernales	Pedernales	75
109	Asuro	Bahoruco, Barahona e Independencia	75
		Total	**21,047.00**

6. Compliance with Sustainable Development Goals (SDG)

6.1 Monitoring of goals

The main SDGs related to water are summarized in SDG-6, Ensure Availability and Sustainable Management of Water and Sanitation for all, with participation and cooperation. In this regard, the UN has launched an initiative to monitor progress in meeting the overall goal for 2030.

6.2 Organizations responsible for monitoring

WHO and UNICEF are responsible for the measurement of sections 6.1 and 6.2.

Box 1. Educational programs

Towards a New Water Culture

The Dominican Republic seeks to make rational use of water, and to this end, it is promoting the "Water Culture" program, under the aegis of INDRHI.[1] The essential purpose of this program is to promote and create awareness in communities, academic centers and civil society towards a change in behavior focused on the protection of water quality and its rational use.

A good example of this can be seen in the implementation of the latter in the microbasin of the Los Baos River, San Juan province, where the Humanism and Democracy Foundation (H+D) and other local institutions have favorably received it and adopted it under the "Río Los Baos Agreement: Water and Development". The project is financed by the Spanish Agency for International Cooperation for Development (AECID). Within the framework of the project, work is being carried out at 22 middle schools in five school districts of the provincial regional department of the Ministry of Education in the province of San Juan de la Maguana.

Moreover, under the methodological approach traditionally implemented, actions have been implemented in the provinces of Santo Domingo, Barahona, Elías Piña, San Juan, Dajabón, Azua, Maria Trinidad Sánchez, Santiago, Monte Plata, San Cristóbal and La Vega, with various consciousness-raising actions.

The program has achieved the incorporation of 40,350 people who have demonstrated a positive change in behavior regarding water use, as reflected in the evaluation and monitoring mechanisms of the implementation process.

The Water Room houses exhibitions on hydraulic works, water quality control and talks about the importance of water. As a result of this process, 8,673 students in basic (elementary) and intermediate education (middle school) and universities, as well as technicians and professionals from different branches interested in the topic, have been trained.

Cultivating Good Water: Río Maimón Basin

Cultivating Agua Buena is an environmental program originally developed by the Government of Brazil in the Paraná River basin. It is implemented using a management model with four strategic components: Management by programs, Management by territorial information, Environmental management and participatory management, operating under the focus of the quality management cycle (Plan, Do, Check and Act).

The Cultivating Good Water project is jointly implemented in the country by the Ministry of Energy and Mines (MEyM) and the Ministry of Economy, Planning and Development (MEPyD). The Brazilian company ITAIPU Binacional, with the support of the Brazilian National Water Agency, provides technical assistance to the aforementioned ministries and the agencies undertaking this program in the basins of the Maimón river in Bonao, the Gurabo stream in Santiago and the Al Medio River basin in Padre las Casas.

1. Law No. 701, passed on April 8, 1965, created the Secretariat of State for Hydraulic Resources.On September 8, Law No. 6 of 1965 was passed, which created the INDRHI.This is how INDRHI was born, as the highest national authority on the surface and groundwater of the country, with the prerogative to control and regulate water use (Article 4 of Law No. 6 -1965).

WHO, UN and Habitat, statistical division, will monitor section 6.3 as regards wastewater treatment. UNEP will be responsible for 6.3.2 on the pollution of water bodies, together with section 6.5.1 on the degree of application of integrated management and 6.6.1 on changes in ecosystems. FAO is responsible for paragraphs 6.4.1 and 6.4.2 on efficiency and scarcity, respectively.

Sections 6.a.1 and 6.b.1 on official contributions for water and sanitation and the degree of institutional regulation with participation will be measured by WHO, UNEP and OECD.

6.3 The Case of the Dominican Republic

Regarding the institutionalization indicator, the Dominican Republic is gradually advancing, since it is discussing three laws to boost the regulation of the development of the new institutional architecture: a) Sectoral Water Law, with separation of roles and a water resource regulator; b) Drinking Water and Sanitation Law, with the Ministry of Health as the governing body; and c) a Service Regulatory Body.

The Chambers of Congress are discussing the Law on Waste, also with separation of roles, with the supervision of MARENA and the creation of a superintendence of the collection, transport and final disposal service.

6.4 SDGs beyond the MDGs

The (current) Sustainable Development Goals exceed the (earlier) Millennium Development Goals in the concepts of monitoring and management in the following six components:

6.1 Drinking water, 6.2 Sanitation and hygiene services, 6.3 Water and wastewater quality, 6.4 Water resource use and water scarcity, 6.5 Water resource management, and 6.6 Ecosystems.

6.5 Cross-border cooperation in water management between the Dominican Republic and Haiti

This subparagraph corresponds to SDG 6.3.1, which proposes the operational arrangement for cooperation and the delimitation of watersheds, linked to SDG 6.5.1 on water management, including: i) A suitable environment, ii) institutions and participation; iii) coordination instruments; iv) financing.

The environment is conducive to strengthening relations with respect to water resources, in view of the fact that there have been bilateral agreements between the Dominican Republic and the Republic of Haiti, the 1929 Treaty of Peace and Perpetual Friendship and Arbitration, the revision protocol of 1936, the 1979 Basic Bilateral Cooperation Agreement -which gave rise to the Bilateral Mixed Commission, which prioritized the following topics in its Fifth Session held in 2010: a) trade, investment and tourism; b) immigration, border, security and justice issues; and c) Transportation, communications and the environment.

The coordinated management of environmental multiservices is necessary in 391 km of border and common basins, mainly the Artibonito basin, which has an area of 9013 km2, 29% of which correspond to the Dominican Republic and the remaining 71% to Haiti.

It is useful to have a binational technical structure that facilitates the exchange of information on the issue of water, and deals with the water balance in common basins, reforestation and technical studies of projects that create capital and welfare for both countries.

The concepts of equity or rational use regarding water balance are not defined between both nations. The regulatory framework lacks the scope to be able to include major water sources in the Artibonito River system and groundwater. This difference hinders good communication between both states, regarding their economic development plans, water availability and its sustainable management.

Water is an economic and social legacy, whose physical and chemical characteristics enable biological processes and constitutes an axis for the development of the border.

In order to resolve problems and differences, with the support of the Global Environment Fund (GEF) and the UNDP, through a participatory process, the governments of the Dominican Republic and Haiti, developed a Strategic Action Plan that meets the need to foster economic development through a common vision of the binational basin of the Artibonito River. In fact, progress has been limited, as a result of which it has been proposed to build water management capacities at the border.

7. Infrastructure and education

7.1 Historical evolution: GDP and Drinking water coverage

Table 18 shows the investment in drinking water and sanitation from 1990 to 2017, and estimated projections based on the minimum needs required to move towards compliance with SDGs.

The value of 0.5% of GDP in the projection was not achieved since it was 0.34% for 2018. The amount of investment must be 3% of GDP and the aim is to achieve this amount progressively.

When plotted on a graph, the values show the status of the sector and the need to undertake firm action to solve this problem (**Figures 3, 4 and 5**).

The investment required to solve the issues of drinking water, wastewater (sewers and treatment plants), stormwater drainage networks and solid waste management requires a sustained investment of 500 to 600 million dollars over the next 12 years to achieve ODS-6.

8. Conclusions

1. The Dominican Republic requires institutional re-engineering, with the separation of roles regarding *water as a resource, water and sanitation* as a resource and *waste management*, also with the separation of roles, in order to achieve universal, equitable access to these services by the entire Dominican population. To achieve this goal, it is necessary to work as a team, with a basin approach and the participation of society at all levels of decision.
2. Since substantial monetary resources are required to achieve sustainable development goals, it would therefore be advisable to study the feasibility of public-private partnership to obtain resources. In itself, the regional and basin approach for undertaking services derived from water as a resource and water as a service together with solid waste, could be a solution that lends social cohesion to human settlements in various river basins.
3. The issue of water quality in binational basins and transboundary aquifers is the technical platform for the design of policies that improve water-related ecosystems, such as forests, mountains, rivers, aquifers and lakes. This is the best approach for the development of cooperation among border towns.

Table 18: Drinking Water as a Share of GDP

Period	Average GDP US $ * 10^6	APS GDP (%)	Water Coverage (%)	GDP/CAP Drinking Water Coverage * 10^6 in US $	Increase in GDP due to Drinking Water Coverage (million US$)
1970 – 1980		0.40			
1980 – 1990	7,074.00	0.37			
1990 – 2000	23,799.30	0.71	65.00	366.14	
2000 – 2005	33,774.70	0.44	71.78	470.53	104.39
2005 – 2010	44,242.42	0.45	74.02	597.68	127.15
2010 – 2015	65,691.0	0.34	74.09	886.70	289.01
2010 - 2015	65,691.0	0.34	84.00	782.04	104.66
2016	68,843.30	0.27	84.00	819.56	37.53
2017	75,040.00	0.30	84.00	893.33	11.30
Projected Data					
2018	78,792.00	0.50	84.84	928.71	109.15
2019	82,731.60	0.75	85.69	965.49	72.16
2020	86,868.18	1.00	86.55	1,003.73	75.02

Source: Civil Engineer Castillo Tió, Mesa del Agua: data drawn from Banco Central/ONE/SISDOM 2014/ MEPyD.

Figure 3. Average GDP US$

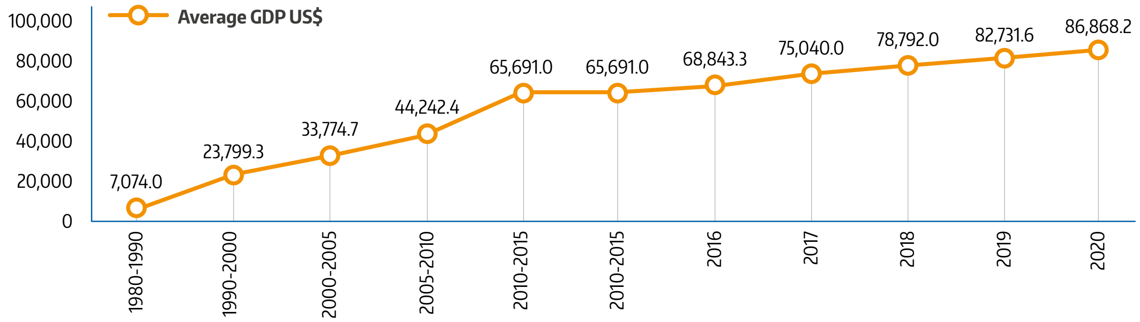


Figure 4. APS GDP (%)

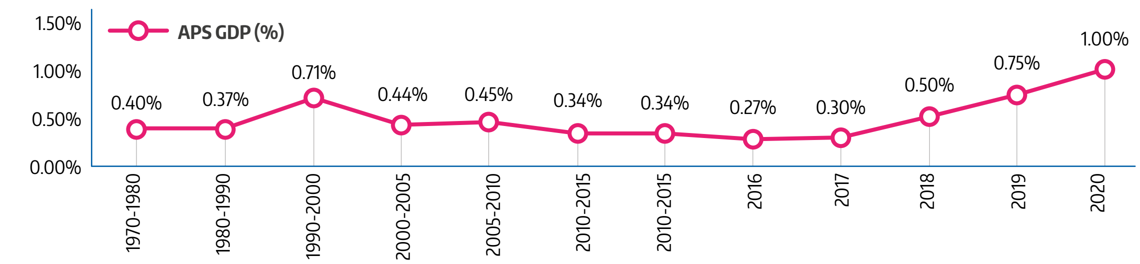
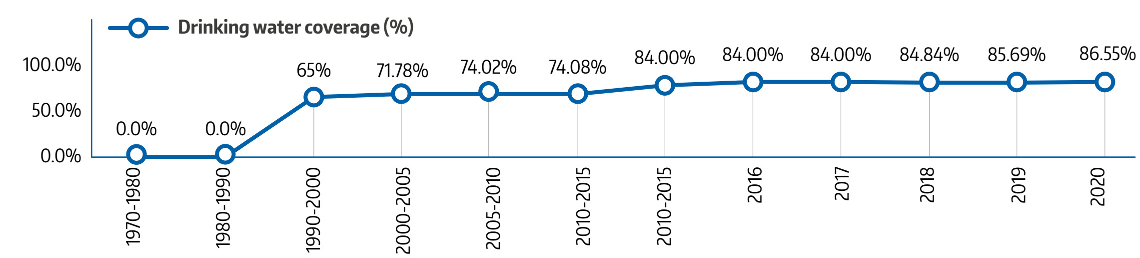


Figure 5. Drinking water coverage (%)



4. It is necessary to organize a day to monitor drinking water quality which includes the source, the presence of biofilm in distribution networks and monitor heath quality in storage and distribution systems to establish a quality model for every aqueduct in the country.
5. It is also essential to develop river quality models in each of the seven main watersheds by measuring the parameters, pH, conductivity, BOD, fecal coliforms, turbidity, OD, nitrates, phosphate color, pH, temperature and establish the thermal profile of the river on the basis of the vegetation.
6. Likewise, it is necessary to characterize groundwater in terms of pH and nitrites.
7. At the same time, the authorities and society itself have to promote quality management, in order to regain confidence in water coming from aqueducts for human consumption.
8. It is essential to quantify the pollution load of the agricultural sector, given the incidence of nitrate content in agricultural waters that can alter the quality of ground and surface water.
9. It is essential to hold a nationwide discussion involving all social strata on a law for the financing of public services.
10. Lastly, with regard to water quality, the Dominican Republic must assess the economic contributions of water use and management. All these elements, presented by way of a conclusion, are essential for achieving a true national policy on water quality in the country.

9. Recommendations

1. All water issues must be seen through the development model in force in the country and, above all, the type of economy that sustains it and a low carbon economy is obviously recommended.
2. The human resources responsible for water resource management and the provision of water and sanitation services (seen as a human right) should be selected on the basis of the criteria of training, relevance and competence.
3. Water is a public good and, as such, the benefits derived from it (or at least a significant portion) should be transferred to finance the works required until full access to water and sanitation is achieved (which is the essence of SDG 6, seen as a fundamental human right).

References

Abreu, R. (2012a). *Diagnóstico y propuestas estratégicas sector agua potable y saneamiento.* Consultoría de Servicios para el Diseño de la Estrategia y Políticas Básicas para el Sector Agua Potable. Santo Domingo: Ministerio de Economía, Planificación y Desarrollo-MEPYD.

Abreu, R. (2012b). *Estrategia y políticas públicas sector agua potable y saneamiento.* Consultoría de Servicios para el Diseño de la Estrategia y Políticas Básicas para el Sector Agua Potable. Santo Domingo: Ministerio de Economía, Planificación y Desarrollo-MEPYD.

Asociación Dominicana de Ingeniería Sanitaria y Ambiental (ADIS) (1996). *Los Desafíos del Sector Agua Potable y Saneamiento de Cara al Siglo XXI.* Primer congreso dominicano de ingeniería sanitaria. Santo Domingo: ADIS.

Comisión Presidencial para la Reforma y Modernización del Estado; Comité Técnico Interinstitucional de Agua Potable y Saneamiento (1998). *Análisis Sectorial de Agua Potable y Saneamiento. República Dominicana. Informe Final.* Santo Domingo: CPRYME-OPS/OMS.

Congreso Nacional (July 30 1962). Ley que crea el Instituto Nacional de Aguas Potables y Alcantarillados INAPA. [Ley 5994 de 1962]. GO: 8680.

Congreso Nacional (September 8 1965). Ley que crea el Instituto Nacional de Recursos Hidráulicos-INDRHI. [Ley 6 de 1965]. GO: 8945.

Congreso Nacional (August 18 2000). Ley que crea la Secretaría de Estado de Medio Ambiente y Recursos Naturales. [Ley 64 de 2000]. GO: 10056.

Congreso Nacional (March 18 2001). Ley General de Salud. [Ley 42 de 2001]. GO: 10075.

Congreso Nacional (July 12 2012). Ley del Sistema Dominicano para la Calidad (SIDOCAL). [Ley 166 de 2012]. GO: 10581.

Congreso Nacional (January 25 2012). Ley que establece la Estrategia Nacional de Desarrollo 2030. [Ley 1 de 2012]. GO: 10656.

Constitución de la República Dominicana (Const.) (2015). Artículos 15 (Tít. I), 50 y 61 (Tít. II), 147 (Tít. IV). Gobierno Dominicano.

Corporación del Acueducto y Alcantarillado de Santo Domingo (2017). Documentación del Departamento de Operaciones de la CAASD Relacionada con sus Actividades de Suministro y Manejo de Calidad de Aguas.

FAO (2015). "Proyecto de Desarrollo de Capacidades para el Uso Seguro de Aguas Servidas en Agricultura". FAO, WHO, UNEP, UNU-INWEH, UNW-DPC, IWMI e ICID.

Fondo de las Naciones Unidas para la Infancia (UNICEF) / Organización Mundial de la Salud (OMS) (2015). *Progresos en materia de agua potable y saneamiento: Informe de actualización 2015 y evaluación del ODM.* Retrieved from http://www.wssinfo.org/fileadmin/user_upload/resources/JMPreport_Spanish.pdf

Foro Centroamericano y República Dominicana de Agua Potable y Saneamiento (FOCARD-APS). (2013). *Gestión de Excretas y Aguas Residuales. Situación Actual y Perspectivas.* El Salvador: FOCARD-APS.

González, E. (2011). *Disponibilidad y utilización de las aguas superficiales y subterráneas.* Encuentro Nacional sobre los Recursos Hídricos. Santo Domingo: INDRHI.

Instituto Nacional de Aguas Potables y Alcantarillado (INAPA) / Banco Mundial (BM) (2016). *República Dominicana / Segundo Informe de Monitoreo de los Avances de País en Agua Potable y Saneamiento - Mapas II.*

Instituto Nacional de Aguas Potables y Alcantarillado (INAPA) (2017). Documentación de los Servicios de INAPA a Nivel Nacional y la Mesa de Coordinación de las Corporaciones de Agua Potable y Alcantarillado.

Instituto Nacional de Recursos Hídricos (INDRHI) (2012). *Plan hidrológico nacional.* Santo Domingo: INDRHI.

Mercedes, Leonardo (2016). *Informe Final Diagnóstico Nacional de Aguas Residuales y Excretas. Formulación Estrategia Nacional de Saneamiento de República Dominicana.* Programa INAPA-AECID DOM-014-B SBCC. INAPA-AECID 001-2013. Santo Domingo.

Ministerio de Economía, Planificación y Desarrollo (MEPYD) (2012). Ley 1-12. Estrategia nacional de desarrollo 2030. Santo Domingo: MEPYD.

Ministerio de Economía, Planificación y Desarrollo (MEPYD) (2017). *Mesa del Agua.* Documento Síntesis Informe del País para el 8º Foro Mundial del Agua.

Ministerio de Economía; Planificación y Desarrollo (MEPYD) (2016). *Informe sobre el cumplimiento de los objetivos del milenio 2015: Transición a los Objetivos de Desarrollo Sostenible.* Retrieved from http://odm.gob.do/Content/Files/Informe_Sobre_el_Cumplimiento_de_los_Objetivos_de_Desarrollo_del_Milenio-República_Dominicana-2015.Pdf

Ministerio de Educación de la República Dominicana (MINERD) (2015). Sistematización del primer año de ejecución de la estrategia de formación continua centrada en la escuela. Retrieved from http://www.inafocam.edu.do/portal/data.2015/sistematización_primer_año_de_ejecución.pdf

Ministerio de Medio Ambiente y Recursos Naturales (MARENA). (2015). *Memoria institucional 2015.* Retrieved from http://ambiente.gob.do/wp-content/uploads/2016/09/MemoriaInstitucional-2015.pdf

Ministerio de Salud Pública de la República Dominicana (MSP) / Organización Panamericana de la Salud (OPS) / Organización Mundial de la Salud (OMS) / Fondo de las Naciones Unidas para la Infancia (UNICEF) (2012). *El Grupo de Agua, Saneamiento e Higiene en República Dominicana y su impacto durante la epidemia de Cólera.*

Ministerio de Salud Pública (MSP) (2014). *Informe preliminar de diagnóstico en hospitales de segundo y tercer nivel de atención.* Documento DIGESA.

Oficina Nacional de Estadísticas (ONE) (2012). *Encuesta Democrática y de Salud (ENDESA).* Portal ODM (Calidad de aguas).

Oficina Nacional de Estadísticas (ONE) (2013). *Encuesta nacional de hogares de propósitos múltiples. ENHOGAR 2013. Informe General.* Santo Domingo: ONE

Oficina Nacional de Estadísticas (ONE) (2014). *Encuesta nacional de hogares de propósitos múltiples. ENHOGAR-MICS 2014. Informe General.* Santo Domingo: ONE.

Oficina Nacional de Estadísticas. (ONE) (2015). *Poblaciones estimadas y proyectadas: Proyecciones y estimaciones urbana y rural 2000-2030.* Retrieved from http://www.one.gob.do/Estadisticas/173/poblacion-estimada-y-proyectada

Presidencia de la República (September 23 2016). Creación de la mesa de coordinación del recurso agua. [Decreto 265 de 2016]. GO: Digital. República Dominicana.

Presidencia de la República (Agost 15 2011). Ley que crea e integra el Consejo Directivo para la Reforma y Modernización del Sector Agua Potable y Saneamiento. [Decreto 465 de 2011]. GO: 10632. República Dominicana.

Presidencia de la República (June 2 1998). Ley que crea la Oficina rectora de la reforma y modernización del sector agua potable y saneamiento. [Decreto 203 de 1998]. GO: 9985. República Dominicana.

Programa de las Naciones Unidas para el Desarrollo (PNUD) (2015a). *Panorama general informe sobre desarrollo humano 2015: Trabajo al servicio del desarrollo humano.* Retrieved from http://www.do.undp.org/content/dominican_republic/es/home/library/human_development/informe-sobre-desarrollo-humano-2015.html

Programa de las Naciones Unidas para el Desarrollo (PNUD) (2015b). *El país República Dominicana en breve.* Recuperado de http://www.do.undp.org/content/dominican_republic/es/home/countryinfo.html

Reynoso, G. (2017). *Contraste de la disponibilidad y demanda de agua por provincia.* Santo Domingo: Consultoría INDRHI – Banreservas.

Rodríguez, H. (2006). *Aguas Subterráneas de la República Dominicana.* Santo Domingo: Instituto Nacional de Recursos Hidráulicos.

Rojas O. F., Horst R., M., Heiland, S. & Venegas I. (2005). *Hacia modelos de gestión sostenibles en agua potable y saneamiento: Evaluación de los existentes y descripción del modelo mancomunitario de carácter mixto.* La Paz, Bolivia.

Secretaría de Estado de Salud Pública (2005). Dec. No. 4205 que establece el Reglamento de agua para consumo humano. In *Reglamentos de la Ley General de Salud,* No. 42-01. Volumen II. (pp. 69-183). Edición Oficial. Santo Domingo: Comisión Presidencial para la Reforma del Sector Salud-CERSS.

Ecuador

Ecuador possesses an extensive, abundant water network fed by the melting of its Andean snow-capped mountains. Although the cholera epidemic of 1991 led to a significant expansion of drinking water coverage, advances in the treatment of wastewater have been limited. Many of its water resources are still contaminated by wastewater, solid waste, industrial chemicals and livestock biosolids that are dumped into the aquatic environment.

Waterfall of San Rafael, Ecuador © iStock

Water Quality in Ecuador

Ricardo Izurieta, Arturo Campaña, Juan Calles, Edmundo Estévez and Tatiana Ochoa

Introduction

Ecuador, a South American country straddling the equator, has an area of 257,217 km^2, with 96.8% corresponding to the mainland and the remainder to a few nearby islands and the Galapagos Archipelago, located 900 km from the Pacific coast. The country is divided into 24 provinces and 221 cantons. It has a population of 16,778,994 inhabitants, with 63.5% living in urban and 46.5% in rural areas. The mainland is divided into three distinct regions: the Coast, a region with a hot climate that extends between the Pacific and the western foothills of the Andes mountain range; the Sierra, a region with cold and temperate climates located between the western and eastern branches of this same mountain range and the East or Amazon region, stretching from the eastern foothills of the Andean mountain range to the Amazonian region of Colombia and Peru (**Figure 2**). In the Sierra region, populations are supplied by water from melted snow from several snow-capped mountains (**Figure 1**) and lagoons (**Figure 3**) in the Andes mountain range, whereas in the western and eastern subtropics and the tropics of the Andean mountain range, the waterfalls (**Figure 4**) and rivers of the Pacific slope and those of the Amazonian slope supply water to towns and cities (**Figure 2**).

Quality of natural surface and groundwater

Surface water pollution, which occurs throughout the country, is related to urban and agricultural sources. Ecuador boasts an extensive water network with major rivers such as the Guayas and Esmeraldas on the Pacific slope, and the Napo and Pastaza on the Amazonian slope. The main sources of pollution nationwide are human settlements and the untreated wastewater they discharge into rivers. Every region in the country has different sources of pollution . On the Coast, pesticide and fertilizer pollution is mainly related to the industrial agricultural production of plantain and African palm. In the coastal zone, pollution of surface

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waters and estuaries is associated with shrimp and aquaculture activities in general, whereas in the Sierra, nonpoint pollution is caused by traditional agricultural systems and export crops such as flowers and broccoli, which involve the extensive use of pesticides and fertilizers. In the Amazon, one of the main sources of river and lagoon pollution is the oil industry and, in recent years, the expansion of mining activity. In the latter case, mining has pollution sources nationwide in places such as Portovelo, Nambija, Zaruma and recently in the north of the province of Esmeraldas.

Another widespread problem of surface water pollution is linked to deforestation and changes in land use throughout the country. Poor farming practices and the geographical conditions of the country increase the amount of sediment in rivers, affecting the storage capacity of reservoirs and dams. Despite the importance of water quality for Ecuador, information on this issue is limited and scattered. The country does not have a national water quality monitoring system and most of the available information has been drawn from specific studies, degree theses or environmental impact assessments.

Biological pollutants

Viruses

Information on viruses in mainland water systems is limited. However, knowledge of these organisms has sometimes been related to diseases that have affected species of commercial interest in the fish industry. In the 1990s, the emergence of Taura Syndrome Virus (TSV) discovered in Ecuador on the Taura River, near the city of Guayaquil, affected

Figure 1. Snowy peak of Cayambe Volcano, in the canton of the same name, Province of Pichincha, Ecuador

Photo: courtesy of Dr. Arturo Campaña.

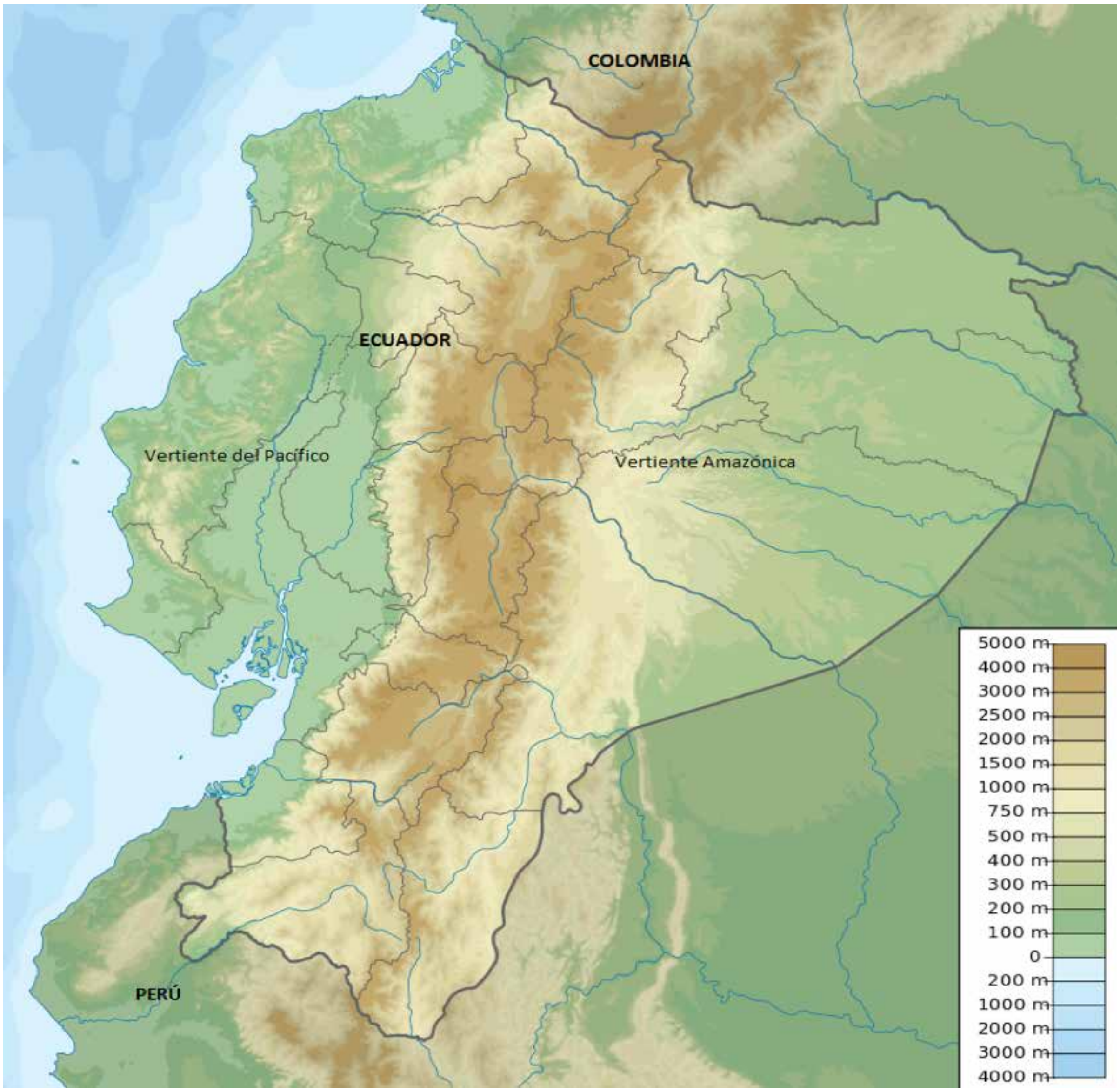
shrimp production and spread to other parts of the country and the world (Cuéllar-Anjel, 2013).Another virus reported in surface waters related to aquaculture activities is Tilapia Lake Virus (TiLV) (Ferguson, 2014), which affects production of this species in Ecuador and other countries.

Bacteria

Studies on surface water pollution have focused mainly on evaluating the presence of *Escherichia coli* as an indicator of biological pollution related to organic pollution. Most surface water quality analyses indicate the presence of *E. coli* in their results. A study conducted by SENAGUA (2010) indicates that 67% of the samples analyzed in the Río Guayas exceed the maximum permitted level (1000 NMP/100ml) of fecal coliforms, reaching levels of up to 16.000 NMP/100ml in the Daule, Cañar, Bulubulu and Chimbo rivers.

According to Levy, the presence of *E. coli* is heavily influenced by rainfall. His study (2009) detected a range of 200-45.000 UFC/100mL in the dry sea-

Figure 2. Map of Ecuador with the hydrographic slopes of the Pacific and the Amazon



son and 300-45.000 UFC/100mL in the rainy season. This study, conducted in the province of Esmeraldas, indicates the pollution levels in surface waters, which are the source of water for human consumption by local communities in this and other areas in the country. The presence of *E. coli* is widespread in surface water sources with ranges that vary according to the type of land use and the presence of nearby villages.

Algae (eutrophication)

In Ecuador, an emblematic case of eutrophication has occurred in the Daule-Peripa reservoir on the Ecuadorian coast, the largest in the country, with an approximate area of 420,000 ha. This process has led to the extensive development of common water hyacinth (*Eichhornia crassipes*) on the surface of the reservoir due to the high concentration of nutrients and low oxygen content.

Other biological indicators

In recent years, the country has undertaken several analyses considering aquatic macroinvertebrates (insects and other aquatic organisms) as indicators of water quality. These organisms live in the substrates of rivers for weeks and months and provide a long-term idea of water quality, because when there are physical or chemical pollutants, these organisms disappear according to their resistance to environmental changes. To this end, indices such as the Biological Monitoring Working Party (BMWP) are used to analyze water quality. This index is widely used in Ecuador and allows for the evaluation of rivers through these organisms (Rios-Touma, 2014; Ambarita, 2016).

The study conducted on the Santiago River basin in the province of Esmeraldas showed that the 10 rivers examined are either in a critical or very critical condition according to the BMWP/Col index

Figure 3. Cajas Lagoon in Azuay Province. Lagoon in Cajas National Park, Azuay Province, Ecuador

Photo: iStock

(Roldán, 2003). Another example of the deterioration of water quality through the application of this index in Guayas River basin (Cárdenas, 2013) shows that 31 of the 43 places studied are in a critical or very critical condition. In his study of the Portoviejo River, Dueñas states that 19 of the 31 sites studied are in poor, bad and very bad condition, reflecting the deterioration of the water quality of this river (Dueñas, 2016). In the Paute River basin, a similar study (Ortíz, 2014) detected that during the dry season, seven of the 17 places studied were in a critical or very critical condition, and that during the rainy season, nine of the 22 places were in a critical or very critical condition.

Another interesting aspect are the analyses carried out to determine the presence of heavy metals in fish. A study of the Santiago River basin in the province of Esmeraldas showed that several fish species may have heavy metal contents exceeding permitted national and international levels (PUCESE 2012).

Chemical pollutants

The information available on chemical pollutants shows that the data collected depends on the purpose of the study and the availability of laboratories to analyze the samples.

Inorganic Pollutants

Arsenic

In Ecuador, arsenic pollution was recently detected in geothermal, ground and surface waters, as well as in sediments. The study *One century of arsenic exposure in Latin America* (Bundschuh J, 2012) highlights key evidence of arsenic pollution in Ecuador. The findings of De la Torre (2004), for example, indicate high concentrations in thermal waters, rivers and lake basins, as well as in Lake Papallacta with ranges of 390–670 μg/L in 2006 and 2007. Environmental technicians and experts declared that a possible cause of the high concentration of arsenic in Lake Papallacta was the removal of sediment from the lagoon during the process of eliminating the crude oil pollution caused by a break in the Trans Ecuadorian Oil pipe System (SOTE) in 2003 (De la Torre, 2004). At the same time, studies by Cumbal and collaborators found measurements of 62 to 698 μg/L along the Tambo River, the main tributary of that lake, together with concentrations of 1,090 to 7,852 μg/L in its thermal waters. They also discovered high concentrations of arsenic in the water systems of the inter-Andean provinces of Carchi, Imbabura, Pichincha and Tungurahua, particularly in their thermal springs (Cumbal, 2009; Bundschuh, 2012).

The river currents of mining areas or those with mineralization show high levels of arsenic, generally in the range of 200-400 ug/L, which do not always have an exclusively anthropogenic origin. In 2007, the rivers of the coastal areas of Ecuador, such as the Gala, Tenguel, Siete, Chico rivers, were reported to be polluted with metals such as mercury, chromium, copper, lead, arsenic - the latter at 15 times the permitted levels-, as a result of the mining operations carried out in the province of Azuay in the sector of Ponce Enríquez. Water from these rivers is used for washing clothes and body hygiene in the absence of safe water, which increases the frequency of exposure through skin contact. In the north of the country, the surface waters of the El Angel, San Pedro and Pichán rivers and the Cachiyacu and Ilalo gorges of the provinces of Carchi, Imbabura, Pichincha, Cotopaxi and Tungurahua, which receive thermal springs from the sources and residual thermal waters from the spas located in this region, contain arsenic in the range of 2 to 171 ug/L. (Cabrera, 2014).

The other study conducted on the Santiago River basin in the province of Esmeraldas shows concentrations of this metal in the water ranging from <0,01 mg/L to 1,5 mg/L, while the concentration of this metal in fish and aquatic organisms, such as shrimp, reaches levels of between 0,19 and 2,3 mg/kg, indicating processes of bio-accumulation in species consumed by local populations (PUCESE, 2012). The presence of this metal in the area is related to mining activities undertaken in the rivers and banks in this part of the country.

Cadmium

A study conducted on 80 km of the Daule River (Huayamave, 2013) found that the concentration levels of 85% of cadmium in the samples were higher than the threshold effect level (TEL) set at a maximum of 0.6 $mg.kg^{-1}$, yet lower than the PEL (probable effect level). A recent study (Araujo, 2016) on the concentrations of cadmium, mercury and lead in the muscle tissue and liver of the yellow fin tuna (*Thun-*

nus albacares) and common dolphin (*Coryphaena hippurus*) offloaded in the Port of Manta, located in the demarcation of Manabi, shows that half the muscle samples of both species have Cd and Hg levels above the safety limit for human consumption established by the European Union (CISPDR 2017).

Mercury

In the Puyango-Catamayo hydrographic demarcation, a study by the Changjiang Institute of Survey Planning, Design and Research (CISPDR, 2017) indicates that, in the southern part, the main pollution indicators detected are total coliforms, fecal coliforms and mercury. This finding is hardly surprising, since this demarcation contains the gold mines of Zaruma and Portovelo, which discharge cyanide and mercury into the Amarillo River and the entire river system related to it. The severity of this problem has been well documented by the ecosystemic research carried out by Guimaraes, showing that this activity emits approximately 0.65 t of inorganic mercury and 6,000 t of sodium cyanide annually, in addition to metals such as lead, manganese and arsenic from rock, significantly reducing the biodiversity downstream, depositing metals in sediments and biota, and even exposing coastal fauna (as well as farmed shrimp) to the dangers of mercurial biomethylation (Guimaraes, 2011).

A recent study on mercury contamination in fish in the Andean rivers of the Amazon in three river basins in Ecuador and Peru (Webb, 2015) documents mercury emission which, in the absence of gold extraction, hydroelectric dams and deforestation, can only be related to oil activity. Mercury levels in the non-migratory variety of tiger fish (*Hoplias malabaricus*) as a bioindicator, were found to be higher in fish in the Corrientes River, belonging to the Pastaza hydrographic demarcation, near the site of an oil spill, in comparison with the two other rivers studied. To complement this study, the same authors conducted another study to determine mercury levels in urine in indigenous people on the Ecuadorian and Peruvian side of the border living near oil production or transportation sites. They found that although their levels are within the limits suggested by the World Health Organization, they were significantly higher in men involved in clearing up the oil spill and women who depend on surface water for household needs, which suggests their exposure to mercury through direct contact with the spilled oil in the first case, and through the consumption of contaminated water in the second.

Chromium

The aforementioned study of the waters of the Daule River (Huayamave, 2013) found average chromium values above the threshold effect level (TEL) in the Balzar and Palestina stations. Another study conducted in the province of Esmeraldas (Correa, 2015) to determine the metal content of the waters, sediment and fish in the Santiago River Basin in the Province of Esmeraldas, during the dry season, found that the levels of aluminum, copper, iron, manganese and lead in water exceeded the Maximum Permitted Levels (TULSMA) in all the stations in the sample. Likewise, metals in sediments proved to have copper, chromium, iron, manganese and zinc levels exceeding the values estimated in the bioassays for the evaluation of sediment toxicity described in NOAA.

A study undertaken in the province of Tungurahua, which has a number of tanneries located on the banks of several of its rivers, revealed that in the discharges from just one of them, chromium (VI) values greatly exceeded the limit permitted by Ecuadorian regulations (TULAS) of 0.5 mg/L. In fact, in the 16 samples taken between May and August 2009, values fluctuated between 52.3 and 392.9 mg/L, equivalent to an average of 160.34 mg/L.

Nitrites

Analyses of the water of the Guayas River in the section corresponding to the city of Guayaquil, conducted by the Cantonal Drinking Water and Sewerage Company, established that the total nitrogen level - which measures its nitrification capacity to nitrites and nitrates - exceeds the permitted limit of 1.2 mg/l, in all eight sampling points, at both high (values between 2 and 3 mg/l), and low tide (values between 2 and 4 mg/L). A study conducted by the National Water Secretariat (Guzmán V 2010) also identified the presence of nitrates (N-NO3) at levels reaching 86,48 mg/l in the water used in the El Mate irrigation system from the Daule River.

Nitrites

In the study of the waters of the Daule River (Huayamave, 2013), nitrite values were also determined for the nitrite ion, ranging from non detection to 0.20 mg/L, which are within the limits permitted by Ecuadorian legislation.

Organic contaminants

The Cayambe-Ecuador EcoHealth Project (CEAS/SIPAE, 2014) monitored the water quality of the Granoble River basins, used primarily to irrigate 2.180 ha of land for growing potato, maize, cut flowers, wheat, barley, other grains and pastureland. This study detected the presence of phthalates used in the production of plastic and, in some cases, as pesticides. In approximately 50% of the 70 samples analyzed between 2004 and 2009, the presence of organochlorines such as Endosulfan and DDT was detected. Organophophorates such as Malathion, found throughout the basin, and Diazinon were among the most frequent, together with toxic carbamates such as Carbofuran and phthalates, fats and other products. The presence of sulfides, phthalates and fats is almost constant. Phthalates indicate the enormous amount of plastic contamination in the area. Carbofuran and Difeconazolle were also found in cows' milk samples (CEAS/SIPAE, 2014).

Figure 4. Blue Waterfall, Puerto Quito Canton, Province of Pichincha, Ecuador

Photo: courtesy of Dr. Arturo Campaña.

A tracking study of organochlorines and organophosphates (no carbamate analysis was planned) in soil and water samples in the Tenguel River basin, in the vicinity of plantain plantations, revealed the presence of Lindane in five (55,6%) of the nine samples, within a range of 0,014 to 0,322 ppb, together with Chlorothalonil in two of the samples and Endosulfan in one. No traces of organophosphates were detected in the water samples.

From the discussion of the results obtained for the water samples of the Daule River in his studies, Huayamave (2013) concludes that organochlorinates pesticides were detected in 53,3% of the samples undertaken and that nine types were detected in the 23 organochlorinates analyzed, 1,2-dichloro-4-isocyanatobenzene was detected in 31%, 4,4-DDD in 19%, aldrin, methoxychlor and endosulfan-sulfate each in 1.7%, and dieldrin, phenamiphos, Heptachlor, HCH-Delta in concentrations of 0.83%. The samples taken on August 3, 2011 contained a total organochlorine concentration of 16,040 $\mu g.L^{-1}$, which is within the limit of 10 $mg.L^{-1}$ of total organochlorines established as a maximum in Ecuadorian legislation. As for organophosphorus pesticides, the author states that they were only detected on three occasions and that, of the 23 organophosphorus analyzed, two were determined as follows: azinphos methyl and azinphos ethyl at concentrations of 0.373; 0.373 and 0.378 $\mu g.L^{-1}$, which is lower than the maximum established by Ecuadorian regulations.

In the inter-Andean province of Cañar, a largely agricultural, floricultural and livestock raising area, a major study on the water quality of the Burgay River was recently conducted to establish the diffuse contamination the river receives due to the presence of pesticides and the associated toxicological risk (Pauta, 2014). In some monitoring stations, sources destined for human supply were found to exceed the concentrations allowed by the Ecuadorian Regulation (TULAS) for organophosphates and organochlorines. The monitoring carried out at seven sampling points between February and November 2013 identified the presence of the following organochlorines: Lindane 14.7 ppm, Cisheptachlorohepoxide 13.1 ppm, pp-DDE 22.6 ppm at one of the points; pp-DDE 61.7 ppm at another; and Profenofos 592 ppb in yet another. The presence of organophosphates such as Diazinon and the following organochlorines was also found at other sampling points: d.-HCH, Aldrin, a- Endosulfan, b-Endosulfan, Endosulfan Sulfate, and Lindane, together with BHC. The most frequently found organosphates, in all stations, albeit at different sampling times, were Lindane and hexachlorin delta (Pauta, 2014).

In a study conducted on the Arenal and Junquillo rivers (Tapia, 2013), in the Los Ríos province, at the mouths of the channels in two plantain plantations, the levels of organophosphates, organochlorinates and carbamates in the water of these rivers was compared before and after aerial spraying. The analyses revealed that whereas prior to the fumigations, they showed levels below the limits allowed by the Ecuadorian environmental legislation, afterwards they experienced a significant increase. Thus, in the Arenal River, the concentration of organochlorines exceeded the permitted limit by eight points and of organophosphorus by five while carbamates exceeded the limit of <0.02 to nine. The Junquillo River has levels of six and seven points higher for organochlorines and organophosphates, respectively, and carbamates from <0.02 to 7.

Lastly, a sampling of the water quality carried out during the rainy season at 16 points distributed throughout the four hydro-social zones of the Provincial Irrigation Plan of the province of Carchi (CEAS/SIPAE, 2014), the leading potato producer in the country but also with a significant increase in floricultural activity in recent years, showed that ten of the 16 samples had carbamate pollution: seven from Carbofuran, an insecticide and nematicide whose use is forbidden, two from Carbaril and one from Methomil.

Radionuclides

Strontium

Studies on radionuclides are uncommon in Ecuador. It is worth mentioning the study conducted by Mena (2016), which found strontium concentrations in *Macrobrachium brasiliense* freshwater prawns in ranges from 777,8 $\mu g.g^{-1}$ in the Due River to in 1.586,1$\mu g.g^{-1}$ in the Conde River, in Ecuadorian Amazonia.

Quality of water for human consumption and wastewater

Biological pollutants

The methodology used in the water quality assessments carried out by the local institutions that provide water for drinking in the country is heterogeneous and, in some cases, does not tally with the evaluations undertaken by national government agencies or academic institutions.

The Public Metropolitan Drinking Water and Sewerage Company (EPMAPS) of the Metropolitan District of Quito certifies water quality through sampling and external analysis with SGS DEL ECUADOR. The Ecuadorian Institute of Normalization (INEN) granted the INEN quality seal in 2015, which is maintained through periodic audits. According to these evaluations, in 2016, the EPMAPS registered a water quality index of 99.7% (EMAPS 2016). According to the 11 monthly reports on the microbiological quality of EPMAPS drinking water for 2017, the presence of fecal coliforms greater than or equal to 1 NMP/100ml (EMAPS 2017) was not reported. However, it should be pointed out that the raw water with which some of the treatment plants are supplied has high levels of fecal coliforms. For example, in the month of November, the presence of 140,345 NMP/100ml and 134,045 NMP/100ml fecal coliforms was found in raw water prior to its entry into the drinking water treatment plants of Guayllabamba and Yaruquí, respectively (EMAPS, 2017; EPMAPS, 2017).It should be noted that levels greater than 1,000 NMP of fecal coliforms per 100ml of water are not even acceptable for effluents from sewage treatment plants, according to the 2012 Guidelines for the Reuse of Water of the United States Environmental Protection Agency (USEPA) (USEPA, 2012).

As for drinking water in the city of Guayaquil, according to the report by International Water Services (Guayaquil) Interagua C Ltda., submitted for the period from August 2016 and July 2017, the Conventional, Lurgi and 10MCS plants, as well as water from the networks, submitted 100% "compliant" reports for fecal and total coliforms for all months (INTERAGUA, 2017).

Measurement of the indicators of the Sustainable Development Objectives (SDG) for Water, Sanitation and Hygiene (ASH), published by the National Institute of Statistics and Census (INEC), analyzed water quality nationwide through the absence-presence test of *E. coli.* According to this study, 20.7% of the national population consumes water contaminated with *E. coli.* An analysis of the results by rural or urban area shows that 15.4% of the urban population and 31.8% of the rural population consume water contaminated with this microorganism (**Figure 5**) (INEC 2017).

Despite the data reported, according to a perception study conducted by the National Institute of Statistics and Census (INEC) in June 2012, Cuenca is recognized as the city with the best water quality in the country and, in general, 66.5% of Ecuadorians stated that they do not trust the quality of the water they consume (INEC 2012).

Viruses

Owing to the limitations in the country due to the costs of technology for the detection of viruses in environmental samples, the information regarding water contamination by viral agents is either non-existent or scarce. One means of overcoming this limitation would be the use of bacteria modified by genetic engineering, which can be lysed by phage viruses, the most commonly used ones being bacteriophage coliphages that specifically lyse *E. coli.* In a study conducted on the northeast coast of the country, 125 villages in the Bourbon region of Esmeraldas, an area with minimal health infrastructure, were considered. The villages reported that 40% use a latrine, and 60% dispose of excreta in the field or rivers, many of these rivers being the primary source of drinking water. Water in the communities is supplied by surface water from rivers, piped water, well water or rainwater. This study detected a geometric average of between 91 and 125 Colony Forming Units (CFU) (Levy, 2012). In population studies conducted in the country, rotavirus has been associated with acute diarrheal disease and, to a lesser extent, Norovirus (Vasco, 2014). Hepatitis A and E viruses have been detected in the surface waters of rivers, primarily due to an almost total absence of urban wastewater treatment systems and discharges from farms for raising pigs or other types of livestock. Although there is no monitoring of the presence of this virus in surface waters, many of the 3,453 cases detected in Ecuador during 2016 are related to untreated water or food contaminated with these viruses (MSP, 2017).

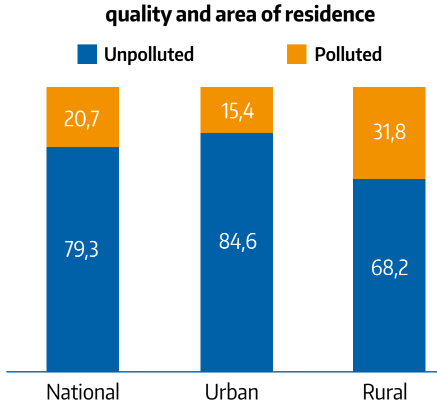
Bacteria

Escherichia Coli

In a study conducted on seven communities located in northeastern Ecuador, on the banks of the Santiago, Cayapas and Onzole rivers, the following findings were reported in dwellings that collected river or piped water to be consumed, which was not treated after having been stored for 24 hours. The results of the samples when taken at the wa-

Figure 5. Measurement of Indicators of Sustainable Development Objectives (SDO) for Water, Sanitation and Hygiene (WSH) published by the National Institute of Statistics and Censuses (INEC)

Percentages of people by water quality and area of residence



At the urban level, of the 15.4% of polluted water, 28,6% is bottled or packaged water

Percentage of persons who drink contaminated water, by type of source

Type of water supply	National	Urban	Rural
Public network / public tap	55,1	64,1	45,8
Other source by pipes	11,2	-	19,8
Protected well / piped	6,3	-	12,0
Bottled / packaged water	17,8	28,6	-
Other*	-	-	-
Total	100	100	100

* Others include: unprotected well, protected spring/slope, unprotected spring/slope, delivery truck/tank, rainwater/other

Table 1. Possible contaminating viruses in Ecuadorian waters

Agent	With Pathology	Reservoir	Water as vehicle	Analysis in drinking water country	Detected in drinking water country	Human cases country
Rotavirus	Gastroenteritis	Human, Animal (da Silva, 2016; Rusinol,2017)	Yes (da Silva, 2016; Rusinol, 2017)	No		Yes (Bhavnan, 2012; Levy, 2012; Vasco, 2014)
Astrovirus	Gastroenteritis and Acute Respiratory Infection	Human(Da Silva, 2016; Rusinol,2017)	Yes (Da Silva, 2016; Rusinol, 2017)	No		Not known
Norovirus	Gastroenteritis	Human	Yes (Katayama, 2017)	No		Yes (Vasco, 2014)
Hepatitis A	Hepatitis	Human	Yes (Van der Poel, 2017)	No		Yes (MSP, 2017)
Hepatitis E	Hepatitis	Human, Animal	Yes (Van der Poel, 2017)	No		Not known
Coxsackie virus	Gastroenteritis, Acute Respiratory Infection, Foot hand disease, Meningitis, Cardiac infection, Peripheral neuropathy	Human	Yes (Rusinol, 2017)	No		Not known
Enterovirus	Gastroenteritis, Acute Respiratory Infection, Foot hand disease, Meningitis, Cardiac infection, Peripheral neuropathy	Human	Yes (Rusinol, 2017)	No		Not known
Polioviruses	Poliomyelitis	Human	Yes (Betancourt, 2016)	No		No case associated with the wild virus since 1990
Adenoviruses	Gastroenteritis and Acute Respiratory Infection	Human	Yes (Allard, 2017)	No		Not known
Echoviruses	Gastroenteritis, acute respiratory infection, meningitis and hepatitis	Human	Yes	No		Not known

ter source (river or piped water), and after 24 hours of storage in the home, reported a geometric mean of MPN of *E. coli* per 100 ml (95% CI) of 111.4 (57.4-216.1) and 121.5 (67.9-217.2), respectively. Therefore, 13.6% of the samples taken at the source and 9.1% of the samples taken at the houses after 24 hours of storage reported <1 MPN/100mL *E. coli.* These results point to a high percentage of *E. coli* contamination of drinking water in rural areas, exacerbated by possible contamination due to poor storage practices in the home (Levy, 2014). In another study conducted in the same geographical area of these three rivers that serve as a source of water for local communities, obvious heterogeneity was observed in the microbiological quality of the waters, which depended largely on the distance from the shore. The logarithmic concentration 10 of *E coli* decreased by 2% for each meter of distance from the shore. Water samples taken from fast flowing areas of the river had concentrations of 0.12 Log 10 lower than waters from the river fords. Likewise, waters at distances of more than 6 meters had concentrations that were 0.27 log 10 lower than shore waters. These findings show the effect of shore distance, speed and water turbulence on the microbiological concentrations (Rao, 2015). Bacterial pathogens such as *Salmonella typhi*, which are related to water and food contamination, are not monitored by water purification systems. However, many of the 1,253 cases of this disease detected in Ecuador in 2016 are related to contaminated water or food (MSP 2017).

Helicobacter pylori

Ecuador has the second highest rate of mortality from gastric cancer in the Americas with an Age-Standardized Mortality Rate (AMR) of 15.6 per 100,000 inhabitants. As regards the incidence of gastric cancer, Ecuador has a rate of 16.9 cases per year per 100,000 inhabitants, surpassed only by Guatemala, Honduras and Costa Rica (Ferlay, 2015). These high rates have been associated with the height above sea level, although it is not known to what extent this association is also determined by socioeconomic, genetic, dietary or environmental factors, and water and sewerage infrastructure (Torres, 2013). The presence of the *Helicobacter pylori* bacterium has been described as a critical factor in the occurrence of gastric cancer, which why it has been categorized as a group 1 carcinogen by the International Agency for Research on Cancer (IARC

Table 2. Possible contaminating viruses in Ecuadorian waters

Agent	Pathology	Reservoir	Water as vehicle	Analysis in drinking water of country	Detected in drinking water country	Human cases country
Campylobacter spp.	Gastroenteritis	Human, Animal	Yes (Pitkanen, 2017)	No		Yes
Escherichia coli	Gastroenteritis	Human, Animal	Yes	Yes	Yes (Levy, 2009 y 2014; Rao, 2015)	Yes
Helicobacter pylori	Gastritis, Gastric cancer	Human	Si (Goodman, 1996; Hulten, 1996; Zhang, 1996; Sasaky, 1999; Brown, 2000) Yes (Sewage) (Goodman, 1996; Hegarty, 1999; Sasaky, 1999)	No		Yes (Sasaki T 2009, Torres J 2013, Ferlay J 2015)
Legionella spp.	Pneumonia, gastroenteritis	Water	Yes	No		
Leptospira spp.	Hemorrhagic fever	Water (Izurieta, 2008; Barragan, 2011; Chiriboga, 2015); Soil, Animal (Barragan, 2016)	Yes 3 (Barragan, 2011)	No		Yes (Chiriboga, 2015; Barragan, 2016)
Salmonella spp.	Gastroenteritis	Human, Animal	Yes (Liu, 2018)	No		Yes (Vasco, 2014; MSP, 2017)
Shigella spp.	Gastroenteritis	Human	Yes (García-Aljaro, 2017)	No		Yes (García-Aljaro, 2017)
Vibrio cholera	Gastroenteritis with watery diarrhea	Water (estuaries) Aguas servidas 37	Yes (Weber, 1994; García, 2012)	No		Yes (Weber, 1994)
Yersinia enterocolitica	Gastroenteritis	Animals (Bottone, 2015)	Yes (Bottone, 2015)	No		

1994). In a study conducted by the authors, a 72.2% prevalence of *H. pylori* was observed in the population of Ecuador and a 54.1% prevalence in that of Panama (Sasaky, 2009). Of these patients, the CagA gene was identified in 45.9% of Ecuadorian samples and 20% of Panamanian samples. These data are important, since patients may remain asymptomatic and present the infection with the CagA gene, which represents a high risk of gastric cancer (Sasaki T 2009). These data correlate with reports on stomach cancer, with rates of 17.4% in Ecuador and 11.1% in Panama. Future research should focus on determining the type of gene with the highest prevalence involved in stomach cancer (Sasaki, 2009). The presence of *H pylori* in water has already been described in several studies (Brown, 2000). Moreover, *H pylori* can live in water for several days in its infectious bacillary form (Brown, 2000). Studies conducted in Colombia, China and Peru support the characterization of *H pylori* infection as a waterborne infection (Klein, 1991; Goodman, 1996; Zhang, 1996).The possible contamination of food irrigated by wastewater is also supported by the findings of molecular epidemiological studies, using PCR techniques, carried out in Peru and Japan, in which this bacterium was detected in wastewater (Hazell; 1994; Westblom, 1997; Sasaky, 1999). In studies conducted in Pennsylvania and Ohio, *H. pylori* was isolated in its active form in surface and groundwater samples (Hegarty, 1999). As has been observed with other bacteria, *H. pylori* can form biofilms in the walls of water pipelines, this being a critical aspect in bacterial survival in water and other environments in order in preventing the spread of this pathogen and its treatment in the human host (García A 2014).

Leptospira

Leptospirosis is caused by spiral-shaped bacteria from the family *Leptospiraceae* and the genus *Leptospira*. These bacteria are long, thin, mobile spirochetes that can live freely in the environment or be parasites in animal hosts. These bacteria require wet environments to survive, such as polluted freshwater sources (lakes, ponds and river fords) or muddy environments where they can remain for many months (Izurieta, 2008). A study to detect *Leptospira* spp. DNA in febrile patients from urban and rural areas of Ecuador reported a prevalence of 64% in rural areas, 25% in semi-urban areas and 21% in urban areas. The percentage of intermediate strains was higher (96%) than that of pathogenic strains (4%) (Chiriboga, 2015). In a similar study conducted on febrile patients from the rural area of the Province of Manabí, the percentages of DNA prevalence of pathogenic leptospires were higher, ranging from 9.5 to 17.3% (Barragán, 2016). In environmental studies, bacteria isolated from rivers in the Napo province of the Ecuadorian Amazon showed their ability to maintain the viability of *Leptospira biflexa* and *Leptospira meyeri* in distilled water for up to one year (Barragán, 2011) .

Cholera

In 1991, Ecuador was one of the Latin American countries that experienced the impact of the introduction of Vibrio cholera into the continent. On February 28, 1991, the first case of the disease was reported in the southern coastal area of the country, with the epidemic spreading to the Andean and Amazonian areas in a matter of weeks. It is important to mention that, despite confirmation of the presence of pathogenic V. cholerae in samples from affected patients, water sample cultures always yielded negative results. This incongruence in the isolation of the vibrio between clinical samples (**Figure 6A**) and environmental samples was explained a few years later when it was shown that V cholerae enters a state of pseudo-spores, which maintain its viability, but cannot be cultivated (Colwell, 1994). However, these V. cholerae pseudo-spores are easily observable in contaminated water samples when examined under an immunofluorescence microscope (**Figure 6B**).

Despite the painful consequences of the numerous lives claimed by the cholera epidemic in the country, many advances in terms of water quality are due to the measures taken at that time by the population and local and national governments. Inadequate levels of chlorine, the existence of clandestine water connections and low water pressures that made water intrusion possible, were some of the factors associated with the presence of *Vibrio cholera* in drinking water (Weber, 1994). Although the country has made substantial progress in drinking water coverage and quality, several rural and peri-urban populations still lack secure water supply sources. The serious shortcomings in the excreta system were also revealed during this cholera epidemic. In one of the small cities of the Andean region, numerous cases of cholera were reported due to the pollution of the river that crosses the city, caused by the elimination of excreta not adequately treated by the hospital where cholera patients were being attended (Izurieta, 2006). In 1998, it was reported that only 5% of sewage effluents in Ecuador underwent any degree of treatment prior to discharge (Izurieta, 2006). There are no current data on the percentage of wastewater adequately treated by local and municipal sewerage systems in the country, prior to its discharge into rivers, lagoons, lakes and seas. Although the cholera epidemic in Ecuador in the early 1990s played a decisive role in making government administration structures aware of the need to improve drinking water quality and increase sewerage coverage, progress in excreta treatment has been non-existent or minimal. It is also worrisome that the incidence of acute diarrheal diseases has steadily risen, even during the first decade of this century. This may be a harbinger of another impending epidemic. It is therefore essential to investigate the clear increase in diarrheal diseases to reinforce the preventive public health measures that were successfully implemented to control the cholera epidemic of the 1990s, in addition to new recommendations (Malavade, 2011).

Protozoa

In the case of protozoa, their presence has mainly been studied in feces. However, specific studies such as the one carried out in the province of Azuay, in the San Fernando district, on water intended for human consumption (Palacios, 2017) detected, in the case of *Cryptosporidium* spp, the presence of oocysts/100 mlof water, and 10 cysts/100 ml of water in the case of *Giardia lamblia*.

Giardia

In a comparative study of children looked after at home versus children cared for at day-care centers, *Giardia* spp was the second agent most frequently associated with diarrheal disease with an average incidence of 11.74 episodes per 1000 child-weeks (Sempertegui, 1995). A study conducted in the province of Azuay, in the San Fernando canton, in water intended for human consumption (Palacios 2017), found an average of 10 cysts/100 ml of water when analyzing the presence of *Giardia lamblia*.

Cryptosporidium

In the same study comparing children cared for at day care centers and in their homes, the incidence of diarrhea associated with *Cryptosporidium* spp was 1.52 and 1.28 episodes, respectively (Sempertegui, 1995). In environmental microbiological studies,

Figure 6A. *Vibrio cholerae* grown from patient stool samples. Figure 6B. *Non-growable Vibrio cholerae* in water samples detected by immunofluorescence. Study conducted by Dr. Ricardo Izurieta at the Microbiology Laboratories of the University of Maryland, College Park (Izurieta R 2006)

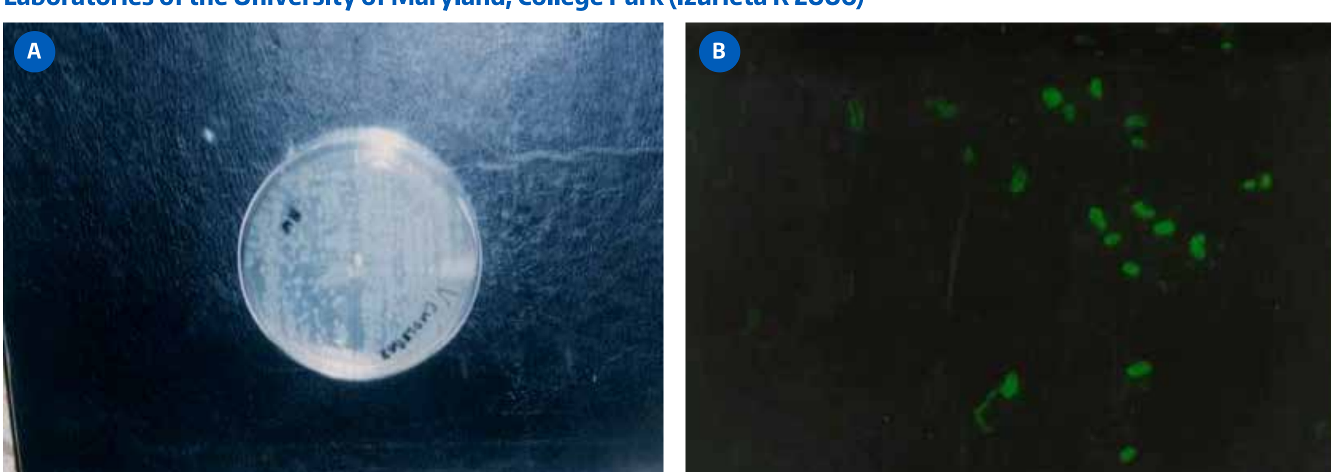


Table 3. Possible parasites and contaminating algae in Ecuadorian waters

Agent		Pathology	Reservoir	Water as vehicle	Analysis in drinking water	Detected in drinking water	Cases in humans
Protozoa	*Criptosporidium* spp	Chronic diarrhea	Animal, Humans	Yes (Palacios, 2017)	Occasionally	Yes (Palacios, 2017)	Yes (Sempertegui, 1995; Jacobsen, 2007)
	Giardia doudenalis	Abdominal pain	Human, Animal	Yes (Palacios, 2017)	Occasionally	Yes (Palacios, 2017)	Yes (Sempertegui, 1995; Palacios, 2017)
	Entoameba histolitica	Dysentery, liver abscess	Human	Yes	No		Yes (Cooper, 1994; Sempertegui, 1995)
	Balantidium coli	Gastroenteritis	Human, Animal	Yes	No		Yes (Sempertegui, 1995; Jacobsen, 2007; CEPAL/GIZ, 2012)
Metazoos	Geo helminths	Gastrointestinal symptoms, malnutrition	Soil	Yes 57(Molleda-Martínez, 2016)	No		Yes (Reyes, 2012; Preciado, 2015)
Algae	Cyanobacteria	Poisoning	Water (Morales, 2013; Guamán, 2016)	Yes (Guamán, 2016)	No	Yes (Guamán, 2016)	Yes (Weirich, 2014)

Cryptosporidium spp has been isolated from surface waters. An analysis of 14 samples of untreated waters from the watersheds of the Quito area identified oocysts of this parasite in five of the samples (Kato 2003). In the aforementioned study, conducted in the province of Azuay, the presence of five oocysts of *Cryptosporium* spp per 100 ml of water for human consumption was detected (Palacios, 2017).

Other protozoa

Other protozoa associated with diarrhea in children include *Entamoeba hystolitica*, *Chylomastix mesnilii* and *Blastocystis hominis* (Sempertegui, 1995; Jacobsen, 2007).

Helminths

In a study on water quality in the province of Esmeraldas, the presence of helminth eggs was detected in the Atacames estuary and river. During the water sampling conducted from July to December 2013, concentrations ranging from 500 to 2000 eggs per liter of water were observed. The isolated helminth eggs corresponded to the species *Coccidio* sp, *Hymenolepis* sp, *Trichuris* sp, *Ascaris* sp, *Oxiuros* sp, *Trichostrogylus* sp, *Taenia* sp and *Ancylostomas* sp. These high concentrations are due to the lack of a sewerage system and wastewater treatment system and the presence of direct discharges with organic content into the river. This poses a high health risk for the local population, since they use water directly from this river (Molleda-Martínez P 2016).

Chemical pollutants

According to the April 2016 Report of Automatic Water Information Management System of the City of Quito, the following physical-chemical parameters meet the established norm: color, residual chlorine free, turbidity, As, nitrates, fluorides, Cr, nitrites, benzopyrene, cyanides, Hg, Cd, Cu, DDT and metabolites, Ni, bromodichloromethane, toluene, 1-2 dichloroethane, lindane, xylene, vinyl chloride , benzene, micorsystin-lr, aldrin, dieldrin, 1-2 dibromoethane, dimethoate, tetrachloroethane, chloropyrifos, styrene, tricloethene, endrin, antimony, Pb, Se, chlordane and Ba. It does not state which treatment plant provided the sample for the analysis or whether it was taken at random.

Arsenic

In 2004, the population of Parroquia Tumbaco, in Quito Canton, reported that the water for human consumption contained arsenic above the tolerance value established by the Ecuadorian standard (García, 2012), which forced the Metropolitan Company of Sewerage and Drinking Water, Quito (EMAAP-Q) to conduct the "Special arsenic monitoring of the rural sources of the Southern and Eastern Central District", operated by this company, in 2005. The results of the monitoring led to the recommendation to prohibit the use of these sources due to the high levels of arsenic found and to analyze the waters of the distribution network of the Tumbaco and Guayllabamba parishes, whose drinking water is obtained from these sources. In 2007, the EMAAP-Q collected 116 samples from the household distribution network of these two parishes, and found that arsenic exceeded the permitted limit in 39 of them (33.6%) (EMAPQ, 2007). Among the samples from Tumbaco, there were some with up to 10 times the permitted levels and in Guayllabamba some with up to three times the limit. Although the country has higher environmental levels of arsenic associated with volcanic activity, in this case, they may be caused by poor waste management and industrial emissions. It should be pointed out that the water systems (both surface and deep) of the two parishes have primarily been affected for over three decades by agroindustrial activity (particularly flower and fruit growing), meaning that their contamination may be associated with arsenic additives commonly incorporated into pesticides, herbicides and fertilizers. The drinking water company eventually decided to install treatment plants in Tumbaco to remove the arsenic, which did not work properly, and led to the closure of two wells and the supply of safe drinking water from other localities.

Quality of water discharged by manufacturing and agricultural industries

Using the Pfafstetter characterization methodology, the National Secretariat of Water of Ecuador (SENAGUA) proposed the organization of its 137 sub-basins and the most important segments of 682 main rivers in nine hydrographic districts: six with rivers that run into the Pacific Ocean and three with rivers that flow into the Amazon River. The country has a wealth of rivers. The combined length of all these rivers is 4.593,3 km. The average pluriannual volume of runoff of these nine demarcations is 318,948.0 hm^3, which, since population density varies between the two demarcations - would be equivalent to an average of 0.019 hm^3 or 19,000 m^3

Figure 7. Demographic Demarcations and Pollution Sources. Ecuador, 2017

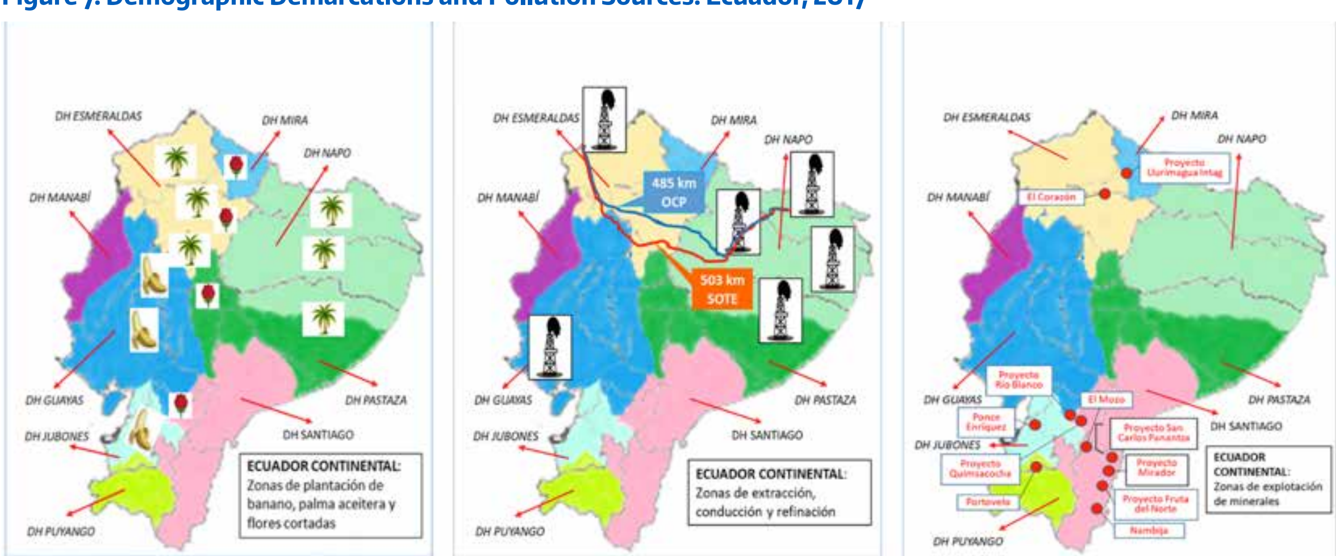
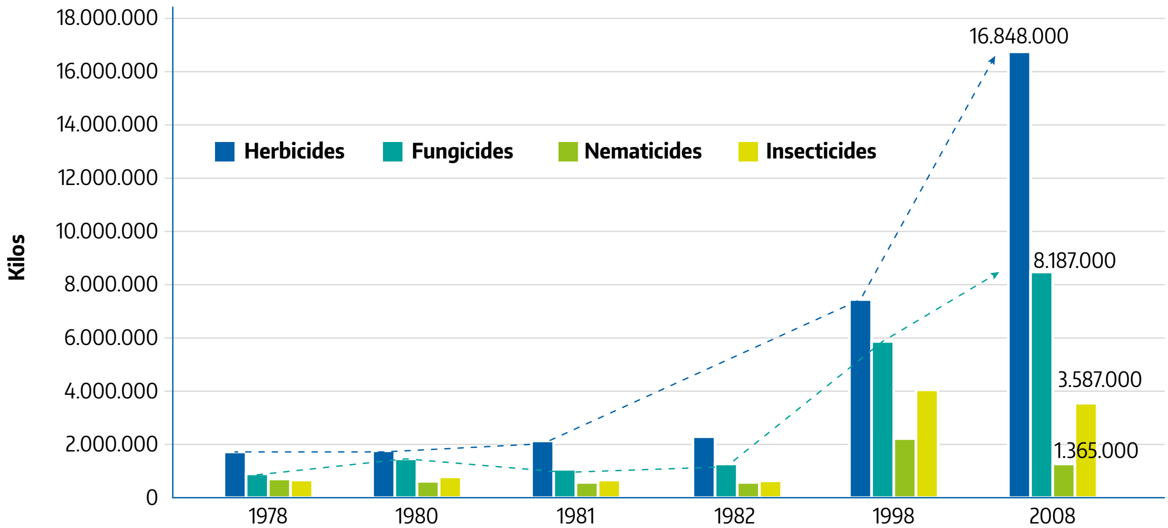


Figure 8: Evolution of imports of herbicides and pesticides, Ecuador 1978-2008



Source: MAGAP, compiled by the author

per year per Ecuadorian inhabitant. It is also estimated that these waters affect 221,043.2 km^2, in other words, over 85.9% of the surface of the mainland territory of Ecuador. Although this also varies, the hm^3/km^2 ratio is more favorable in the hydrographic districts of the Amazon basin (Napo 2,0, Santiago 1,8 and Pastaza 1,4) than in those of the Pacific coast (Esmeraldas 1,3, Mira 1.1, Guayas 0.9, Puyango Catamayo 0.9, Manabí 0.7 and Jubones 0.6). Let us now briefly examine the relationship between these hydrographic demarcations and the three blocks of industrial activity with the greater scope and capacity for pollution (**Figure 7**).

It is interesting to note that all the Ecuadorian hydrographic districts, with the sole exception of Manabí, are affected by some form of industrial-level activity emitting potentially contaminating chemicals from their waters.

Since the middle of the last century, the Ecuadorian *export agroindustry* has been part of a production model based on the use of pesticides (we prefer to call them agrotoxins), promoted by the Green Revolution, which began with plantains (in the 1950s) and continued with the African palm (in the 60s) and the production of cut flowers (in the 80s), to which broccoli was added more recently. Approximately 270,000 ha are currently used for plantain production, 260,000 ha to palm and 6,000 ha to flowers. Together, they constitute an area of 535,000 ha of exposure to chemicals and employ 650,000 direct workers. In other words, 12% of the active population employed in the country is linked to agroindustrial production with a high chemical demand. To understand the actual dimension of the current polluting potential of these industries for the population and the ecosystem, it is important to examine the evolution of imports of herbicides and pesticides. The following graph shows that between 1978 and 2008, the volume of imports (including all products) rose exponentially from approximately 3 million k to over 30 million.

Between 1982 and 1998, the time of the start and growth of the flower production sector, there was a break in the trend, followed by a sharp rise in agrochemical imports. In 10 years (1998 to 2008), herbicide imports also grew by approximately 125%. In turn, fungicide exports rose by 38% while nematicide and pesticide exports fell slightly. According to our calculations, in 2008, exports would have totaled 5.1 kilos per cultivated hectare per year.

Policies and regulations

The Ecuadorian Water Secretariat (SENAGUA) is the sole water authority, responsible for this sector throughout the country. However, the quality standard for surface water currently in force is established by the Ministry of the Environment, through the Unified Secondary Legislation Text (MAE, 2003). This standard defines the parameters and permitted limits of water quality for various uses. Book VI, which contains these parameters, was modified in 2015 through agreements No. 028 and No. 061. This book determines the permitted criteria for the preservation of aquatic and wild life in fresh and seawater marine and estuaries. It also defines the criteria for the water quality from urban and industrial waste and the quality of water for human consumption.

Lax or non-existent policies, lack of compliance with existing norms, as well as the absence of rigorous sanctions to match the scope of environmental crimes have contributed to the pollution of several water resources nationwide (CEPAL/GIZ, 2012). These resources have been polluted by the dumping of wastewater and disposal of solid waste into water bodies, as well as chemical contamination by the industrial sector and agrochemicals and animal bio-solids from agricultural and livestock farms that dump their waste into rivers, lakes, lagoons and seas.

Bibliographical references

Allard A, V.A. (2017). Adenoviruses. *Global Water Pathogens Project.* J.B. Rose and B. Jiménez-Cisneros (eds.). Michigan State University/UNESCO. www.waterpathogens.org/book/rotavirus

Figure 9. Dr. Arturo Campaña during the collection of water samples for quality studies, at a flower farm in Cayambe Canton, Province of Pichincha, Ecuador.

Photo: courtesy of Dr. Arturo Campaña.

Ambarita N, L.K.; Boets, Pieter; Everaert, Gert; Hanh-Tien, Nguyen; Forio, Marie; Liz, Sasha; Musonge, Peace; Suhareva, Natalija; Bennetsen, Elina; Landuyt, Dries; Dominguez-Granda, Luis; & Goethals, Peter (2016). *Ecological water quality analysis of the Guayas river basin (Ecuador) based on macroinvertebrates indices.* https://www.researchgate.net/publication/291387793_Ecological_water_quality_analysis_of_the_Guayas_river_basin_Ecuador_based_on_macroinvertebrates_indices

Araujo CVM, C.-M. L. (2016). Heavy metals in yellowfin tuna (*Thunnus albacares*) and common dolphinfish (*Coryphaena hippurus*) landed on the Ecuadorian coast. *Sci Total Environ* 541: 149-154.

Barragan V, C.J.; Miller, E; Olivas, S; Birdsell, D; Hepp, C; Hornstra, H; Schupp, JM; Morales, M; Gonzalez, M; Reyes, S; De la Cruz, C; Keim, P; Hartskeerl, R; Trueba, G; Pearson, T (2016). High Leptospira Diversity in Animals and Humans Complicates the Search for Common Reservoirs of Human Disease in Rural Ecuador. *PLoS Negl Trop Dis* 10(9): e0004990.

Barragan VA, M.M.; Travez, A; Zapata, S; Hartskeerl, RA; Haake, DA; Trueba, GA (2011). Interactions of leptospira with environmental bacteria from surface water. *Curr Microbiol* 62(6): 1802-1806.

Betancourt WQ, S.L. (2016). Polioviruses and other Enteroviruses. *Global Water Pathogens Project.* J.B. Rose and B. Jiménez-Cisneros (eds.). Michigan State University/UNESCO. http://www.waterpathogens.org/book/rotavirus

Bhavnan D, G.J.; Cevallos, W; Trueba, G; Eisenberg, JN (2012). Synergistic effects between rotavirus and coinfecting pathogens on diarrheal disease: evidence from a community-based study in northwestern Ecuador. *Am J Epidemiol* 176(5): 387-395.

Bottone, E.J. (2015). Yersinia enterocolitica: Revisitation of an Enduring Human Pathogen. *Clinical Microbiology Newsletter* 37(1): 1-8.

Brown, LM (2000). *Helicobacter pylori*: epidemiology and routes of transmission. *Epidemiol Rev* 22(2): 283-297.

Bundschuh J, L.M.I.; Parvez, Faruque; Román-Ross, Gabriela; Nicolli, Hugo B; Jean, Jiin-Shuh; Liu, Chen-Wuing; López, Dina; Armienta, María A; Guilherme Luiz, RG; Cuevas Gomez, Alina; Cornejo, Lorena; Cumbal, Luis; Toujaguez, Regla (2012). One century of arsenic exposure in Latin America: A review of history and occurrence from 14 countries. *Science of The Total Environment* 429: 2-35.

Cabrera MA., P.D.; Pulla, MF (2014). Arsénico en el agua. *Revista Galileo*

Cárdenas, M (2013). *Calidad de las aguas de los cuerpos hídricos de la provincia del Guayas mediante el uso de macroinvertebrados acuáticos registrados durante noviembre de 2012 y marzo de 2013.* P. d. Guayas. Guayaquil, Ecuador, Prefectura del Guayas.

CEAS/SIPAE, C.d.e. y A.S. e. S.C.y.S.I.d.I.s.l.P.A.e.e.E.S. (2014). *Plan Provincial de Riego de la provincia del Carchi Quito, Ecuador*

CEPAL/GIZ, C.p.A.L. y e.C.C. y A.d.C.I.A.G. (2012). Diagnóstico de la Información Estadística del Agua. Ecuador 2012

Chiriboga J, B. V.; Arroyo, Gabriela; Sosa, Andrea; Birdsel,l Dawn N; España, Karool; Mora, Ana; Espín, Emilia; Mejía, María Eugenia; Morales, Melba; Pinargote, Carmina; Gonzalez, Manuel; Hartskeerl, Rudy; Keim, Paul; Bretas, Gustavo; Eisenberg, Joseph NS; Trueba, Gabriel (2015). "High Prevalence of Intermediate *Leptospira* spp. DNA in Febrile Humans from Urban and Rural Ecuador." *Emerging Infectious Diseases* 21(12): 2141-2147.

CISPDR, C.I.o.. P.D.a.R. (2017). *Planificación Hídrica Nacional del Ecuador (2014-2035).* Secretaría Nacional del Agua. Quito: S.N.d. Agua.

Colwell, R; Huq, A. (1994). Vibrios in the Environment: Viable but Nonculturable *Vibrio cholerae. Vibrio cholera and Cholera*. Wachsmuth, K; Blake, P; Olsvik, O. (eds.) Washington DC: ASM Press.

Cooper P, G.R.H. (1994). Gastrointestinal illness associated with balantidium coli infection in rural communities in Ecuador. *Parasitología al día* 18(1/2): 51-54.

Correa M, B.M.; Rebolledo, E; Mihi, DR; Salinas, E (2015). Análisis del contenido de metales en aguas, sedimentos y peces en la Cuenca del Río Santiago, Provincia de Esmeraldas. *Revista Investigación y Saberes* 4(2).

Cuéllar-Anjel, J. (2013). Síndrome de Taura. *Factsheets*.

Cumbal L, B.J.; Aguirre, V; Murgueitio, E; Tipán, I; Chávez, C (2009). The origin of arsenic in waters and sediments from Papallacta Lake in Ecuador.

Natural arsenic in groundwaters of Latin America--Occurrence, health impact and remediation. Bundschuh, MA Armienta, J Matschullat, & A.B. (eds.). Mukherjee Leiden (The Netherlands): CRC Press/Balkema, Taylor & Francis Group.

Da Silva M, M.M.; Victoria, M (2016). Rotavirus and Astroviruses. *Global Water Pathogens Project.* J.B. Rose and B. Jiménez-Cisneros (eds.). Michigan State University/UNESCO http://www.waterpathogens.org/book/rotavirus

De la Torre E, G.A.; Munoz, G; Criollo, E (2004). *Estudio de aguas superficiales y sedimentos de la cuenca de los ríos Sucus, Tambo y Papallacta.* Quito, Ecuador Unpublished report.

Dueñas, JA, G.P. (2016). *Ecological assessment of Portoviejo river basin (Ecuador), 2016.*

EMAPQ, E.M.d.A.y.A.P.d.Q. (2007). *Auditoría ambiental a la calidad del agua de consumo humano de las poblaciones de Guayllabamba y Tumbaco.* Quito, Ecuador.

EMAPS, E.P.M.d.A.P.y.S. (2016). *Memoria de Sostenibilidad 2016.* Dirección de Comunicación Social y Transparencia de la Empresa Pública Metropolitana de Agua Potable y Saneamiento Calidad de Agua Potable en Plantas de Tratamiento. D. d. Producción. Quito: Empresa Metropolitana de Alcantarillado y Agua Potable de Quito.

EMAPS, E.P.M.d.A.P.y.S. (2017). *Calidad de Agua Potable en Plantas de Tratamiento. Parámetros Operativos de Control de Calidad de Agua en Plantas de Tratamiento Periodo Noviembre 2017 Calidad de Agua Potable en Plantas de Tratamiento.* D. d. Producción. Quito: Empresa Metropolitana de Alcantarillado y Agua Potable de Quito.

EPMAPS, E.P.M.d.A.P.y.S. (2017). *Parámetros Operativos de Control de Calidad de Agua en Plantas de Tratamiento Periodo Enero-Diciembre 2017 Calidad de Agua Potable en Plantas de Tratamiento.* D. d. Producción. Quito: Empresa Metropolitana de Alcantarillado y Agua Potable de Quito.

Ferguson H, K.R.; Beltran, S; Reyes, E; Lince, JA; Del Pozo, J (2014). Syncytial hepatitis of farmed tilapia, *Oreochromis niloticus* (L.): a case report. *J Fish Dis* 37(6): 583-589.

Ferlay J, S.I.; Dikshit, R; Eser, S; Mathers, C; Rebelo, M; Parkin, DM; Forman, D; Bray, F (2015). Cancer incidence and mortality worldwide: sources, methods and major patterns in GLOBOCAN 2012. *Int J Cancer* 136(5): E359-386.

Garcia-Aljaro C, M. M., Muniesa M (2017). Pathogenic members of Escherichia coli & Shigella spp. Shigellosis. *Global Water Pathogens Project.* J.B. Rose and B. Jiménez-Cisneros (eds.). Michigan State University/UNESCO. http://www.waterpathogens.org/book/rotavirus

García, A; Salas-Jara,.M.J.; Herrera, C.; González, C. (2012). *Sistematización de experiencias del "Grupo pro agua sin arsénico" en la Parroquia de Tumbaco.* Licenciatura en Gestión para el Desarrollo local Sostenible, Universidad Politécnica Salesiana.

García, A; Salas-Jara,.M.J.; Herrera, C.; González, C. (2014). Biofilm and *Helicobacter pylori*: From environment to human host. *World Journal of Gastroenterology* : WJG 20(19): 5632-5638.

Goodman KJ, C.P.; Tengana Aux, HJ; Ramirez, H; DeLany, JP; Guerrero Pepinosa, O; Lopez Quinones, M; Collazos Parra, T (1996). *Helicobacter pylori* infection in the Colombian Andes: a population-based study of transmission pathways. *Am J Epidemiol* 144(3): 290-299.

Guamán M, G.N. (2016). *Catálogo de microalgas y cianobacterias de agua dulce del Ecuador.* C.p.l.I. Energética. Quito: Corporación para la Investigación Energética.

Guimaraes JR, B.O.; Miranda, MR; Barriga, R; Cueva, E; Betancourt, S (2011). Long-range effect of cyanide on mercury methylation in a gold mining area in southern Ecuador. *Sci Total Environ* 409(23): 5026-5033.

Guzmán V, N.R. (2010). *Línea de base para el monitoreo de la demarcación hidrográfica del Guayas.* Quito: Secretaría Nacional del Agua.

Hazell SL, M. H. M., Hedges M, Shi X, Hu PJ, Li Y Y, Lee A, Reiss-Levy E (1994). Hepatitis A and evidence against the community dissemination of Helicobacter pylori via feces. *J Infect Dis* 170(3): 686-689.

Hegarty JP, D. M., Baker KH (1999). Occurrence of Helicobacter pylori in surface water in the United States. *J Appl Microbiol* 87(5): 697-701.

Huayamave, J (2013). *Estudio de las aguas y sedimentos del río Daule, en la Provincia del Guayas, desde el punto devista físico químico, orgánico, bacteriológico y toxicológico.* Doctoral, Universidad de Las Palmas de Gran Canaria.

Hulten K, H. S., Enroth H, Klein P D, Opekun AR, Gilman RH, Evans DG, Engstrand L, Graham DY, El-Zaatari FA (1996). *Helicobacter pylori* in the drinking water in Peru. *Gastroenterology* 110(4): 1031-1035.

IARC, W. G.o.t.E.o.C. (1994). Schistosomes, liver flukes and *Helicobacter pylori*. Risks to Humans. Lyon, 7-14 June 1994. *IARC Monogr Eval Carcinog Risks Hum* 61: 1-241.

Instituto Nacional de Estadística y Censos (INEC) (I.N.d.e.y.C). (2012). *Anuario Estadístico 2012 de la República del Ecuador.* Quito: INEC.

Instituto Nacional de Estadística y Censos (INEC) (I.N.d.E.y.C.) (2017). *Medición de los indicadores ODS de Agua, Saneamiento e Higiene (ASH) en el Ecuador.* Quito: INEC.

INTERAGUA/I.W.S.G.I.C.L. (2017). *Informe Anual 2016-2017.* Guayaquil: I.W.S.G.I.C.L./INTERAGUA.

Izurieta, R (2006). *A Death Foretold in the Times of Cholera.* Latin American and Caribbean Studies, USF, University of South Florida.

Izurieta, R, G.S.; Clem, Angela (2008). Leptospirosis: The "mysterious" mimic. *Journal of Emergencies, Trauma, and Shock* 1(1): 21-33.

Jacobsen, KH, R.P.S.; Quist, BK; & Rydbeck, BV (2007). Prevalence of intestinal parasites in young Quichua children in the highlands of rural Ecuador. *J Health Popul Nutr* 25(4): 399-405.

Katayama H, V.J. (2017). Norovirus and other Calicivirus. *Global Water Pathogens Project.* J.B. Rose and B. Jiménez-Cisneros (eds.). Michigan State University/UNESCO. http://www.waterpathogens.org/book/rotavirus

Kato S, A. L.; Egas, J; Elson, L; Gostyla, K; Naples, L; Else, J; Sempertegui, F; Naumova, E; Egorov, A; Ojeda, F; Griffiths, J (2003). Waterborne *Cryptosporidium oocyst* identification and genotyping: use of GIS for ecosystem studies in Kenya and Ecuador. *J Eukaryot Microbiol* 50 Suppl: 548-549.

Klein, P D, G.D.Y.; Gaillour, A; Opekun, AR; & Smith, EO (1991). Water source as risk factor for *Helicobacter pylori* infection in Peruvian children. Gastrointestinal Physiology Working Group. *Lancet* 337(8756): 1503-1506.

Levy K, A.; Larissa, Robb; Katharine, A; Cevallos, William;Trueba, Gabriel; & Eisenberg, Joseph N.S. (2014). Household Effectiveness vs. Laboratory Efficacy of Point-of-use Chlorination. *Water research* 54: 69-77.

Levy K, H.A.E.; Nelson Kara, L; Eisenberg, Joseph NS (2009). Drivers of Water Quality Variability in Northern Coastal Ecuador. *Environmental science & technology* 43(6): 1788-1797.

Levy K, H.A.E.; Nelson Kara, L; Eisenberg, Joseph NS (2012). Rethinking indicators of microbial drinking water quality for health studies in tropical developing countries: case study in northern coastal Ecuador. *Am J Trop Med Hyg* 86(3): 499-507.

Liu H, W.C.A.; Li, Baoguang (2018). Presence and Persistence of Salmonella in Water: The Impact on Microbial Quality of Water and Food Safety. *Frontiers in Public Health* 6: 159.

MAE, M.d.A.d.E. (2003). Texto Unificado de Legislación Secundaria del Ministerio del Ambiente. Decreto ejecutivo No. 3516. Quito: Ministerio del Ambiente de Ecuador.

MAE, M.d.A.d.E. (2015a). Sustitúyase El libro VI del Texto Unificado de Legislación Secundaria. Acuerdo Ministerial No. 028. Quito: Ministerio del Ambiente de Ecuador.

MAE, M.d.A.d.E. (2015b). Reforma del Libro VI del Texto Unificado de Legislación Secundaria. Acuerdo Ministerial No. 061. Quito: Ministerio del Ambiente de Ecuador.

Malavade S, N.A.; Mitra, A; Ochoa, T; Naik, E; Sharma, M; Galwankar, S; Breglia, M; & Izurieta, R (2011). Cholera in Ecuador: Current relevance of past lessons learnt. *Journal of Global Infectious Diseases* 3(2): 189-194.

Mena, J.; Encalada, A. (2016). *Impactos de actividades antropogénicas discriminados por elementos mayores y traza en el camarón de río Macrobrachium brasiliense en la Amazonía ecuatoriana.* MSc, Universidad San Francisco de Quito.

Molleda-Martínez, P R.C.A. (2016). Estudio preliminar sobre la identificación y cuantificación de huevos de helmintos en el estuario y Río Atacames, Esmeraldas, Ecuador. *Revista Científica Hallazgos* 21 1.

Mora-Alvarado, D. (2003). Agua para consumo humano y disposición de excretas: situación de Costa Rica en el contexto de América Latina y el Caribe - 1960/2000. *Revista Costarricense de Salud Pública* 12: 31-46.

Morales E, L. V.; Navarro, L; Santana, V; Gordillo, A; & Arévalo, A (2013). Diversidad de microalgas y cianobacterias en muestras provenientes de diferentes provincias del Ecuador, destinadas a una colección de cultivos. *Revista Ecuatoriana de Medicina y Ciencias Biológicas* 34(1-2): 129-149

MSP, M.d.S.P.d.E. (2017). *Gaceta Epidemiológica,* Ministerio de Salud Pública del Ecuador. 52.

OMS/OPS, O.M.d.l.S.O.P.d.l.S. (2001). *Informe Regional sobre la Evaluación 2000 en la Región de las Américas: Agua potable y saneamiento, estado actual y perspectivas.* Washington DC, USA Organizacion Mundial de la Salud/Organización Panamericana de la Salud

Ortíz A, R.P. (2014). *Efecto de la variación temporal en la calidad del agua y comunidad de macroinvertebrados en la cuenca del Río Paute.* Licenciatura, Universidad del Azuay.

Palacios, T (2017). Prevalencia de *Cryptosporidium* spp. y *Giardia* spp. en terneros, y su presencia en agua y en niños con problemas digestivos en el cantón San Fernando, Ecuador. *MASKANA* 8 (1): 111-119.

Pauta, G (2014). *Estudio integral de la calidad del agua del Río Burgay y evaluación del riesgo toxicológico por la probable presencia de plaguicidas.* Maestría en toxicología industrial y ambiental, Universidad de Cuenca

Pitkanen T, H.M. (2017). Members of the family Campylobacteraceae: Campylobacter jejuni, Campylobacter coli. *Global Water Pathogens Project.* J.B. Rose and B. Jiménez-Cisneros (eds.). Michigan State University/UNESCO. http://www.waterpathogens.org/book/rotavirus

Preciado, A. (2015). *Prevalencia de la parasitosis intestinal en alumnos de primero a quinto grado de la escuela Helena Criollo desde mayo a junio del 2014.* BS, Universidad Técnica de Machala.

Proano, G. (2007). *Determinación de los índices ambientales por contaminación del uso de pesticidas agrícolas en las plantaciones de banano del sector de Tenguel – Provincia del Guayas.* Maestría en Ingeniería Ambiental, Universidad de Guayaquil.

PUCESE, P.U.C.d.E.M.d.A.d E (2012). *Informe final de monitoreo de calidad ambiental de ríos de la cuenca del Santiago afectados por la actividad minera aurífera entre el periodo noviembre del 2011 a noviembre del 2012.* P.d.R A.y. Social. Esmeraldas, Ecuador: Ministerio del Ambiente de Ecuador.

Rao G, E.J.N.S.; Kleinbaum, David G; Cevallos, William; Trueba, Gabriel; Levy, Karen (2015). Spatial Variability of *Escherichia coli* in Rivers of Northern Coastal Ecuador. *Water* 7(2): 818-832.

Reyes, J.A. (2012). *Evaluación del RT-PCR ejn el diagnóstico de 6 parásitos intestinales en un área con parasitismo de baja intensidad en el Trópico.* Master, Universidad San Francisco de Quito.

Rios-Touma B, A.R.; Prat, N (2014). The Andean Biotic Index (ABI): revised tolerance to pollution values for macroinvertebrate families and index performance evaluation. *Rev Biol Trop* 62 Suppl 2: 249-273.

Roldán, G. (2003). *Bioindicación de la calidad del agua en Colombia: propuesta para el uso del método BMWP Col.* Medellín: Editorial Universidad de Antioquia.

Rusinol M, G.R. (2017). Summary of Excreted and Waterborne Viruses. *Global Water Pathogens Project.* J.B. Rose and B. Jiménez-Cisneros (eds.). Michigan State University/UNESCO. http://www.waterpathogens.org/book/rotavirus

Sasaki T, H.I.; Izurieta, Ricardo; Kwa Boo Hoe; Estevez, Edmundo; Saldana, Azael; Calzada, Jose; Fujimoto, Saori; & Yamamoto, Yoshimasa (2009). Analysis of *Helicobacter pylori* Genotype in Stool Specimens of Asymptomatic People. *Laboratory Medicine* 40(7): 412-414.

Sasaky K, T. Y., Sata M, Fujii Y, Matsubara F, Zhao M, Shimizu S, Toyonaga A, Tanikawa K (1999). "Helicobacter pylori in the natural environment." *Scand J Infect Dis* 31(3): 275-279.

Secretaría Nacional del Agua (SENAGUA) (2010). *Línea base para el monitoreo de la calidad del agua de riego en la Demarcación Hidrográfica del Guayas.* Quito: SENAGUA .

Sempertegui F, E.B.; Egas, J; Carrion, P; Yerovi, L; Diaz, S; Lascano, M; Aranha, R; Ortiz, W; Zabala, A; Izurieta, R; & Griffiths, J (1995). Risk of diarrheal disease in Ecuadorian day-care centers. *Pediatr Infect Dis* J 14(7): 606-612.

Tapia, LM (2013). *Manejo de agroquímicos para la producción de banano y su efecto en la calidad de vida de los trabajadores de las bananeras Bansol y Carolina del cantón Baba año 2013. Propuesta de disminución de riesgos.* Master, Universidad Técnica Estatal de Quevedo.

Torres, J C.P.; Ferreccio, Catterina; Hernandez-Suarez, Gustavo; Herrero, Rolando; Cavazza-Porro, Maria; Dominguez, Ricardo; & Morgan, Douglas (2013). Gastric cancer incidence and mortality is associated with altitude in the mountainous regions of Pacific Latin America. *Cancer causes &*

control : CCC 24(2): 249-256.

USEPA, U.S.E.P. (2012). *Guidelines for Water Reuse. Special Restricted Crop Area in Mendoza, Argentina* 0. National Risk Management Research Laboratory Office of Research and Development Cincinnati. Cincinnati, Ohio U.S. Agency for International Development Washington, D.C.

Van der Poel W, R.A (2017). Hepatitis A. *Global Water Pathogens Project.* J.B. Rose and B. Jiménez-Cisneros (eds.). Michigan State University/UNESCO. www.waterpathogens.org/book/rotavirus

Van der Poel W, R.A. (2017). Hepatitis E. *Global Water Pathogens Project.* J.B. Rose and B. Jiménez-Cisneros (eds.). Michigan State University/UNESCO. http://www.waterpathogens.org/book/rotavirus

Vasco G, T.G.; Atherton, R; Calvopina, M; Cevallos, W; Andrade, T; Eguiguren, M.; & Eisenberg, JN (2014). Identifying etiological agents causing diarrhea in low income Ecuadorian communities. *Am J Trop Med Hyg* 91(3): 563-569.

Webb J, C.O.T.; Mainville, Nicolas; Mergler, Donna (2015). Mercury Contamination in an Indicator Fish Species from Andean Amazonian Rivers Affected by Petroleum Extraction. *Bulletin of Environmental Contamination and Toxicology* 95(3): 279-285.

Weber JT, M.E.; Canizares, R; Semiglia, A; Gomez, I; Sempertegui, R; Davila, A; Greene, K D; Puhr, ND; & Cameron, DN (1994). Epidemic cholera in Ecuador: multidrug-resistance and transmission by water and seafood. *Epidemiol Infect* 112(1): 1-11.

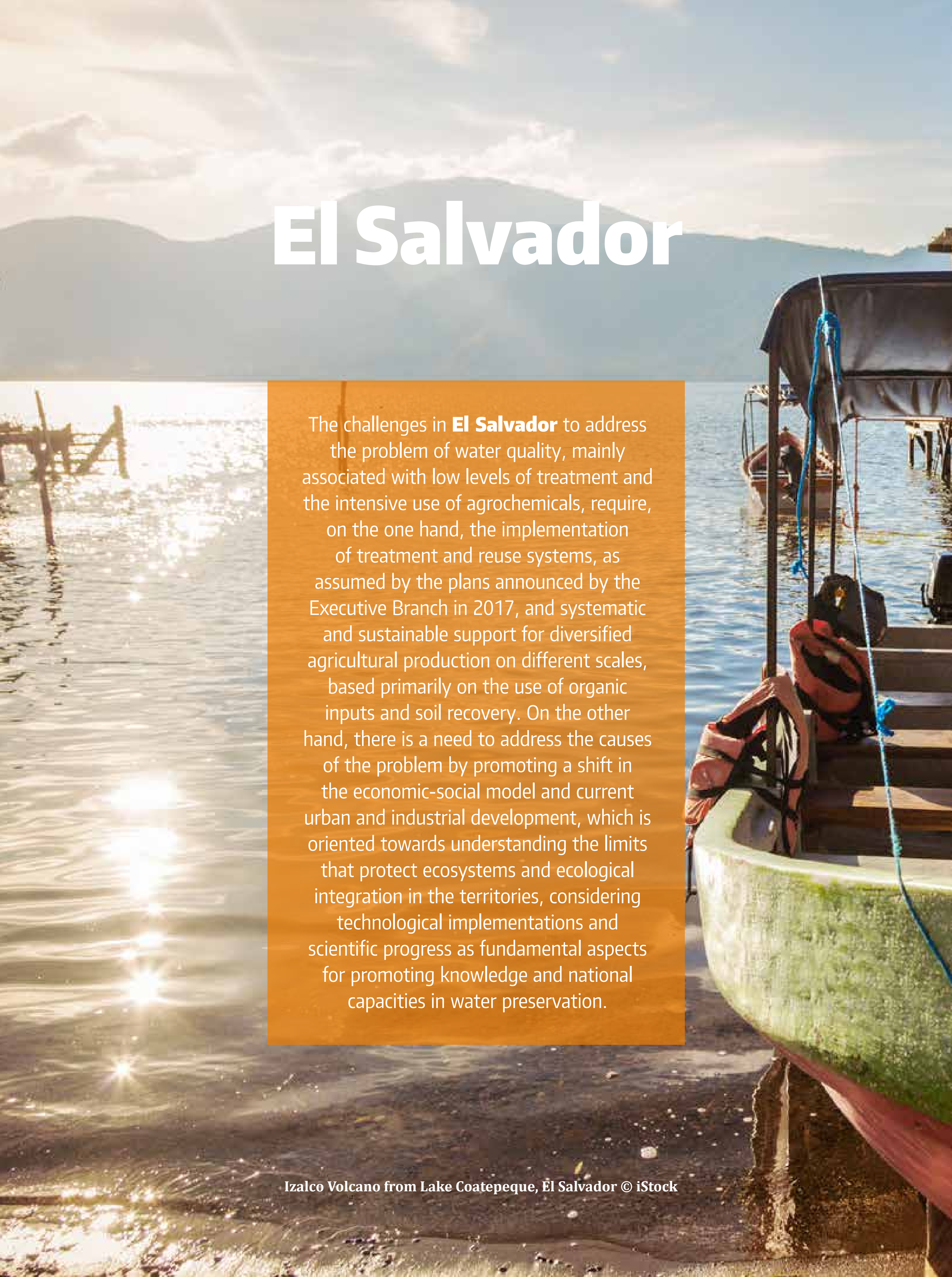
Weirich CA, M.T. (2014). Freshwater harmful algal blooms: toxins and children's health. *Curr Probl Pediatr Adolesc Health Care* 44(1): 2-24.

Westblom, T.U. (1997). Molecular diagnosis of Helicobacter pylori. *Immunol Invest* 26(1-2): 163-174.

Zhang L, B.W.; You, WC; Chang, YS; Kneller, RW; Jin, ML; Li, JY; Zhao, L; Liu, WD; Zhang, JS; Ma, JL; Samloff, IM; Correa, P; Blaser, MJ; Xu, GW; & Fraumeni, JF (1996). *Helicobacter pylori* antibodies in relation to precancerous gastric lesions in a high-risk Chinese population. *Cancer Epidemiol Biomarkers Prev* 5(8): 627-630.

El Salvador

The challenges in **El Salvador** to address the problem of water quality, mainly associated with low levels of treatment and the intensive use of agrochemicals, require, on the one hand, the implementation of treatment and reuse systems, as assumed by the plans announced by the Executive Branch in 2017, and systematic and sustainable support for diversified agricultural production on different scales, based primarily on the use of organic inputs and soil recovery. On the other hand, there is a need to address the causes of the problem by promoting a shift in the economic-social model and current urban and industrial development, which is oriented towards understanding the limits that protect ecosystems and ecological integration in the territories, considering technological implementations and scientific progress as fundamental aspects for promoting knowledge and national capacities in water preservation.



Izalco Volcano from Lake Coatepeque, El Salvador © iStock

Water Quality in the Americas: El Salvador

Julio César Quiñónez Basagoitia

1. Introduction

1.1 Background

This document is part of the IANAS initiative to address, at the continental level, water quality in the Americas, focusing on an analysis of the current status, local problems and dynamics, national strategies adopted -their progress and challenges, normative and legal frameworks, technological implementations and research conducted through national efforts at institutions, universities and academia, as well as an analysis of impacts on water quality, caused by social and economic dynamics, in order to identify opportunities, successful experiences and solutions.

According to the Sustainable Development Goals (SDG), established in the 2030 Agenda and assumed by the countries in the UN General Assembly in September 2015, water quality represents one of the main factors highlighted and prioritized in SDG-6, regarding Clean Water and Sanitation. A propos of this, water availability and specifically water quality represent one of the main challenges in El Salvador, insofar as its progressive deterioration affects the health of the population, the availability of water for human consumption, food production, the increase in potabilization costs and the preservation of ecosystems and the environment.

El Salvador has an area of 21,040.80 km^2 and a population in 2017 of 6,581,860 inhabitants, according to the demographic characteristics recorded in the Household and Multiple Purposes Survey (EHPM) (DIGESTYC, 2017). This survey states that 3,959,652 people reside in urban areas and 2,622,208 in rural areas, accounting for 60.2% and 39.8% of the population, respectively. The Metropolitan Area of San Salvador (AMSS) is home to 25.7% of the total population of the country (1,693,186 inhabitants).

Figure 1 shows the distribution of population density in the country, the reddish color of the AMSS being the urban area with the highest population density. It is set in the hydrographic basin of the Acelhuate River, the main urban river in the country with a high level of pollution due to discharges with little or no domestic or industrial wastewater treatment. According to a report by the Central American Forum and the Dominican Republic on Drinking Water and Sanitation (FOCARD-APS, 2013:8), only 8.52% of the flows operated

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Figure 1. Population Density Projection Map

Source: MARN, 2016.

by the National Administration of Aqueducts and Sewers (ANDA) receive prior treatment before being discharged into waterways. Moreover, the level of efficiency of the systems is unknown, since the treatment capacity of many of them is exceeded, at least partly as a result of the incorporation of new sewage networks and the high concentrations of the constituents of effluents.

Regarding this situation, and in order to address the low treatment levels, the Ministry of Environment and Natural Resources (MARN) announced the "Urban Rivers Recovery Plan" (2016), designed to implement actions in four urban watersheds, and thereby reduce pollution in the Acelhuate River by 80%. Its implementation includes the construction and rehabilitation of two wastewater treatment plants in San Salvador (**Figures 2 and 3**), in densely populated areas and industrial zones, and two other treatment plants in the Suquiapa river basins, in the city of Santa Ana, and on the Rio Grande de San Miguel, in the city of the same name. The diagnosis and inventory of the main industries that flow into the most polluted sections are already available and the designs of the Systems proposed by a number of industries have already been prepared, and are under review by MARN (2017):55).

Although the MARN initiative focuses on the control and decontamination of urban rivers, the results of which are expected to materialize in public works following the obtainment of financing and the construction of the four large treatment plants in an estimated period of three years (2018-2020), and a general Plan of Action for the decontamination and recovery of the Acelhuate River in 10 years, the announcement of the Plan - beyond the plan itself- opens up the possibility of placing the problems of Water Quality and Water Pollution at the center of public attention as a priority national problem. Its solution requires an intersectoral approach, to increase research, technological implementations and the role of universities and academia. The state must also formalize a new regulation for the discharge of treated effluents, control of agrochemicals and socialization of the problem, taking into account the context and analysis of causal variables and the consequences and implications of the deterioration of water quality in human development. This perspective calls for greater responsibility and commitment by the economic sectors in the decontamination, recovery and water-environmental sustainability of the country.

A key aspect, albeit one that has not had public projection or an official announcement by the MARN, has been the drafting of the Technical Wastewater Regulation, which includes the review of the quality limits for wastewater discharge into receiving bodies, as reflected in the MARN Work Report (2017:54). This Regulation was submitted to the Salvadoran Technical Regulatory Body (OSARTEC) for its socialization with the regulated sectors, but it is not yet considered an official, updated normative instrument. In 2017, the document entitled Recommendations for the Selection of Urban Wastewater Treatments for El Salvador was drafted in conjunction with CEDEX of Spain. Guidelines were also drawn up for Wastewater Treatment Plant Improvement Plans, which have been available to municipalities and companies in the wastewater treatment subsector, and a wastewater reuse document was prepared with the purpose of safely treating wastewater, as noted in the MARN Work Report (2018:55).

From this perspective, although important actions have been undertaken to address the water quality situation, it is essential to prioritize the analysis of its problems, its context and implications, as well as solutions, while promoting the communication and public socialization of a topic that is directly linked to the health, social, economic and human development of the country. The goal is to incorporate these aspects within comprehensive planning, which will be reflected through its follow-up, monitoring and obstacles encountered, and by highlighting its achievements and expected results through the systematization of indicators and an established schedule, in accordance with SDG-6 . According to this objective, at least half of all untreated water must be reduced within 12 years, which implies that there should be national wastewater treatment coverage of at least 54.3% by 2030.

Figure 2. Sites selected for intervention. Acelhuate River Basin

Figura 3. Rehabilitación de un tramo del río Acelhuate. Quebrada El Piro

Purpose: Equipment of public spaces in metropolitan area

	Short Term	Medium Term	Long Term	
				
	Awareness, Dialogue and Compliance	**Sanitation and Recovery**	**Accessibility and Equipment**	**Impacts**
Technical Actions	**Observation of urban rivers** Creation of researcher/expert teams **Technical regulations of waste water** **Joint inspections by ANDA, MARN and MINDAL** **Environmental geocompliance platforms**	**Decontamination of fluvial channels** (Construction of treatment plant) Works for protection against flood-related disasters Urban Permeation Measures	**Monitoring of river course** • Water Quality • Compliance with norms Resource management: Water and Energy Risk Management	Would remove 5% of entire organic load of the Acelhuate river Capable of generating 45 kw of electricity Access to public and leisure spaces for population of San Salvador Municipal Council Management and prevention of disaster risk Economic development
General Actions	Awareness and information campaigns and programs (new river culture) Creation and organization of community work and cleaning groups **Communal spaces to increase awareness**	**Design and improvement of paths** **Construction of pedestrian bridges and cycle lanes** Treatment of borders Relocation of communities located in risk zone Lighting in public spaces	**Supply of educational and leisure equipment** **Creation of touristic and cultural spaces, and artistic partnerships** **Establishment of urban agriculture companies** **Housing project alongside river**	

1.2 Principal water quality problems in the country

The principal water quality problems are directly associated with the low level of wastewater and industrial water treatment and the limited use of treated water, extractive mining activities, open solid waste dumps, the presence of high fecal coliform concentrations in certain groundwater bodies and the intensive use of agrochemicals in agricultural plantations, mainly in coastal areas where an increase in liver affectations and chronic kidney diseases, unrelated to traditional causal conditions such as hypertension and diabetes mellitus, has been reported.

All these aspects that have become more complex over the years are a reflection of the gap created by not having a management model or public planning for sanitation, as well as the absence of a National Water Authority, to establish guidelines for decision making within the perspective of sustainable, equitable development, which prioritizes the control, reduction and elimination of polluting sources.

There is a need for a public authority constituting an executive body, which will ensure compliance with the legal framework, and focus on cooperation links and inter-institutional coordination, the promotion of knowledge and research, the formulation of technical regulations regarding the implementation of economically and technologically feasible treatment systems. It is also essential to update the regulations concerning disposal, discharge conditions and the use of treated effluents, and promote environmental cultural values, which will contribute to increasing interest, participation, and awareness by citizens and the various social, economic and political sectors, in an integral understanding of the problem and its solutions.

One aspect that has contributed to the failure to launch a process to begin reversing the acute deterioration of water quality in El Salvador, and to consolidate an institutional mechanism of regulation, control and integral preservation of water resources, is the non-approval of a General Water Law, due to the prolongation of discussions in the Legislative Assembly, following the submission of its Bill by the Ministry of Environment and Natural Resources in March 2012.

One of the essential points raised in the Bill is the conception of the public nature of the governing body, which has encountered strong opposition in the political factions that represent and defend the interests of key business groups linked to water use and exploitation, who are pushing to establish a private authority for water management.

In this regard, the Office for the Defense of Human Rights (PDDH), the Catholic Church hierarchy, environmental organizations and the José Simeón Cañas Central American University (UCA) have urged those responsible for making political decisions to reflect and exercise their constitutional function of legislating for the benefit of the country. They have stated that water is a national supreme good for public use, whose domain belongs to the Nation and, therefore, that the state must exercise its co-participation as a priority over other sectors, assuming responsibility for ensuring and promoting the proper administration, public management and governance of water, as essential aspects that cannot be marginalized, relegated or transferred to other sectoral or private entities. This is particularly true since SDG-6 establishes the priority to achieve universal, equitable access to drinking water and sanitation at a fair, affordable price for all.

In this respect, the challenges for the preservation of water quality and the associated problems are an integrating effort that must be assumed and conducted as a state priority, since this objective is directly linked to an extension of the sanitation strategy, pollution control and reduction and agrochemical use, the regulation of domestic discharges, the regulation and sustainable zoning of territories, and a reformulation of the regulatory framework on the disposal and permissible concentrations of industrial discharges. At present, in many essential parameters, regulations are a long way from the guidelines and values of concentrations allowed in accordance with international standards.

1.3 Objectives and scope of the Water Quality chapter-El Salvador

The purpose of this chapter is to highlight and analyze the elements and aspects that constitute the problems and implications of the deterioration of water quality, and to promote guidelines for the adoption of actions in various cross-cutting axes, based on the Sustainable Development Objectives, with an emphasis on SDG-6 regarding water and sanitation.

2. Water quality authorities and governance

2.1 Legal framework

Although the country does not yet have a General Water Law, the legal framework for water quality control and governance is governed by legal powers conferred mainly on MARN, through the Environment Law, and Ministry of Health (MINSAL), through the Health Code. Other partial and sectoral competences are assigned in accordance with the legal functions of certain public institutions such as ANDA and the Ministry of Agriculture and Livestock (MAG).

Article 49 of the Environment Law (1998) establishes that MARN is responsible for supervising water quality on the basis of technical standards. To this end, it has a water quality laboratory, which obtained its quality accreditation under ISO/IEC/17025:2005 in 2016. It is also the entity responsible for the issuance of technical guidelines, which must guarantee that all discharges of polluting substances into receiving bodies are previously treated by those who produce them.

These aspects also extend to the protection of coastal-marine, ecosystem and soil areas, with special emphasis on Art. 50 on the exercise of the prevention and control of soil contamination, for which it must "*promote the integrated management of pests, fertilizers and the use of fertilizers, fungicides and natural insecticides in agricultural activity, in order to achieve the gradual substitution of agrochemicals by bio-ecological natural products*". This is an essential aspect that requires broad public projection at the national level, in order to promote a turnaround and begin a process of transformation towards the use of organic products compatible with aquifer and surface water protection.

On the other hand, in Art. 59, the Health Code (1988) confers on MINSAL the power to develop environmental sanitation programs and actions, such as the eradication of vectors, in order to improve the quality of water supply, as well as measures for the disposal of excreta and wastewater mainly in rural areas, where sanitation usually involves latrines, septic tanks and absorption wells. These actions are also designed to control soil, water and air pollutants, in order to protect the health of the country's inhabitants.

From the perspective of the agricultural sector, Art 100 of the Law of Irrigation and Drainage (1970) provides that sewage of any kind and discharges into natural or artificial channels must be treated and purified in advance as established by MAG and the Ministry of Health, and that these entities must "*exercise the necessary vigilance and supervision in manufacturing, mining or agricultural establishments, whose activities may make waters unusable*". At the same time, Art. 101 establishes that the Executive Power in the branch of Agriculture and Livestock "*will establish the measures for: a) Preventing water pollution; b) preventing the use of water that reduces soil fertility of the soil; and c) protecting aquatic fauna and flora*".

With the entry into force of the Environment Law in 1998, these aspects related to the protection of water and natural systems become more clearly the direct responsibility of MARN, although formally, they remain the express attributions of the MAG set out in the Law on Irrigation and Drainage, which, in practice, would imply the exercise of joint, coordinated and binding work between both institutions for the protection of water and natural resources, as well as the promotion of sustainable agricultural production. This is particularly important given that one of the problems with the greatest impact on water quality is intensive agrochemical use, mainly reflected in sugarcane plantations and conventional agriculture for the production of basic grains, the importance of increasing agro-productive diversity on a smaller scale and the implementation of a permanent mechanism for the gradual substitution of organic inputs for agrochemicals, as established by the Environmental Law.

Regarding the attributions of the ANDA Law, this autonomous entity has its own physical-chemical analysis laboratory, through which it controls and monitors the quality of the water it supplies the population through its aqueduct system. It also has a technical regulation to establish the maximum permitted concentrations of wastewater discharged into the sewer system, from building and industrial projects.

Taking into account these four key areas in the life of the country, which could also include the Hydroelectric Commission of the Lempa River (CEL), the Public Works Portfolio (MOP) and the Offices of Urban Planning and Territorial Development, the governance of water quality and the environmental perspective from each entity have historically been characterized by the dispersion of roles, approaches and purposes, based on partial and sectoral Law competencies, and a legal framework which lacks a National Water Authority. However, the creation of the Environmental Sustainability and Vulnerability Cabinet in 2014, which comprises seven ministries, the Technical Secretariat of the President's Office and two autonomous institutions, has made it possible to undertake articulated, planned and coordinated actions with MARN to implement joint measures in order to strengthen the control, regulation and monitoring the institution performs, among other aspects, related to water resource protection and management.

However, one of the main obstacles to the preservation of water quality and the natural environment, is in the permitted concentrations of the constituent parts of effluents in discharges into receiving bodies, established in the national regulations, which, in many cases, far exceed those of international guidelines. This is reflected in the ranges of discharge values established in the Mandatory Salvadoran Standard (2009), drafted and approved with the majority representation of the economic and productive sectors of the country, the values of which, assigned by type of industry (coffee processing, tanneries, distilleries, food processing, dairy products, sugar mills, soaps, detergents and medicines, etc.), are high for certain parameters, such as BOD5 (60-3,000 mg/l), COD (100-3,500 mg/l) and Total Suspended Solids TSS (60-1000 mg/l). These values significantly exceed the natural assimilation capacities of the receiving bodies and international guidelines, such as those in the Safety and Environmental Health Guidelines (World Bank, US EPA, Levi Strauss & Co., 2007), which establish guidelines for the discharge of BOD5 (30-50 mg/l), DQO (125-250 mg/l) and Total Suspended Solids (SST) (45-50 mg/l). The same situation of discrepancies between Salvadoran regulations and international guidelines is reflected in the case of heavy metals.

A propos of this, it is important to note that in 2005, Decree No. 50 and Reform 51 (ANDA, 1987) were modified as regards the ANDA regulations concerning the discharge of special wastewater into the sewerage network. The new regulations (ANDA, 2005) showed a significant increase in the permissible values of fats, heavy metals and phenolic compounds. This modification has become an incident factor in accentuating the reduction of efficiencies and the treatment capacity of installed systems.

2.2 Relations with NGOs, universities, scientific research, etc.

The contribution and interest of universities and certain NGOs in the preservation and monitoring of water quality has increased and strengthened in recent years. Work and research have largely been undertaken in coordination and complementarity with MARN and ANDA. One significant effort has involved the Cooperation Agreement between the José Simeón Cañas Central American University (UCA) and the MARN in 2017, involving the compilation of an Atlas comprising 50 maps with various types of information on the state of the Quebrada El Piro in urban and environmental terms. This gorge is located in the southwest of the capital, San Salvador, and the project forms part of the decontamination plan for the Acelhuate River. Likewise, in 2013 the UCA undertook a pilot study on the eutrophication of reservoirs, using remote analysis and monitoring technologies. At the same time, within the framework of the expansion of the groundwater monitoring network, in 2017, a well was drilled on the UCA premises, including equipment with measuring and data collection instruments for analysis and follow-up.

The University of El Salvador has undertaken research in Coatepeque lake to monitor the proliferation of cyanobacteria, which has been complemented by research undertaken by MARN.

Other important actions include the project to improve water quality through the elimination of the aluminum ion from the drinking water supply in the San Diego department of Morazán, signed by the Association Basic Sanitation, Health Education and Alternative Energies (SABES) and the MARN.

2.3. Monitoring and database

2.3.1 Surface water

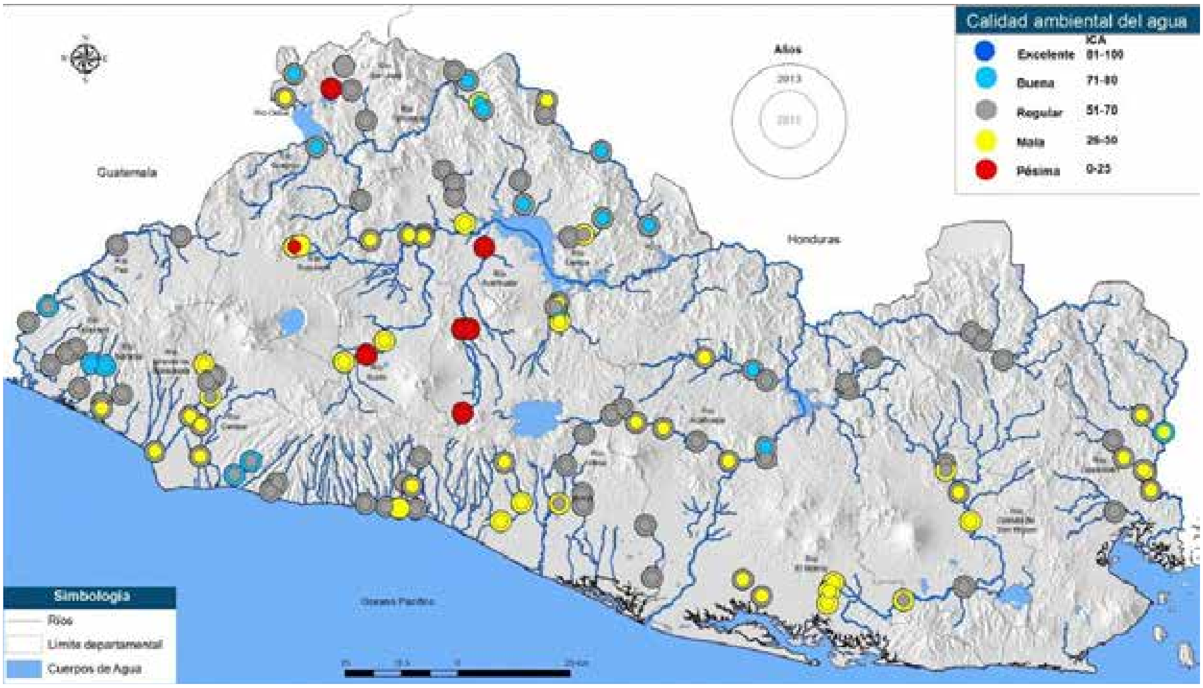
In order to determine the spatial impact of water quality status over time and to have an instrument for management and decontamination for priority areas, in 2007, 2009, 2010, 2011 , 2013 and 2018, the MARN undertook annual reports on the National Surface Water Monitoring Program. Monitoring has been undertaken at between 118 and 123 sampling points in 55 rivers, which are extremely important due to their use for human consumption, irrigation, recreation and maintenance of aquatic life. The rivers were evaluated using the Water Quality Index (WQI), which has been formulated with a score of between 0 and 100. Excellent water quality has been set at values of between 81-100 while at the other extreme, poor quality has been established as values between 0 and 25. In order to determine the WQI, specific weights are assigned to each of the nine priority analysis parameters, where dissolved oxygen,

Table 1. Percentage of sites in relation to surface water quality

Water Quality	Percentage of sites					
	2006	2007	2009	2010	2011	2013
Excellent	0%	0%	0%	0%	0%	0%
Good	17%	3%	0%	2%	12%	5%
Regular	50%	45%	60%	65%	50%	73%
Bad	20%	46%	31%	27%	31%	17%
Very Poor	13%	6%	9%	6%	7%	5%

Source: Programa de Monitoreo de la Calidad del Agua (MARN, 2013).

Figure 4. Surface Water Classification Map according to the ICA, 2011-2013



Source: Programa de Monitoreo de la Calidad del Agua (MARN, 2013).

fecal coliforms, pH and BOD5 have the highest values of specific weights. The methodology was developed on the basis of the US National Sanitation Foundation (NSF), assigning importance on the basis of national guidelines.

Recently, in September 2018, MARN launched the on-line platform "Water Information System" (SIHI), which provides information on the water balance, water management, quality indicators, and the geographical information system, among other aspects, which is extremely useful for institutions and sectors related to water use. www.marn.gob.sv/sihi

According to the MARN water quality report (2011), 88% of the rivers had a WQI of between "*average*" and "*terrible*", due mainly to high concentrations of fecal coliforms. In 2013, greater deterioration was detected, amounting to 95% for the same category rank (MARN, 2013). **Table 1** shows the level of water quality for the years between 2006 and 2013.

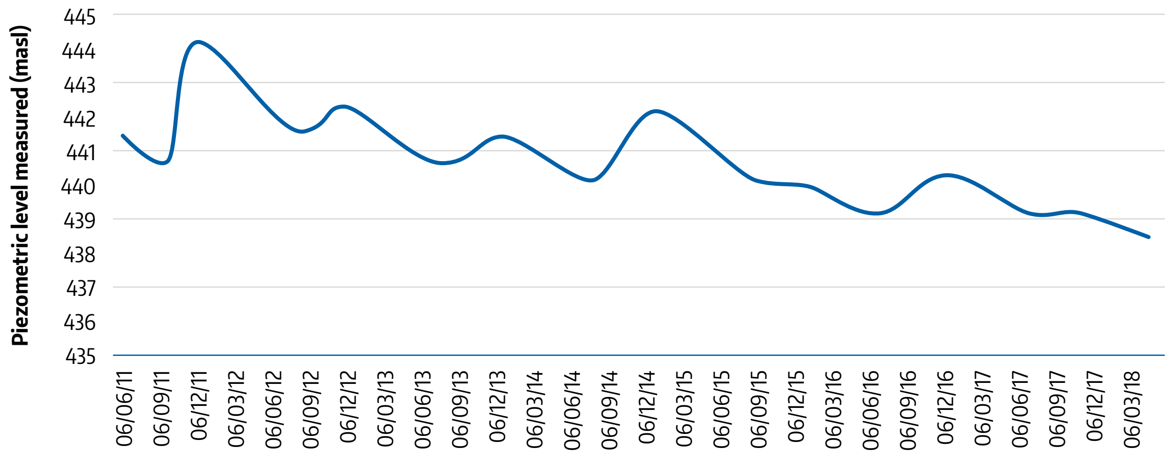
Figure 4 shows the classification of surface water quality at the national level for the period 2011-2013, indicating the "*terrible*" category in red spots, mainly in the Acelhuate river basin.

In the last monitoring report carried out in 2017, MARN reported an improvement in average quality whereas no WQI in the category of "*terrible*" was obtained. A total of 68% were classified as "*average*" or "*bad*", and 32% of the measurement points obtained a "good" WQI (MARN, 2017). Conversely, the same study notes that currently no site has water suitable for potabilization by conventional methods compared to 2013, when 29% of the sites analyzed were suitable for purification through these methods. There has also been a decrease in the number of rivers suitable for irrigation (28% in 2013 and 10% in 2017).

In the case of the measurements made in the Acelhuate River during 2017, only two measurement points were established, unlike the four points recorded in previous reports. For both measurement points in relation to previous years, in 2017, fecal coliform concentrations were 7.9 and 1.6 million NMP/100ml. Those registered in 2013 for those same points are 0.79 and 0.22 million NMP/100ml, and for 2011 0.35 and 0.05 million NMP/100ml, reflecting a gradual increase in fecal coliform concentrations between 2011 and 2017.

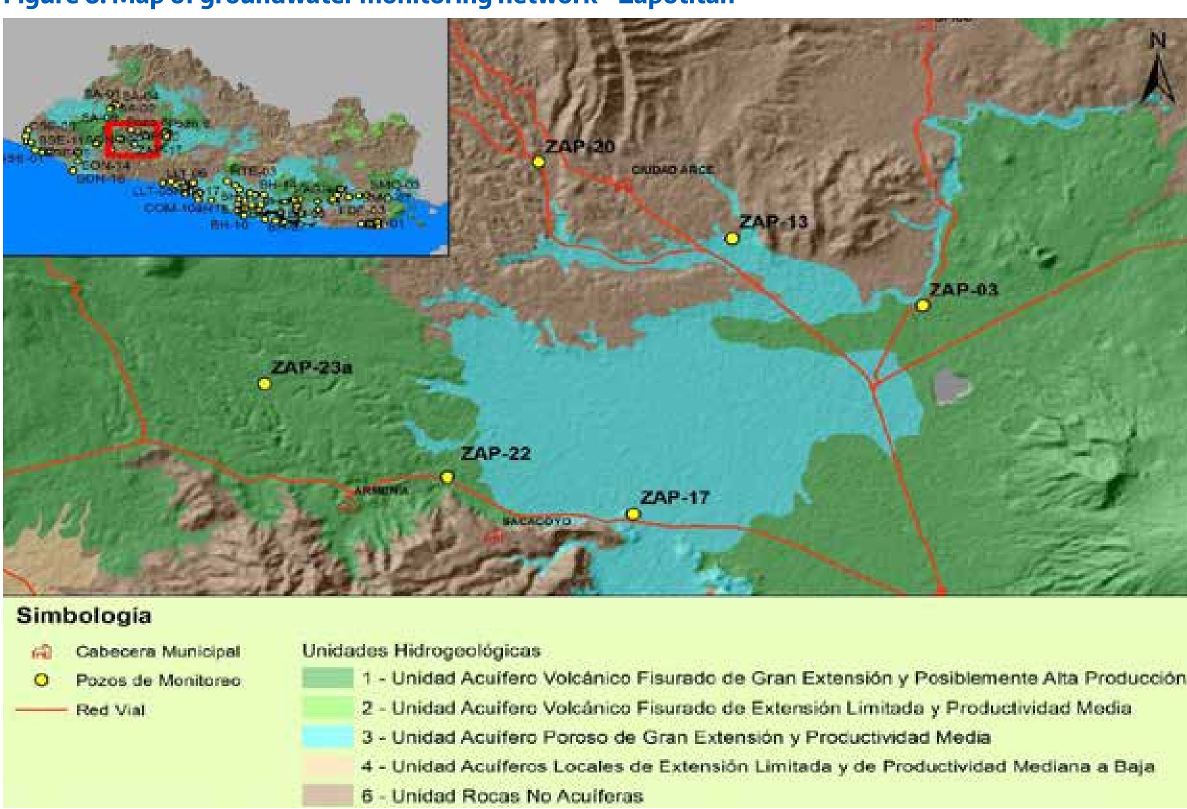
The 2017 results show the gradual pollution experienced by certain rivers located in the southwest zone of the capital, precisely within the urban expansion advancing in the balsam mountain range with the rapid deterioration of its basins that stretch as far as the coastal plain. The San Antonio and El Jute rivers, regarded as clean and located in areas with abundant forest cover and valued for their attractive landscape and as carriers of water resources to support communities and local biodiversity, are currently experiencing high pollutant loads resulting from domestic and industrial wastewater from new housing, commercial and industri-

Figure 5. Monitoring of piezometric levels in the Nejapa aquifer



Source: Informe de monitoreo de niveles piezométricos acuífero de Nejapa y San Salvador, Sección Hidrogeología (DGOA, 2018).

Figure 6. Map of groundwater monitoring network – Zapotitán



Source: Hydrogeological monitoring report (DGOA, 2016).

Table 2. Physical-chemical results of four wells in the Santa Ana aquifer, 2016

Parameter	Unit	NSO 13.07.01.08	SA-01	SA-02	SA-04	SA-09
Hydrogen potential (pH)	-	6-8.5	6.88	6.69	6.88	8.32
Electrical conductivity (CE)	µsiemens/cm	-	571.5	510	494.5	727
Salinity	ppt	-	0.3	0.2	0.2	0.4
Alkalinity	mg/l $CaCO_3$	-	182.76	139.25	163.18	211.05
Bicarbonate (HCO_3)	mg/l $CaCO_3$	-	182.76	139.25	163.18	175.57
Boron (B)			4.88	3.9	2.99	3.98
Calcium (Ca)	mg/l Ca	-	54.55	39.14	56.23	66.13
Carbonates ($CaCO_3$)	mg/l $CaCO_3$	-	0	0	0	35.47
Chlorides (Cl^-)	mg/l Cl^-	-	31.55	26.62	20.95	46.83
Total hardness of water	mg/l $CaCO_3$	500	203.31	177.9	215.8	251.1
Fluorine (F)	mg/l F	-	0.24	2.28	0.25	0.19
Phosphate (PO_{43}-)	mg/l PO_{43}-	-	0.02	0.65	0.11	0.24
Iron (Fe)	mg/l Fe	0.30	0.052	0.173	<0.009	<0.009
Magnesium (Mg)	mg/l Mg	-	16.3	19.47	18.31	20.88
Manganese (Mn)	mg/l Mn	0.10	<0.024	<0.024	<0.024	<0.024
Nitrates (NO_3-)	mg/l NO_3-	45.00	16.9	42.02	81.4	89.09
Potassium (K)	mg/l K	-	13.1	8.95	5.23	15.1
Silica (SiO_2)	mg/l SiO_2	-	77.22	89.09	108.86	103.59
Total dissolved solids (TDS)	mg/l	1000	280	249.5	242	356
Sodium (Na)	mg/l Na	200.00	25	22	19.5	35.5
Sulfates (SO_4)	mg/l SO_4	400.00	46	34	46	50

Hydrogeological monitoring report: Santa Ana aquifer (DGOA, 2016).

al projects. Thus, for example, in 2013, the fecal coliform concentration of the sampling point in those rivers reported values of 200 and 210 NPM/100ml, respectively. On the other hand, in 2017, it reported values of 92,000 and 49,000 NPM/100ml, respectively. Similar deterioration has been observed in other parameters, such as BOD5, phosphates, phenols and the loss of dissolved oxygen.

2.3.2 Groundwater

Groundwater has been monitored since 2012 through the Hydrogeology section of the General Directorate of the MARN Environmental Observatory (DGOA-MARN). It involves the analysis and interpretation of existing hydrogeological information, the measurement of piezometric levels and sample-taking for the physical-chemical characterization of the groundwater, in order to analyze its suitability for human consumption. Regarding piezometric monitoring, the Nejapa aquifer reports a constant decrease in its levels as illustrated in **Figure 5**. Located 24 km from the capital, it constitutes one of the main groundwater reservoirs for supplying water to the population of the AMSS. However, in recent years, it has been severely affected by the extractions carried out by beverage companies and the recent construction of large-scale logistics and urban projects, which have placed it in a permanent situation of overexploitation, as analyzed in the study presented by the Municipality of Nejapa, international cooperation entities and social and environmental organizations united in the Water Forum (Quiñónez, 2013).

The water quality of the Zapotitán, Santa Ana and San Miguel aquifers was monitored in 2016 (DGOA-MARN, 2016). The Zapotitán aquifer is the main Irrigation District in the country, located about 30 km west of the AMSS. Its main purpose is the irrigation of sugarcane, corn and bean fields, as well as plots of vegetables and fruit trees on a smaller scale. On the other hand, the aquifers of Santa Ana and San Miguel correspond to the hydrogeological areas for the water supply of the most important cities after the capital, located in the west and east of the country, respectively.

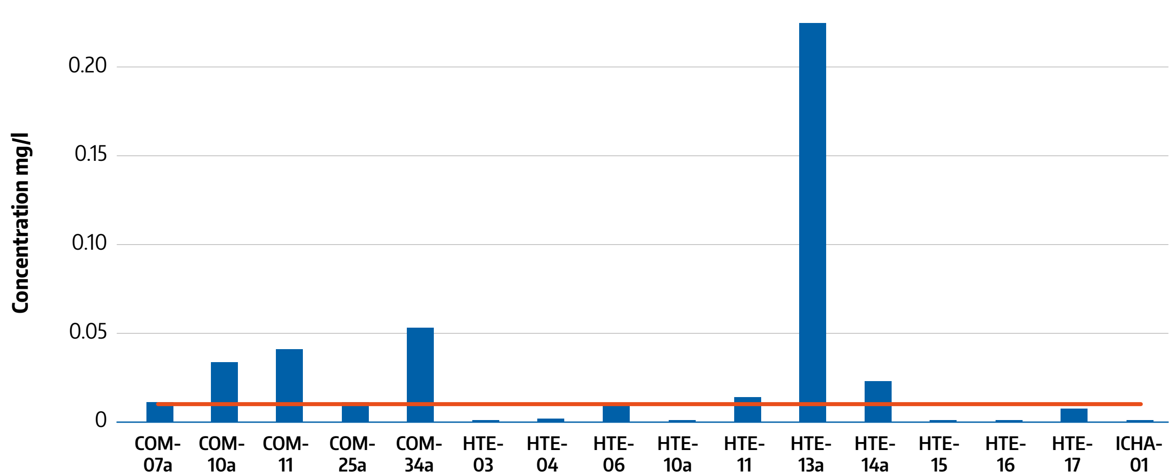
The parameters analyzed in the 2016 monitoring were as follows: pH, conductivity, salinity, alkalinity, bicarbonate, boron (only in the dry season), calcium, carbonates, chloride, total hardness, fluorine, phosphates, iron, manganese, magnesium, nitrates, ammonia nitrogen, potassium, silica, total dissolved solids, sodium, sulfates, among others, according to the NSO for drinking water (MINSAL, 2009). DGOA monitoring does not contemplate bacteriological analysis. **Figure 6** shows the hydrogeological units and monitoring network of the Zapotitán area and the map of El Salvador and the national groundwater monitoring network for semi-deep wells.

According to the parameters analyzed in the dry season (November-April) of 2016, and in the three study sites, nitrates (NO3) and Boron (B) had values exceeding the NSO standard for drinking water, with values for the case of the Santa Ana aquifer> 81 mg/l for nitrates and between 2.99-4.88 mg/l for boron, with permissible values being 45 mg/l and 0.3 mg/l, respectively. In the same Department of Santa Ana, located in the west of the country, the arsenic concentrations (As) measured are within the regulation of 0.01 mg/liter, with concentrations reported within the range of 0.00074-0.00189 mg/l. **Table 2** shows the results obtained.

A second and third report is the Physico-Chemical Characterization of Groundwater in Porous Aquifers in the Coastal Zone (DGOA-MARN, 2015 and 2016), which refers to shallow aquifers with domestic artisanal wells with an average size of 10 m and a moderate yield, hydrogeologically characterized as a "Porous aquifer unit with a large size and average productivity," essential for supplying the inhabitants and communities in the area which lack potable water service through distribution systems involving indoor or community pipes. However, given the conditions of vulnerability to pollution of the aquifer, and according to the same study, the extracted water is only used for domestic purposes and not for human consumption.

The vast territory of the coastal plain, particularly the areas formed by the low areas of the departments of Usulután, San Vicente, Cuscatlán and San Miguel, is extremely vulnerable to the impacts of pollution due to the intensive use made of agrochemicals, mainly in sugarcane plantations and, to a lesser extent, in agricultural plots assigned for the production of corn, beans and certain vege-

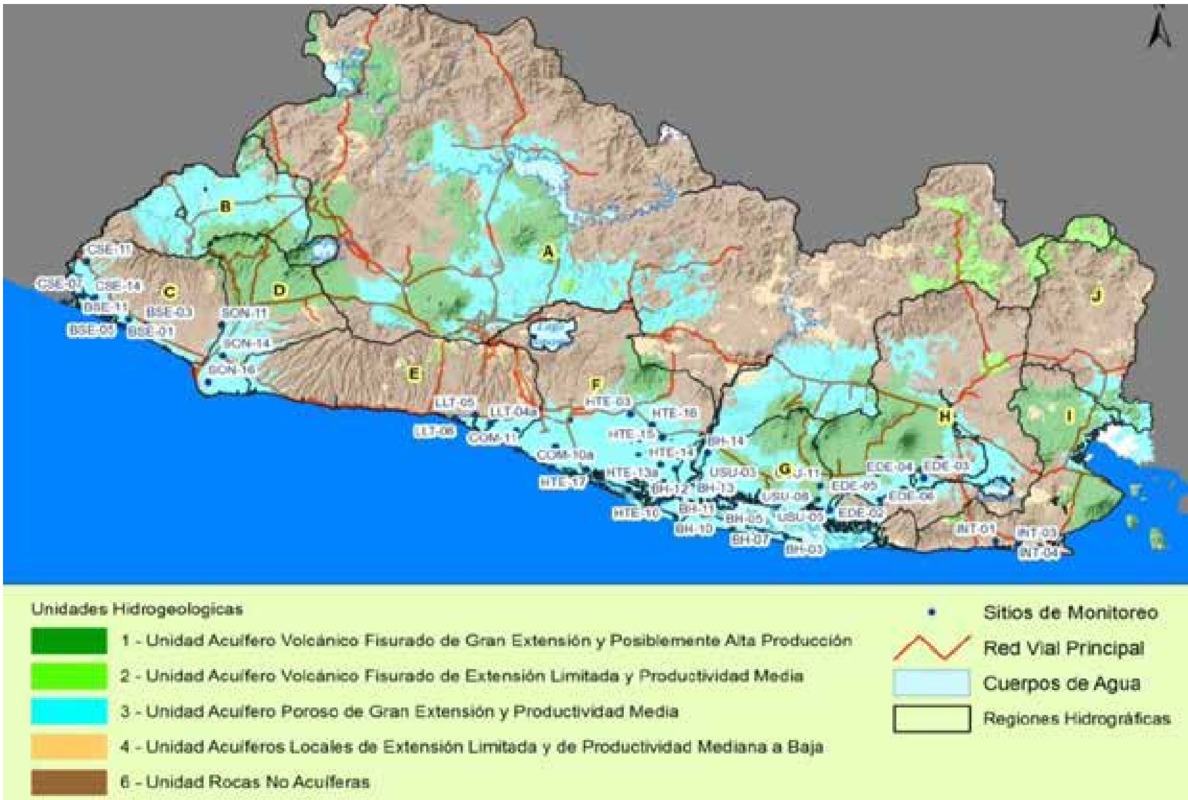
Figure 8. Arsenic concentrations



	COM-07a	COM-10a	COM-11	COM-25a	COM-34a	HTE-03	HTE-04	HTE-06	HTE-10a	HTE-11	HTE-13a	HTE-14a	HTE-15	HTE-16	HTE-17	ICHA-01
Dry Season	0.011	0.034	0.041	0.01	0.053	0.001	0.002	0.008	9E-04	0.014	0.223	0.023	0.001	0.002	0.012	0.002
Norm	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010

Source: Well monitoring report (DGOA, 2016).

Figure 7. Map of monitoring of artesian wells, 2015



Source: Well monitoring report (DGOA, 2015).

tables during the rainy season. Moreover, most of the population in these specific areas, indicated as F and G in **Figure 7** and estimated to be in the order of 70,000 inhabitants, lacks adequate wastewater treatment systems, and their disposal is carried out using latrines and sinkholes, which become focal points of contamination for the surface aquifer.

According to the report, monitoring was carried out in October 2015 –during the rainy season- in the coastal strip of the country and in 50 artesian wells. The metals or metalloids analyzed were arsenic, total iron (Fe) and manganese (Mn). In 43 sites, the presence of As was found in groundwater and, in 18 of them, values exceeded the maximum permissible levels of 0.01 mg/l, reaching a maximum value of 0.12 mg/l in the HT13a well in the F region. Monitoring of this same well in May 2016 (dry season) yielded an As value of 0.23 mg/l, as shown in **Figure 8.** This zone corresponds to the delta region at the mouth of the Lempa River, whose flows interact with the phreatic levels of the porous aquifer and in an area of high susceptibility to external contaminants.

In this respect, the reports establish the need to undertake research to determine whether the origin of these concentrations is natural and typical of the hydrogeological characteristics of the aquifer or whether it is due to external agents.

As regards iron, its presence was identified in over 90% of the sampling wells and, in 15 of them, it was found that its concentration exceeded the limit established by the standard of 0.3 mg/liter, with significantly high values, as shown in **Figure 9**.

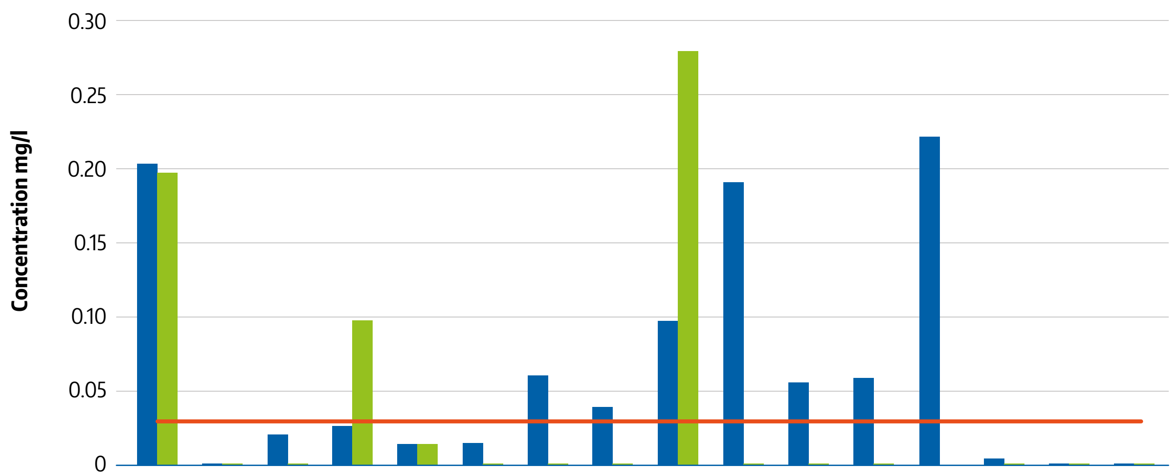
Likewise, the presence of manganese was identified in over 90% of the wells monitored and, in more than 50%, it was determined that concentrations exceeded the admissible limit established by the NSO standard, which is 0.1 mg/l (**Figure 10**). Manganese is used in the manufacture of detergents, cleaners, bleaches and disinfectants such as potassium permanganate, an oxidizing agent employed in various industrial products. However, the report states that more research is needed to establish the origin and causal aspects of high concentrations.

3. Main water quality problems in the country

3.1 Eutrophication

In 2013, in order to determine the status of the wet-

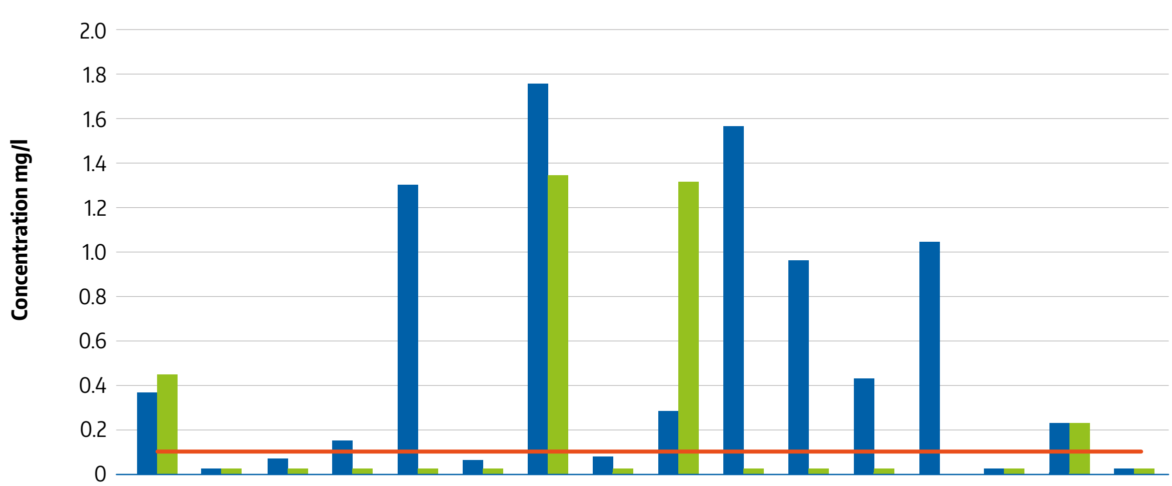
Figure 9. Iron concentration



	COM-07a	COM-10a	COM-11	COM-25a	COM-34a	HTE-03	HTE-04	HTE-06	HTE-10a	HTE-11	HTE-13a	HTE-14a	HTE-15	HTE-16	HTE-17	ICHA-01
Dry Season	2.038	0.0089	0.209	0.271	0.056	0.147	0.607	0.392	0.971	1.912	0.56	0.589	2.222	0.042	0.0089	0.0089
Rainy Season	1.979	0.0089	0.0089	0.982	0.0089	0.0089	0.0089	0.0089	2.796	0.0089	0.0089	0.0089	-	0.0089	0.0089	0.0089
	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300

Source: DGOA, 2016.

Figure 10. Manganese concentration



	COM-07a	COM-10a	COM-11	COM-25a	COM-34a	HTE-03	HTE-04	HTE-06	HTE-10a	HTE-11	HTE-13a	HTE-14a	HTE-15	HTE-16	HTE-17	ICHA-01
Dry Season	0.366	0.024	0.07	0.148	1.3	0.062	1.75	0.1	0.281	1.562	0.957	0.43	1.043	0.024	0.232	0.024
Rainy Season	0.444	0.024	0.024	0.024	0.024	0.024	1.341	0.024	1.314	0.024	0.024	0.024	-	0.024	0.228	0.024
Norm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

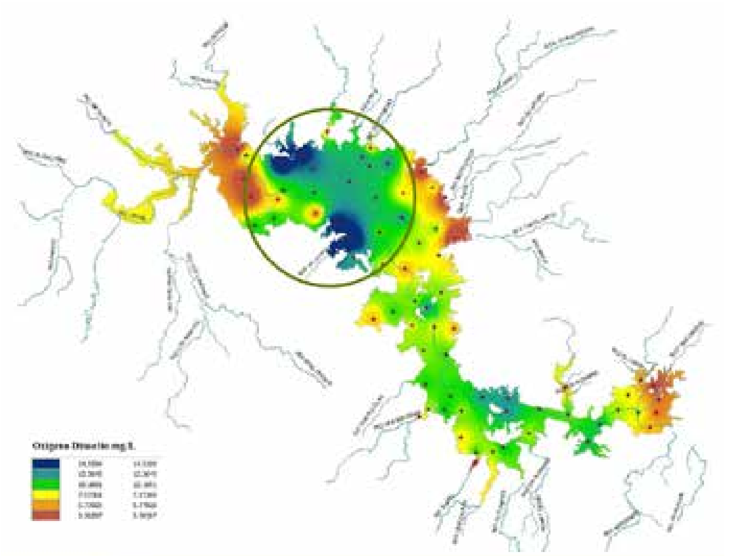
Source: DGOA, 2016.

lands and their eutrophication conditions, the UCA, in coordination with MARN, monitored the physical-chemical variables in the "Cerrón Grande" reservoir, including conductivity, dissolved oxygen, temperature, oxide-reduction potential and pH (UCA, 2013).

This dam, the largest body of water in the country, with an area of 135 km^2, is located on the river Lempa. It was built as part of the construction of the Cerrón Grande Hydroelectric Power Plant in 1976. Three main rivers converge on the reservoir of urban basins and agro-industry, including the Suquiapa river basin, which collects the waters from the city of Santa Ana, the Sucio River, whose basin is formed by large agricultural, residential and industrial regions, and the Acelhuate river basin, which constitutes the hydrographic area of the AMSS.

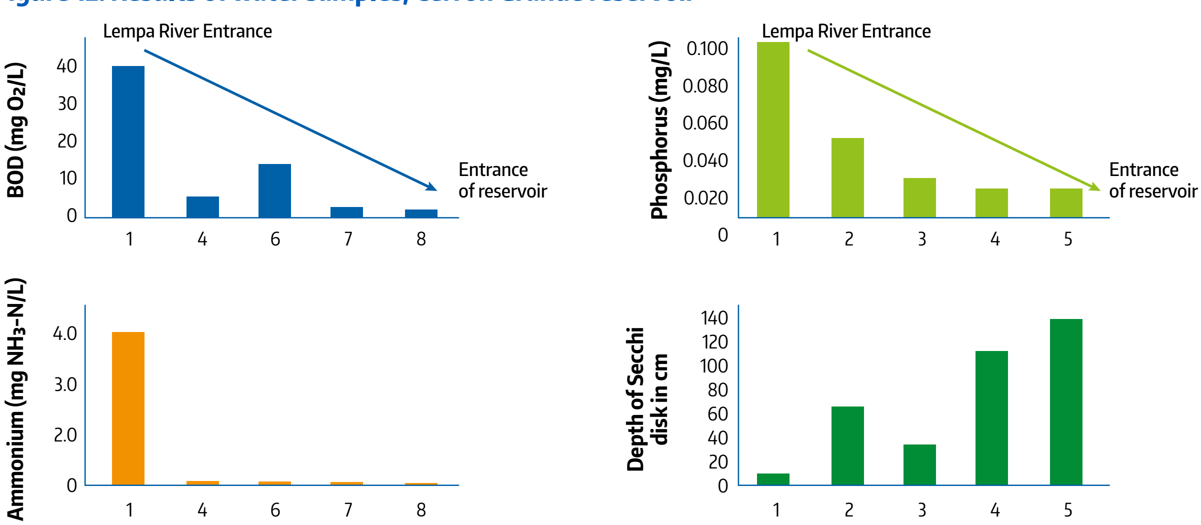
In addition to finding out about the conditions of the wetland, the UCA study sought to design a methodology for continuous water quality monitoring as a pilot project, while evaluating advanced technologies for its remote monitoring. On the basis of the results, it drew up water quality maps and incorporated new Internet technologies and *Wireless Sensor Networks*, using numerical methods, simulation tools and geographic information systems. Figure 11 shows the spatial dispersion of the dissolved oxygen of the surface layer in different colors, with those in the order of 14 mg/l reflected in blue concentrations and those from 3.5 to 5 mg/l in orange-red. **Figure 12** shows the results of water samples from their entrance to the reservoir in the Northwest area until their exit in the point area of the dike in the Southeast, showing that large concentrations occur at the entrance to the reservoir, as a result of being the area of confluence and the entrance to the Acelhuate, Suquiapa and Sucio river dam.

Figure 11. Dispersion of dissolved oxygen, Cerrón Grande reservoir



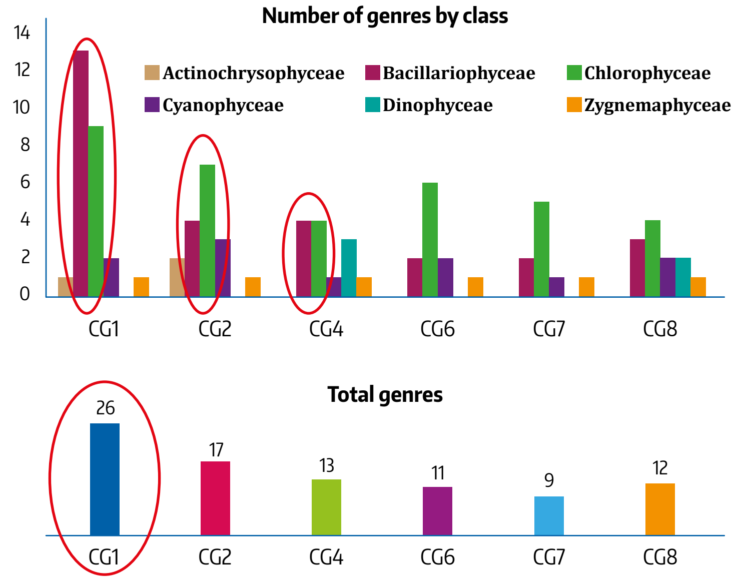
Source: UCA, 2013.

Figure 12. Results of water samples, Cerrón Grande reservoir

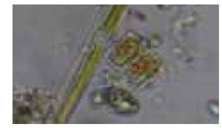


Source: UCA, 2013.

Figure 13. Taxonomic groups found, Cerrón Grande reservoir

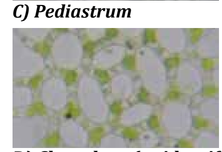


A) Microsystis



B) Synedra

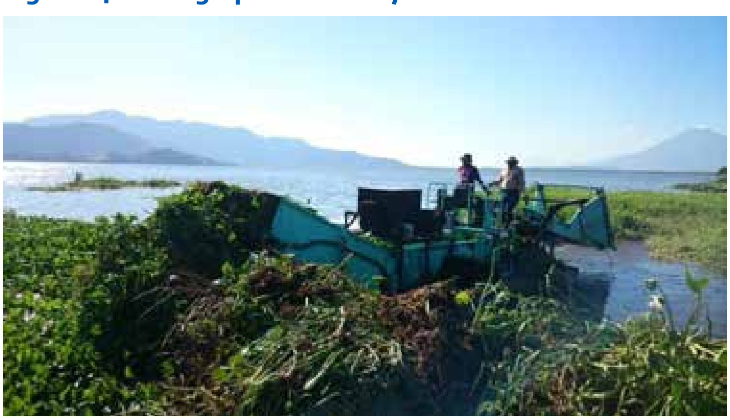
C) Pediastrum



D) Clorophyta **(unidentified genres)**

Source: UCA, 2013.

Figure 14. Photograph of water hyacinth removal



Source: MARN, 2016.

Figure 15. Coatepeque Lake

A characterization of the type of algae was also carried out, representing the taxonomic groups found, as shown in **Figure 13**.

For its part, MARN, in the "Water Hyacinth Control" Report (2016), reports high levels of eutrophication in major wetlands nationwide, with 50% to 60% water hyacinth coverage (*Eichhornia crassipes*), as in the case of the RAMSAR, Olomega and Jocotal sites located in the east of the country, and the Nahualapa Lagoon in the central zone. According to the report, these recurrent annual cycles of eutrophication are caused by the high content of nutrients (nitrates and phosphates), as well as organic matter entering the wetlands from domestic wastewater and waste leached from livestock areas. **Figure 14** shows the removal of water hyacinth in Olomega, in the department of La Unión.

Another key site for analysis is Lake Coatepeque, one of the most important natural beauty and tourist sites in the country located in the Apaneca-Ilamatepec mountain range, in Los Volcanes National Park, declared a Biosphere Reserve by UNESCO in 2007. The lake, with an area of 24.8 km^2, located 740 meters above sea level, has a watershed with an area of 70.25 km^2, comprising hillsides and walls that surround the lake and reach heights of between 250 and 300 m. Its basin is endorheic, in other words, the runoff has no outlet and instead drains from the slopes that border it, given its volcanic geological formation, directly into the lake, which has subterranean connections with other rivers in the area.

This physiography means that all anthropic actions, involving tourism or agroproduction, undertaken on its banks and hillsides, have direct repercussions on its natural processes and bio-aquatic system.

The last decade has seen changes in the color of Lake Coatepeque, in October 2006, September 2012, September 2015, August 2016 and June 2017 during the rainy season. On this last date, it only achieved 20% of the turquoise shade it had in 2012 (see **Figure 15**).

This situation has been monitored by the University of El Salvador (UES) and MARN (2016) since the first event occurred, with a number of physical-chemical parameters being evaluated such as dissolved oxygen, surface temperature, pH and level of transparency through the Secchi disk. In the last event of June 2017, as in August 2016, the presence of cyanobacteria, mainly *Microcystis aeruginosa*, was detected (see **Figure 16**). According to the results, a stable temperature of 26.9° was found in the surface layer with a depth of 16 m, where the thermocline is located, with a pH of 8.5 and a dissolved oxygen concentration of 6 to 7.5 mg/l , which decreased as the depth increased.

According to the study undertaken by the UES (2013), an average population between 10,000 and 60,000 cel/ml was determined for the five sampling points, with a maximum value of 130,000 cel/ml. During this event, in September 2012, almost the entire surface of the lake turned a shade of turquoise. However, the events of 2016 and 2017 were less intense than those observed in 2012. Some of the parameters analyzed by MARN in 2016 are shown in **figures 17 and 18.**

According to the WHO guidelines, blooms and accumulations of cyanobacteria may occur in the presence of high concentrations of nutrients (phosphorus and nitrogen), which generally come from wastewater effluents and runoff with concentrations derived from agricultural fertilizers, which is increased by the susceptibility to erosion, deforestation and sediment trawling, as happens in certain areas of the Coatepeque Lake watershed. These blooms can occur for periods with a duration of hours, weeks or seasons, and their accumulation tends to be recurrent in the same water bodies. Their cell tissue can accumulate as slag, usually on the surface or in the thermocline zone of thermally stratified bodies of water. Blooms are the result of a changing state, which can be caused by the enrichment of nutrients as external agents in aquatic ecosystems (see **figures 19 and 20**). The WHO has established a guideline value for drinking water of 0.001 mg/L (1.0 µg/L) for the presence of cyanotoxins or total microcystin RL. Likewise, for recreational use, it has established a guideline of 20,000 cel/ml.

Figure 16. National University Study

"Intense Proliferation of Cyanobacteria in Coatepeque Lake, Santa Ana; tests of paralyzing toxins and causative organisms"

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Source: UES, 2013.

Figure 17. Sampling of parameters

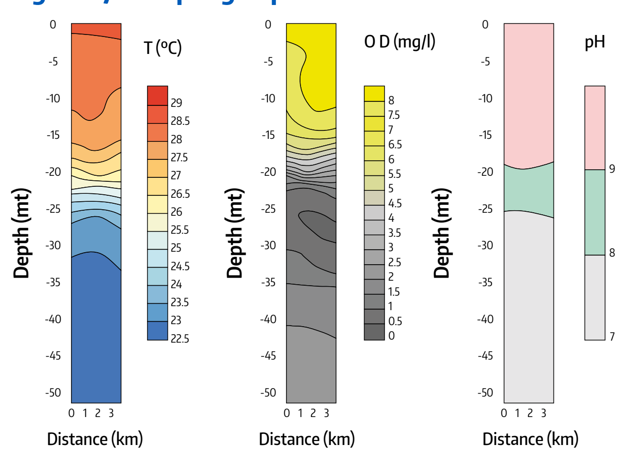
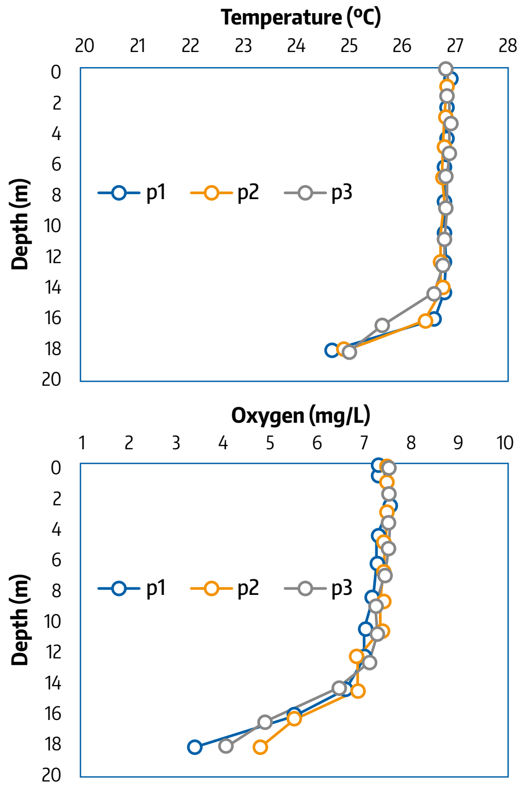


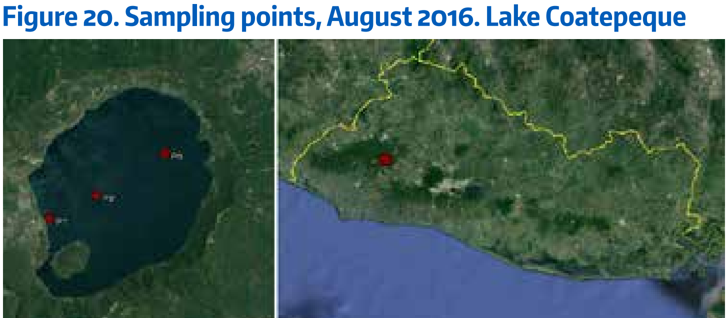
Figure 18. Variation of parameters with depth



Source: MARN, 2016.

Figure 19. Cyanobacteria present in Lake Coatepeque 2017

Figure 20. Sampling points, August 2016. Lake Coatepeque



Toxins are released as a result of the aging of cell blooms, or treatment with algaecides (copper derivatives or organic herbicides), which promotes the rupture of the cells. Thus, for example, the treatment of cell blooms with copper sulfate may lead to cell death and a complete release of toxins into the surrounding water.

According to prospective epidemiological studies cited in the document Cyanobacteria and cyanotoxins: *Impacts on human health* (García, undated), the measured effects were: eye irritation, skin rash, vomiting, diarrhea, cold symptoms, mouth ulcers and fever, derived from recreational contact with water with the presence of Microcystis spp in concentrations mainly over 20,000 cel/ml and in prolonged bathing times, which may develop into cumulative liver damage when exposure becomes recurrent.

Given this situation, in 2016, the MARN undertook actions to improve sanitation, "*formulating guidelines for wastewater management in Lake Coatepeque, in response to the diagnosis made of 472 activities carried out on the banks of the lake, which identified deficiencies in the discharge of its wastewater. Specific proposals for treatment and discharges were drawn up for the activities identified in restaurants (100 visitors per day), recreational farms and homes*" (MARN, 2017:54).

3.2. Agrochemicals

Intensive agrochemical use has become one of the main pollutants affecting surface and groundwater, particularly in certain areas of the coastal plain, which greatly affects the livelihoods of the local population as regards the water supply for various domestic uses, food production and the health of its inhabitants.

According to the annual MINSAL reports (2013-2014 and 2014-2015), Chronic Noncommunicable Diseases (NCDs) have become a major challenge for the health system due to the growing number of people affected and treated at hospital centers in comparison with the period 2008-2009. Among the most recurrent is Chronic Kidney Disease (CKD), which, according to the research (MINSAL, 2015: Chap. 4), in its early stages, reveals its toxic nature in patients directly related to the use of agrochemicals or residence in areas with high exposure to the latter. These chemicals also have a major effect on

Table 3. Results of water analysis for human consumption

Type of analysis	Total samples	Total within norm	Percentage within norm
Bacteriological	7881	7315	92.82%
Physical-chemical	752	596	79.26%
Trace of metals	459	317	69.06%

Source: MINSAL, 2017.

water sources, mainly in the artisanal wells of surface aquifers located in the low-lying areas of the country or coastal plain, which are essential for supplying the population, since this area is the hydrographic area where the largest number of cases has been reported.

Studies have determined a type of CKD with a different origin from the causal variables according to global averages, in which 43 to 50% of CKD is associated with Diabetes Mellitus and 20 to 30% with arterial hypertension. By 2013, CKD had been established as the leading cause of death in the public health system. At the same time, MINSAL determined that the harmful effects of agro-industry, mining and agrochemicals, are reflected in the high number of people affected, a growing contribution to general mortality, an increasing incidence in the burden of premature disability in the population, a complex level of approach and high care costs. Some of the research that has served as a basis for addressing this problem and the adoption of measures includes: PAHO (2013), MEDICC Review (2014), Orantes, C.M. (2009), Jayasumana, C. *et al.* (2014), among others.

These studies have established that dehydration and extreme heat are contributing factors rather than the primary factors responsible for kidney damage. At the same time, as reported by MINSAL, histopathological studies with an emphasis on the early stages of the disease confirm that kidney damage in patients who have been systematically exposed to agrochemicals is due to tubular damage, consistent with the toxic origin of the ailment. Central America is the main region in the world to use these products intensively, and it is estimated that approximately 400,000 people may suffer a symptomatic episode of agrochemical poisoning every year.

As a result of the presentation of this research and their analyses, it was possible to influence the passage of the Law on Pesticide, Fertilizer and Agricultural Product Control, designed to regulate the production, marketing, distribution, import, export and use of pesticides, fertilizers, herbicides, improvers and other chemical or biological chemical products for agricultural, livestock and veterinary uses and their raw materials. Moreover, as a result of monitoring these polluting agents, in 2015, MINSAL incorporated the analysis of carbamate, organochlorine and paraquat pesticides into drinking water monitoring. Of 386 samples analyzed, 41% tested positive for carbamates; while paraquat was found in 74.19% of a second group of 461 samples, and in a third group of 296 samples, 36.48% tested positive for the presence of organochlorines. **Table 3** shows the consolidated result of water analysis for human consumption, undertaken nationwide in the period 2016-2017.

In order to strengthen its field of action regarding this problem, MINSAL coordinated efforts with MAG and MARN to reactivate the National Pesticide Commission (CONAPLAG) and formulate and update regulatory documents, including the Salvadoran Technical Regulation of Maximum Residual Limits of Chemical Pesticides in Fruits and Vegetables, the Quality Standard for Fertilizers and their Raw Materials, the Standard for the Verification of Pesticide Quality and the update of Agreement No. 18 to restrict the use of pesticides, dicamba, terbufos, phorate, aldicard, glyphosates and paraquat. The Declaration of San Salvador: Approach to Central American Chronic Interstitial Tubule Renal Disease (ERTCC) which predominantly affects agricultural communities, was issued in San Salvador, on April 26, 2013.

3.3. Heavy metals

Heavy metal pollution has been reflected in a specific, significant way in zones of incidence of mining exploration in the north of the country, in the department of Cabañas, and in the east, in the Municipality of Santa Rosa de Lima, directly affecting the San Sebastián river (Pacheco *et al*., 2016).

In the case of Cabañas, in the municipalities of Guacotecti, San Isidro and Ilobasco, in 2013, MINSAL confirmed the presence of arsenic in much higher concentrations than those allowed and three chemical parameters that require special treatment. This situation is particularly important, given that the region in the north of the country is characterized by an acute water shortage, due to its high dependence on agricultural activities for the feeding of local communities and the presence, until some time ago, of international mining industries which for many years undertook explorations pending the final permits for their exploitation of gold in the area, which involved the diversion of rivers, the retention of flows and the use of cyanide, mercury and arsenic in drilling, leaving residual traces in community water sources.

Given the case of the San Sebastián mine and due to the direct impact on the health of residents in the municipalities of the Department of Cabañas and the enormous outcry by social and environmental organizations, universities and Catholic Church organizations, as well as the denunciation by communities for over 12 years of soil, food and water contamination, and the high level of conflict created in the same area of the Department of Cabañas -which claimed several local victims- on March 29, 2017, the Legislative Assembly finally decreed, by consensus vote of all the political parties, a national ban on metal mining and the use of toxic substances such as mercury and cyanide.

3.4 Deforestation

Deforestation and changes in land use due to the advancement of agricultural plantations and urban expansion have a significant impact on water availability and quality, since water recharge and natural damping zones are lost, contributing to an increase in erosion processes, soil loss and local climate regulation, the percolation of pollutants into the subsoil and greater atmospheric and environmental pollution.

According to the SDGs approach, trees and forests play an essential role in the water cycle, carbon sequestration, food production and the maintenance of ecosystems as shapers of the livelihoods of local populations, when they are integrated on the basis of an agroforestry and diversified production approach. This promotes greater soil protection and conservation, increased agricultural yields, a reduction in the intensive use of agrochemicals and the promotion of biological chains and microorganisms in the soil, which contribute to nutrient fixing and crop improvements.

Historically, El Salvador has been among the most deforested countries in the continent and according to the FAO report on The State of the World's Forests (2016), it is among the countries that have experienced a "net increase in agricultural area and a net loss of the forest area", which is contrary to the SDG guidelines, which promote agricultural intensification without increasing its area, among other aspects, through technological implementation and sustainable agricultural diversification. At the same time, the report considers that countries that promote investment and added value in agriculture have addressed the problem of forest loss much more effectively than those that have made limited investment, noting that successful cases of preservation and integration of forests in food security strategies promote an increase in agricultural productivity. In this respect, unlike the rest of the Central American countries, only Costa Rica has experienced a "*net increase in forest area and a net loss of agricultural area*".

In the urban sphere, the elimination of tree cover has a direct impact on people's health, the loss of microclimates and public spaces with natural shade and the loss of carbon fixing and the regulation of air pollution.

According to WHO statistics (WHO, 2016) for 2012, El Salvador is among the seven countries with the highest mortality rate attributed to environmental air pollution with 44.6 deaths/100,000 inhabitants. Likewise, in 2014, it ranked second out of a total of 34 American countries considered in the report, as regards the highest average annual concentration of particulate material in urban areas (PM2.5) of 37.1 $\mu g/m^3$, behind Honduras, which reports 40.3 $\mu g/m^3$, the permissible guideline being 15 $\mu g/m^3$ according to local regulations.

One aspect that has had a significant impact on the loss of quality of life and public spaces in the main cities has been the gradual elimination of the coverage of trees planted in the 70s, due to programs to create room for the setting up of power lines by

Figure 21. Urban images of tree cover removal

electric companies and municipalities, road and parking extensions, the installation of billboards, aerial enlargement for public viewing of commercial areas, etc., which has irreparably damaged the most important natural heritage of the metropolitan area and other cities, which provided multiple benefits. Several of the trees whose foliage and main branches have been removed lose their configuration and natural symmetry, making them more prone to falling in the winter season or strong winds. This is borne out by the images shown in **Figure 21**.

Since 2008, MARN has had air monitoring stations, and measured the parameters of carbon monoxide (DO), sulfur dioxide (SO2), nitrogen oxide (NO2) and particulate material (PM10 and PM2.5) measured in $\mu g/m^3$.

Salvadoran regulations set permissible limits of particulate matter of PM10 = 50 annually and 150 in 24 hours measured in $\mu g/m^3$, and of PM2.5 = 15 annually and 65 in 24 hours. According to the daily averages for PM2.5, in its report on Days with the Highest Pollution Reported by the Automatic Stations in the AMSS 2009-2016, MARN (2016) reported the following days as being outside the norm for the following years, out of 365 days measured at the UDB station: 2012=97, 2013=97, 2014=65 and 2015=18.

This situation is significantly reflected in the impact on people's health, since according to the MINSAL work reports, on an interannual basis, "*acute respiratory infections rank first among the reasons for consultation in the network of MINSAL establishments and second among the causes for* *hospitalization, which corresponding to the high environmental pollution and low air quality expressed n the high concentrations of harmful particles for the health of the population*". It also states that this situation is responsible for cardiovascular and respiratory diseases, chronic changes in physiological functions, and restrictions in intrauterine growth, leading to low birth weight and growth retardation.

Taking into account the problems of deforestation and the loss of forests, the MARN carried out the "Plantathon 2017" Day at 215 sites identified nationwide, with the mobilization of volunteers in various parts of the country, which involved planting 13 million trees according to the MARN Work Report, June 2017-May 2018. The project is part of efforts to restore degraded areas and landscapes, through the promotion of citizen participation, education and awareness in environmental matters. A key aspect is the inclusion of a monitoring and maintenance schedule, since in the past, in reforestation campaigns as part of the commitments to implement economic, road, and industrial projects, initial success in tree planting has been reduced by the loss of plantlets caused by lack of irrigation and maintenance in the early years.

3.5 Salinization

From the perspective of groundwater, marine intrusion in certain coastal areas is a phenomenon that has been exacerbated, partly as a result of the gradual loss of natural buffer areas at the coastal-marine interface-such as the mangrove forest and humid subtropical forest – and partly as a result of the excessive extraction of fresh water in shallow or surface (10-25 m) and deep aquifers, which creates an imbalance in hydrostatic pressures that permits the rise of the marine wedge, contaminating freshwater and the surface area of water use, mainly through the artisanal wells of the local population. This situation is also exacerbated by the reduction or elimination of flows from the rivers and natural tributaries that drain the coastal zone, which, as a result of a decrease in their level, stop interacting with the riparian zones and the subsurface waters of the shallow aquifer, which leads to a discharge or lateral contribution of aquifer flows into river channels and therefore a decrease in phreatic levels.

This decrease in river flows, mainly in the dry season, has been experienced in the past two decades due to the deforestation processes, expansion of the agricultural frontier and reduction of the infiltration capacity of the zones of water recharge in the hydrographic basins, leading to a decrease in the outcrops and water sources that support the base flow of rivers.

At the same time, given the growing demand for water for irrigation, caused mainly by the expansion of agricultural plantations, small rivers and tributaries have often been cut off by temporary dams, causing the retention of flows and the damming of water for its extraction through motor pumps, which drive the flows to the spray irrigation distribution systems, or through a network of troughs to retain soil moisture, as has happened in the west of the country. Retaining flows leads, among other aspects, to the virtual elimination of the flows entering key areas of coastal ecosystems, which require freshwater flows for their survival and sustenance, through the appropriate mixture with the saltwater that comes in from the sea currents when the tide rises.

A representative case study of this situation has been the research carried out in 2016 on the hydrological conditions of the shallow aquifer in an area of the western department of Ahuachapán and the elimination of flows in the summer season, which ceased entering the ecosystem mangrove due to the building of temporary dams for the retention of flows and the creation of reservoirs to irrigate sugarcane areas (Quiñónez, 2016). The dynamics of intertidal flows were used to calculate the required freshwater flows that should enter the ecosystems to maintain the estuarine environment, which should be maintained in a salinity range between 12-22 ‰ (per thousand) equivalent on average to an optimum concentration of dissolved mineral salts of 15,000 mg/l as a necessary condition for the preservation of biodiversity and the high productivity of mollusks and other heterotrophic species. In the absence of freshwater flows, the salinity conditions of the waters of ecosystems become equivalent to the salinity of the sea water, in the order of 35 ‰, which leads to the deterioration and loss of mangrove areas, as well as the low productivity of mollusk species, severely affecting the livelihoods and economy of local populations, as has happened in the study area.

Table 4. Socio-economic indicators

Indicador Socioeconómico	Nacional	Urbano	Rural	Hombres	Mujeres
Población económicamente activa (%)	72.6	62.0	38.0	45.6	54.4
Tasa de desempleo (%)	7%				
Escolaridad promedio (grados realizados)	6.8	7.9	5.1	6.9	6.7
Tasa de analfabetismo (%)	10.5	6.7	16.4	8.5	12.2
Pobreza (%)	29.2	27.4	32.1		
Pobreza Extrema (%)	6.2	5.3	7.7		
Pobreza relativa (%)	23.0	22.2	24.4		

Among some of the physical-chemical analyses carried out in key artisan wells for the use of the local population during the dry season, the results established 840 µS/cm in 2013 and 1,375 µS/cm in 2016 for electrical conductivity. Concentrations of 80.8 mg/l in 2013 and 421.25 mg/l were obtained for sodium in 2016. In both parameters, measured in 2016, the guide values for water for human consumption are significantly exceeded, with 600 µS/cm for electrical conductivity and 200 mg/l for sodium.

3.6 Wastewater and impacts on surface water, bodies of water and aquifers

Wastewater produces an enormous impact on surface water bodies and aquifers, as reflected in the Surface Water Monitoring Program carried out by MARN, due to the low level of wastewater treatment, equivalent to 8.5% of public coverage nationwide. Although nationwide coverage of discharge into sanitation service is high, estimated at 97.9%, 63.5% is undertaken through septic tanks and well sumps. This device, used mainly in rural areas, has frequently been a causal variable of bacteriological contamination foci in groundwater, due to poor designs or inadequate constructions with low maintenance.

Figure 22. Poverty condition

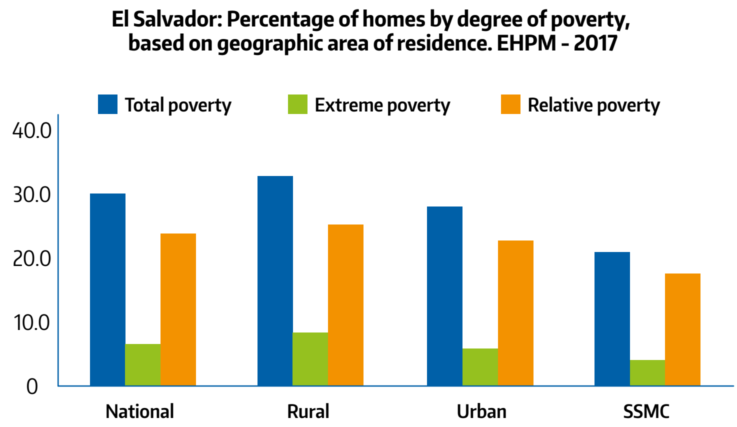
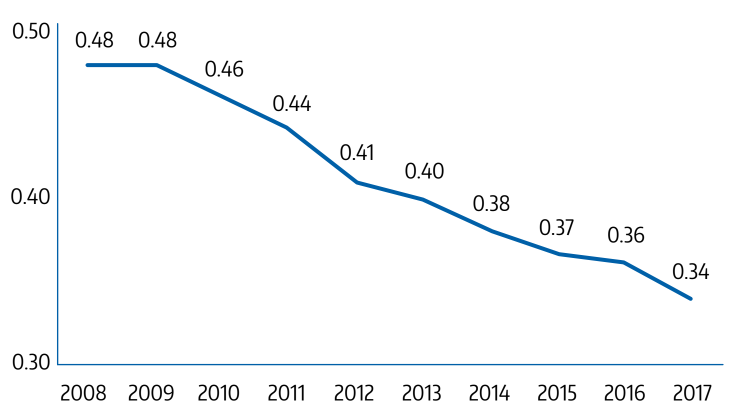


Figure 23. GINI Coefficient, Income Distribution Indicator



Source: DIGESTYC, 2017.

4. Social and economic aspects

4.1 Health, poverty, educational attainment in communities, gender, rural and urban areas

In 2017, the country had a poverty rate of 29.2%, with 6.2% living in extreme poverty, according to EHPM (DIGESTYC, 2017), as indicated in **Figure 22.** Likewise, **Table 4** shows that the unemployment rate is 7% and that average educational attainment nationwide is eight grades. Illiteracy rates fell from 17.97% in 2008 to 10.5% in 2017 with 91 municipalities being declared free of illiteracy, out of a total of

262 municipalities in the country. Public health expenditure increased by 3.7% as a percentage of GDP in 2007, equivalent to US $1,269.6 million, to 4.5% in 2016, equivalent to US $1,821.1 million.

One important aspect is the steady reduction of the GINI index shown in **Figure 23**, which fell from 0.48 to 0.34 between 2008 and 2017, reflecting a reduction in inequalities and an improvement in income distribution.

Some of the public policies that have contributed to the reduction of inequities in the social sphere and public assistance are as follows: the Universal Social Protection System - which included the delivery of agricultural packages of improved seeds, school packages of uniforms, shoes, supplies, and school snacks -, literacy work -encompassing 91 municipalities now free of illiteracy, the Program of Temporary Admission Support, the Women's City Project, the Universal Basic Pension for Older Adults and the Comprehensive Health Reform, which significantly reduced the burden of illness and contributed to reducing the population's spending through a set of measures involving the elimination of all types of charges in the public system, the implementation of the Family Health and Specialized Care program for the lowest income sectors, as well as the approval and implementation of the Medicines Law, a price regulation mechanisms that has generated annual savings of US $80 million in expenses for the population and enabled a significant increase in the supply of medicines in the public service network from 50% in 2008 to 85% in 2013.

Although all these aspects have constituted a significant achievement in the human development indicators associated with poverty reduction and social inequities, access to water, its quality and water-environmental problems constitute a primary challenge, These factors have a major impact on the deterioration of the health and sustainable human development of the population.

In this respect, according to MINSAL, the deficiency of the water supply as regards both quality and quantity constitutes a substrate for the proliferation of diseases that require a vector for transmission such as arbovirosis (chikungunya, dengue, Zika, yellow fever), since their absence forces the lower income population to buy, store and dispose of water in containers inside the home, which, when not handled properly, create positive indoor indexes for the *Aedes aegypti* vector of up to 95% at certain times of the year. In the same vein, it has been possible to establish that the incidence rate of dengue increases insofar as the population stratum lacks access to a continuous supply of indoor water. Thus the population with the lowest economic resources and least access to indoor potable water has the highest rates of infection from dengue, as well as being forced to pay high costs for obtaining water in containers or barrels.

From this perspective, although water pipeline coverage for human consumption is relatively high -88.3% nationwide in 2017-, interruptions or the modality of a supply by hours and on certain days of the week, mainly in the peri-urban and rural areas, has become a determining factor in the reduction of water quality and, therefore, has a great impact on the health of the population.

5. Progress regarding Sustainable Development Goals (SDG-6)

One of the priority goals of SDG-6 is universal access to potable water and sanitation at an affordable price, given that at least half the untreated flows must be treated by 2030. This means that 54.3% of the flows must be adequately treated over the next 12 years.

With regard to water at the national level, according to the EHPM (DIGESTYC, 2017), water service and access through pipes is 88.3%, including indoor supply, public jet or tap, and transportation from a neighbor's facility. A total of 11.7% of the population is supplied by artisan wells, springs or streams, or through direct purchase from tankers or other means. In urban areas, water access through pipelines amounts to 95.5% and in rural areas to 75.6%.

Regarding the sanitation and disposal of excreta by sanitary service, in 2017, nationwide coverage amounted to 97.9%, including disposal through the sewerage network and a septic tank and well sump. A total of 36.5% of this coverage is achieved through sewerage and 63.5% through septic tanks and well sumps.

On this point, SDG-6 seeks to achieve adequate, equitable sanitation, and hygiene for all, noting that improved sanitation should not only consist of encouraging adequate disposal of excreta, no open defecation and the use of hand soap to maintain hygiene and health, but also the proper treatment of domestic sewage through single-family or collective systems to guarantee the non-contamination of the subsoil, groundwater and surface water.

Although significant actions are underway to comply with SDG-6 - as noted in the background section of this paper - regarding the implementation of regulations, regulations, river recovery plans, designs, improvements and the construction of treatment systems, it is important to establish a schedule of follow-up, monitoring and verification of action plans, as well as strategies and levels of treatment that should periodically be achieved in conjunction with society as a whole.

At the same time, the protection and restoration of ecosystems plays a key role in SDGs. In this respect, it is worth noting the current efforts and commitments assumed by El Salvador in 2012 regarding the restoration of 1 million hectares before 2030, equivalent to nearly half the country (territorial extension: 2.1 million ha) within the framework of the Bonn-2017 Challenges, which are linked to the SDG-6 and SDG-15 targets in the fight against desertification and drought, the promotion of biodiversity and sustainable forest management.

Although action plans and projects oriented towards restoration are already in place, they are primarily based on the implementation of agrosilvopastoral systems, riverside gallery forest, agroforestry systems involving monocultures and coffee renewal, among others, without explicitly contemplating the promotion and implementation of natural or primary forest as part of the national ecosystem restoration strategy. It is important to reconsider and redefine this aspect, since native forests contribute with rates in the order of 468 t/ha for holm oak forest, taking into account the carbon present in the leaves on the ground, roots and air cover (Bernardus, 2001). This is much higher than the contribution provided by agro-pastoral and agroforestry systems (with an average carbon capture of 120 t/ha), while native forests also contribute to reconstituting biosphere areas for the production and preservation of oxygen, soil, biodiversity and water.

6. Satisfactory experiences in water quality improvements

6.1 Watershed restoration and protection plans

The recovery of water sources and soil productivity conditions, through extensive reforestation work on slopes and recharge zones, the construction of infiltration ditches in contour lines, diversification of agricultural production and measures to reduce sedimentary trawling and erosion constitute an excellent experience carried out in the La Poza micro-basin, located in the department of Usulután (GWP, 2008). The microbasin covers an area of 10.4 km^2 and the greatest problem that arose in 2002 was the growing difficulty of access to water to supply approximately 15,000 people. Through community work, the implementation of a payment system for environmental services, and the support of several NGOs and international aid workers, the basin was recovered and the problem solved. After a few years, a substantial increase in availability was obtained as regards water quantity and quality (Rivera, 2008), in addition to growing environmental awareness among the population.

6.2 Pilot experiences

By mid-2018, the VIDA reforestation project, undertaken by the Hydroelectric Commission of the Lempa River, CEL, achieved the planting of two million trees in areas near the 15 de Septiembre hydroelectric dam, belonging to sub-basins of the Lempa River in the department of San Vicente. According to its representatives, this project will be expanded in phases to new areas and seeks to restore certain sub-basins which feed into the hydroelectric dams and to improve the well-being and quality of life of families living in these sub-basins.

Another experience with a great potential for continuity and permanence in the future is the “Plantathon” initiative, whose 2017 and 2018 editions were led by MARN and created by the National Council for Environmental Sustainability and Vulnerability (CONASAV), with the support of several cooperation entities, municipalities and organizations involved in environmental preservation. As mentioned earlier, 2017, 13 million trees were planted, including approximately 12 million coffee plantlets suitable for planting. On June 5, 2018, within the framework of World Environment Day, the goal to plant five million trees was established.

7. Conclusions and Recommendations

7.1 Conclusions

- At the level of certain institutions, the situation of water quality has become a topic of primary concern and interest due to its impact on health, supplying water for the population, the preservation of ecosystems and its impact on water availability for various uses. In response, various actions, plans and programs have been implemented by public entities -MARN and MINSAL-, cooperation agencies, and social and citizen organizations to decontaminate priority areas, construct wastewater treatment infrastructure in certain sites, monitor water quality and undertake studies and research, which have contributed to understanding and addressing the issues raised. This has been done within a framework of greater inter-institutional coordination and with the promotion of citizen and community participation, albeit with limited dissemination, socialization and public and political discussion of the problem and its solutions, progress and its implications, even though this is an issue that should dominate interest and attention in national life.
- The lack of a General Water Law based on the equity and priority of the human right to access to water and the sustainability of ecosystems, under the governance of a public governing body, severely limits the formulation of a planned strategy and a management model to achieve sanitation, decontamination and the preservation of water quality. This absence also becomes an obstacle to the establishment of public policies, their financing and consensual guidelines for promoting a socio-economic development model compatible with water preservation.

However, insufficient use has been made by the executive branch of the power to enact by-laws, which, although transitory, would contribute to shaping and embarking on a much more solid, clearly defined course in the area of environmental water preservation, in conjunction with other sectoral and institutional laws.

The studies and research conducted through international cooperation agreements, and projects and theses by universities and experts in the national field, some under agreements with public entities, have significantly contributed to expanding the analysis, monitoring and knowledge of specific situations concerning water quality. However, in many cases, these have been valuable but focused and occasional efforts, which lack follow-up, data collection and processing and information for updating, deepening and analysis over time, which would contribute to consolidating a systematic approach, linked to the challenges raised by water quality, wastewater treatment, the obtainment of by-products and their benefits in various fields.

7.2 Recommendations

- Launching a strategy for the preservation of water and its associated natural assets, as regards both quantity and quality, in order to comply with the Sustainable Development Goals, is a priority. It involves undertaking a configurating, integral action in national life, given that the issue of water and decontamination is a central area that on the one hand, affects the health of the population and the life of ecosystems and, on the other, is directly linked to and determined by the impacts of the economic, agro-productive development and urban planning of the country. The small size of El Salvador and the interaction of its territories, which are part of the same interconnected hydrographic regions, means that actions implemented in one place impact on other important sites and the livelihoods of the population. This means that precaution, care, participation, education, the promotion of an environmental culture and citizen involvement become active principles that must be present in a water preservation strategy, while recognizing and valuing the water-environmental limits of the country, which should regulate economic and social undertakings.
- Passage of the General Water Law is a pressing need in the country, which must be based

on the Human Right to Water, and assume the principles of equity, affordable access and sustainability, which constitute the basis for conceiving of water as a supreme public asset, whose governance should primarily be the responsibility of the state.

Considering this perspective and the current legal framework, the state should exercise its power to issue Executive Decrees that formally strengthen and protect the actions and undertakings by State Portfolios, so that actions and lines of work related to water quality are established. that can be developed and deepened in conjunction with cooperation agencies, experts in different areas and through accords and permanent agreements with universities and academia.

- It is important to have specializations at the master's and doctoral degree level in the various degree courses related to water quality, wastewater treatment systems, sanitary engineering and bioengineering and related specialties from environmental sciences in order to reconfigure the territories and design a sustainable Socio-Economic Development Model compatible with the conditions of the country and its population. This underlines the importance of creating a National Center for Research and Experimentation on aspects linked to water quality, which would ensure continuity in the analysis and intensification of studies and research, thereby strengthening the agreements they sign with state entities and making it possible, as mentioned earlier, to develop and complete lines of work which, on the one hand, would contribute to the accumulation and appropriation of national and local knowledge from the field of science and, on the other, would encourage the implementation of technologically and economically viable processes, promoting modernization and efficiency oriented towards fair and equitable human development.

8. References

Administración Nacional de Acueductos y Alcantarillados (ANDA) (1961). *Ley de Asociación Nacional de Acueductos y Alcantarillados.* Decreto de Ley Directorio Cívico Militar No. 341. El Salvador: Presidencia de la República/ANDA.

Administración Nacional de Acueductos y Alcantarillados (ANDA) (1987). *Reglamento sobre la Calidad del Agua, el Control de Vertidos y las Zonas de Protección.* Decreto No. 50 y Reforma 51. El Salvador: Presidencia de la República/ANDA.

Administración Nacional de Acueductos y Alcantarillados (ANDA) (2005). *Norma para Regular Calidad de Aguas Residuales de Tipo Especial Descargadas al Alcantarillado Sanitario.* El Salvador: ANDA.

Asamblea Legislativa de la República de El Salvador (1970). *Ley de Riego y Avenamiento.* Decreto Legislativo 153. El Salvador: Presidencia de la República de El Salvador/MAG.

Asamblea Legislativa de la República de El Salvador (1988). *Código de Salud.* Decreto 955. San Salvador: Presidencia de la República de El Salvador/MINSAL.

Asamblea Legislativa de la República de El Salvador (1998). *Ley de Medio Ambiente.* Decreto Legislativo 233. El Salvador: Presidencia de la República de El Salvador/MARN.

Banco Mundial, US-EPA, Levi Strauss & Co. (2007). *Criterios y Recomendaciones Nacionales sobre Calidad del Agua: Valores Guía sobre Vertidos Industriales.* "Industry Sector Environmental Health and Safety (EHS) Guidelines" and "Global Effluent Guidelines" Appendix V.

Consejo Nacional de Ciencia y Tecnología (CONACYT) (2009). *Norma Salvadoreña Obligatoria, NSO 13.49.01.09: "Aguas Residuales Descargadas a un Cuerpo Receptor".* Acuerdo 249. El Salvador: CONACYT.

De Jong, Bernardus H.J. (2001). *Cambios de usos de suelo y flujos de carbono en los Altos de Chiapas, México.* Simposio Internacional Medición y Monitoreo de la Captura de Carbono en Ecosistemas Forestales. Valdivia, Chile. Available at https://www.uach.cl/procarbono/pdf/simposio_carbono/02_De_Jong.PDF

Dirección General de Estadística y Censos (DIGESTYC) (2017). *Encuesta de Hogares y Propósitos Múltiples (EHPM). Principales Resultados.* El Salvador: Ministerio de Economía.

Dirección General del Observatorio Ambiental (DGOA) (2015). *Informe de Acuíferos Porosos en la Zona Costera.* El Salvador: DGOA.

Dirección General del Observatorio Ambiental (DGOA) (2016). *Informe de Acuíferos Porosos en la Zona Costera.* El Salvador: DGOA.

Dirección General del Observatorio Ambiental (DGOA) (2018). *Reporte de Niveles Piezométricos Acuífero de Nejapa.* El Salvador: DGOA.

Dirección General del Observatorio Ambiental (DGOA/MARN) (2016). *Informe de monitoreo de los acuíferos de Zapotitán, Santa Ana y San Miguel.* El Salvador: DGOA/MARN.

Foro Centroamericano y República Dominicana de Agua Potable y Saneamiento (FOCARD-APS) (2013). *Gestión de las excretas y aguas residuales: Situación actual y perspectivas.* El Salvador: FOCARD-APS. 33 pp.

García, S. (s/f). *Cianobacterias y cianotoxinas. Impactos sobre la salud humana.* Traducción y resumen del libro de Jamie Bartram e Ingrid Chorus, *Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management.* WHO,1999. Available at http://www.msal.gob.ar/images/stories/ministerio/intoxicaciones/cianobacterias/cianobacterias_y_cianotoxinas.pdf

Global Water Partnership (GWP) (2008). *Microcuenca La Poza El Salvador.* Available at https://www.gwp.org/globalassets/global/toolbox/case-studies/americas-and-caribbean/el-salvador.-development-of-community-participation-in-the-microbasin-la-poza-343-spanish.pdf

Jayasumana C., Gunatilake S. (2014). Hard Water and Nephrotoxic Metals: Are they the Culprits Behind the Epidemic the Chronic Kidney Disease of the Unknown Etiology in Sri Lanka? *Environ. Res. Public Health,* 2014,11, 2125-2147.

MEDICC Review (2014). *Chronic Kidney Disease Hits Agricultural Communities.* Vol. 16 No. 2.

Ministerio de Medio Ambiente y Recursos Naturales (MARN) (2011). *Programa de Monitoreo de la Calidad del Agua.* El Salvador: MARN.

Ministerio de Medio Ambiente y Recursos Naturales (MARN) (2013). *Programa de Monitoreo de la Calidad del Agua.* El Salvador: MARN.

Ministerio de Medio Ambiente y Recursos Naturales (MARN) (2016a). *Informe del Estado Actual del Lago de Coatepeque, Agosto de 2016.* El Salvador: MARN.

Ministerio de Medio Ambiente y Recursos Naturales (MARN) (2016). *Control de jacinto de agua en los humedales Olomega, Jocotal, y Nahualapa.* El Salvador: MARN.

Ministerio de Medio Ambiente y Recursos Naturales (MARN) (2016b). *Días de mayor contaminación reportados por las estaciones automáticas ubicadas al Este y al Centro del AMSS para el periodo 01-01-2009 al 31-08-2016.* El Salvador: MARN.

Ministerio de Medio Ambiente y Recursos Naturales (MARN) (2017a). *Plan de Recuperación de Ríos Urbanos: presentación de plan acción en junio de 2016.* El Salvador: MARN.

Ministerio de Medio Ambiente y Recursos Naturales (MARN) (2017b). *Informe de Labores junio 2016-mayo 2017.* El Salvador: MARN. 139 pp.

Ministerio de Medio Ambiente y Recursos Naturales (MARN) (2018a). *Programa de Monitoreo de la Calidad del Agua.* El Salvador: MARN.

Ministerio de Medio Ambiente y Recursos Naturales (MARN) (2018b). *Informe de Labores junio 2017-mayo 2018.* El Salvador: MARN. 138 pp.

Ministerio de Salud (MINSAL) (2009). *Normativa Salvadoreña Obligatoria para agua potable, NSO 13.07.01.08, 2009.* El Salvador: MINSAL.

Ministerio de Salud (MINSAL) (2014). *Informe de Labores 2013-2014.* El Salvador: MINSAL.

Ministerio de Salud (MINSAL) (2015). *Informe de Labores 2014-2015.* El Salvador: MINSAL.

Ministerio de Salud (MINSAL) (2016). *Informe de Labores 2015-2016.* El Salvador: MINSAL.

Ministerio de Salud (MINSAL) (2017). Informe de Labores 2016-2017. El Salvador: MINSAL.

Orantes, C.M. et al. (2009). "Chronic Kidney Diseases and Associated Risks Factors in the Bajo Lempa Región of El Salvador: Nefrolempa Study", *MEDICC Review.* Available at: http://www.medicc.org/mediccreview/index.php?is.&id=221&a=va

Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO) (2016). *Estado de los Bosques del Mundo. Los bosques y la Agricultura: desafíos y oportunidades. Resumen.* Available at http://www.fao.org/3/a-i5850s.pdf

Organización Panamericana de la Salud (OPS)/ Organización Mundial de la Salud (OMS) (2013). "Chronic kidney disease in agricultural communities in Central America" en *Iris PAHO.* Washington DC: OPS/OMS. Available at: http://iris.paho.org/xmlui/handle/123456789/4718

Pacheco V.; Quiñónez B, J.; Tara Van Ho; Lizama, E. (2016). *El Legado de la mina San Sebastián y sus Impactos en la vida de las poblaciones afectadas.* Entidad promotora: Procuraduría para la Defensa de los Derechos Humanos (PDDH). El Salvador. Available at: https://issuu.com/pedrocabezas/docs/informe_especial_pddh__legado_de_la

Quiñónez, J. (2013). *Revisión de los aspectos hidrológicos e hidrogeológicos del estudio de impacto ambiental de Planta Nixapa, Industrias La Constancia, Municipio de Nejapa, San Salvador.* El Salvador. Available at https://www.alianzaporlasolidaridad.org/wp-content/uploads/Maq.-Tierrra2.pdf

Quiñónez, J. (2016). *Análisis hidrológico de los impactos de la expansión de la caña de azúcar en zonas frágiles de ecosistemas y de recarga hídrica en San Francisco Menéndez, Ahuachapán.* El Salvador.

Rivera, R., FUNDE, FAO-Facility (2008). "Pago por servicio ambiental en la microcuenca La Poza, municipios de Ozatlán y Usulután, departamento de Usulután, República de El Salvador" en *Mecanismos de compensación relacionando bosques con agua en Centroamérica y El Caribe de habla hispana.* El Salvador: FAO, MAG. The National Forest Programme FACILITY. Available at: http://www.fao.org/forestry/19357-0d452bc832742ca4c18f88a8d3d3e14b1.pdf

Universidad Centroamericana "José Simeón Cañas" (UCA) (2013). *Monitorización de variables físico-químicas en humedales RAMSAR de El Salvador.* El Salvador: UCA.

Universidad de El Salvador (UES) (2013). *Intensa proliferación de cianobacterias en el Lago de Coatepeque en el evento de septiembre de 2012.* El Salvador: UES.

WHO (2016). Annex A: Summary of the SDG Health and Health-Related Targets. Official WHO Statistics.

Grenada

Although it is a small developing island in the southern Caribbean and has abundant supplies of fresh water, **Grenada** faces constant obstacles that make it difficult to guarantee optimal water quality. Technical and economic limitations have led to an inefficient distribution system and a repeated lack of capacity, which have prevented it from guaranteeing full compliance with the physical, chemical and microbiological standards for water quality. An integral strategy designed to address these challenges, focused on improving the governance, development and rigorous implementation of legal instruments, will ensure that the population of Grenada continues to have access to safe drinking water.

Waterfall Concord, Grenada © iStock

Water Quality in the Americas: Caribbean-Grenada

Kerry Mitchell, Martin S. Forde and Allan Neptune

1. Introduction

Located at 12°07′N 61°40′W, the state of Grenada, which comprises of three islands –Grenada, Carriacou, and Petit Martinique– is the most southerly Caribbean country of the Windward Islands. All three islands are volcanic in origin principally composed of andesite domes, basalt flows and sedimentary deposits. The largest of the three islands at 312 km^2 is Grenada with its highest point being 840 m (**Figure 1**), followed by Carriacou at 34 km^2 and Petite Martinique at 2 km^2 (Allen et al., 2014). Twenty five percent of the total land area of the island of Grenada lies above 305 m and approximately seventy percent of the mountainous slopes have gradients greater than 20°, resulting in a topography characterized by high peaks, steep slopes and deep valleys throughout the island (Forde and Neff, 2015). The ambient temperatures in Grenada range between 24 and 30°C with relatively high humidity all year with slight variations depending on time of day (McSweeney et al., 2006).

Grenada experiences two meteorological seasons; a dry season typically spanning the months of January to May and a wet season spanning the months of June to December, with a mean annual precipitation of 2350 mm, and is classified as tropical rainforest under the Köppen Geiger scheme (AQUASTAT, 2014; Brink and Robinson, 2005). Hence, for Grenada the principal challenges in efficient water resource management lies principally not in the quantity available, but in water losses (non-revenue water) throughout the distribution system in the form of leaks, evaporation from reservoirs, and uptake and transpiration from surrounding vegetation. Water losses due to transpiration have been attributed to the increased presence of the dominant tree species Talipariti elatum (locally known as Blue Mahoe), which has been historically used in reforestation and forest conservation techniques in the protected areas that encompass many catchment areas around the island (FAO, 1998; Government of Grenada, 2001a). Non-revenue water is currently estimated at 25%, lower than the 35% average in developing countries (Kingdom et al., 2006).

The island has 71 designated watersheds from which water can be extracted up to a maximum yield of 54,600 m^3 per day in the rainy season and 31,800 m^3 per day in the dry season (CDB, 2016). There are four water supply treatment facilities where coagulation, flocculation, sedimentation, filtration and finally chemical disinfection are used to treat surface-sourced water. There are an additional 22 other surface-sourced water supply facilities

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where only filtration and chemical disinfection is done. For water extracted from groundwater sources, there are seven treatment plants equipped with disinfection facilities dedicated to their treatment (NAWASA, 2018). Finally, there are two desalination plants, one on the island of Carriacou and other on the island of Petite Martinique, which are used to augment rainwater harvested supplies on these two islands.

While Grenada can be characterised as having sufficient quantities of freshwater resources, especially during the rainy season, it has experienced challenges in ensuring the quality of the water delivered for human consumption. Most of these challenges can be linked to the lack of adequate financial resources needed to establish regulatory oversight and implement water sampling programmes that are sufficiently comprehensive and frequent in order to enhance the assurance that potable water is produced. The potential negative impact of not meeting these challenges is exacerbated by non-existing or poorly implemented policies and legislation essential to ensure safe drinking water is produced and delivered to everyone. This chapter explores these issues, presents water quality data over the past decade, and highlights the challenges currently faced in the provisioning of high quality water to the people living in Grenada.

Figure 1. Map of Grenada, Carriacou, and Petite Martinique

2. Water quality governance

The governance of water resources in Grenada depends on the coordinated efforts of multi-sectorial stakeholders whose overreaching mandate is the protection of the environment and the population's health. Legal instruments utilized include but not limited to are the Forest Soil and Water Conservation Act (1984) and the Water Quality Act (2005), as executed and enforced by the Ministry of Agriculture and the Ministry of Health respectively.

The main abstractor of water is The National Water and Sewerage Authority (NAWASA). This statutory body, under the Ministry of Communications, Works, Physical Development, Public Utilities, ICT & Community Development, is mandated by the NAWASA Act (1990) with the provisioning of water supplies and the conversion, augmentation, distribution and proper use of actual and prospective water resources including preservation and protection of catchment areas. NAWASA is also mandated to handle sewerage and the proper treatment and disposal of sewerage and other effluents. This body is responsible for the administration and provision of all potable water for domestic purposes and ensure a satisfactory supply of water for agricultural, commercial and industrial purposes. The Act also confers authority to NAWASA for all acquisitions for water and sewerage works, application of tariffs, acquisition and maintenance of property used as water sources. In collaboration with the Ministry of Agriculture, as per the aforementioned Forest Soil and Water Conservation Act (1984), special emphasis is given to the protection of the integrity of water catchment zones (Government of Grenada, 2007a, 1990).

Although not currently fully operational, a ministerial board designated by the Ministry of Health as the Sanitary Authority in the Water Act of 2005, is charged with regulatory oversight of the quality of water intended for human consumption by means of regular sampling and analysis. The board determines the frequency of sampling and testing, ensures that users are warned of potentially poor

Figure 2. Grenada's water supply and distribution network (Source: NAWASA)

water quality where necessary, and implements action programs for the improvement of water quality. This ministerial board operates through consensus of its members (Government of Grenada, 2005).

Currently NAWASA undertakes this responsibility with regular reporting to the ministerial board. Samples are taken from influents and effluents at all water treatment plants and select private and public access points along the distribution network on average four times per month. Routine physicochemical and microbiological analyses include pH, turbidity, free chlorine and total coliforms. Based on WHO guidelines as stipulated in the Water Quality Act of 2005, periodic sampling at points along the distribution network are carried out and analyses done for other organic and inorganic constituents including but not limited to nitrates, biological oxygen demand, chlorine residue, conductivity, alkalinity, sulphates, organic carbon, iron, and odour (ECLAC, 2007; Government of Grenada, 2005). Currently, these analyses are done infrequently and/or after a specific natural or anthropogenic event that may negatively affect water quality. The main reason for these tests being conducted infrequently and only in response to suspected contamination is lack of adequate financial resources. All collected data is stored in an internal database, reported weekly to the Sanitary Authority, and made available to local, regional and international entities upon request and subsequent approval from the ministerial board.

3. Problems impacting water quality

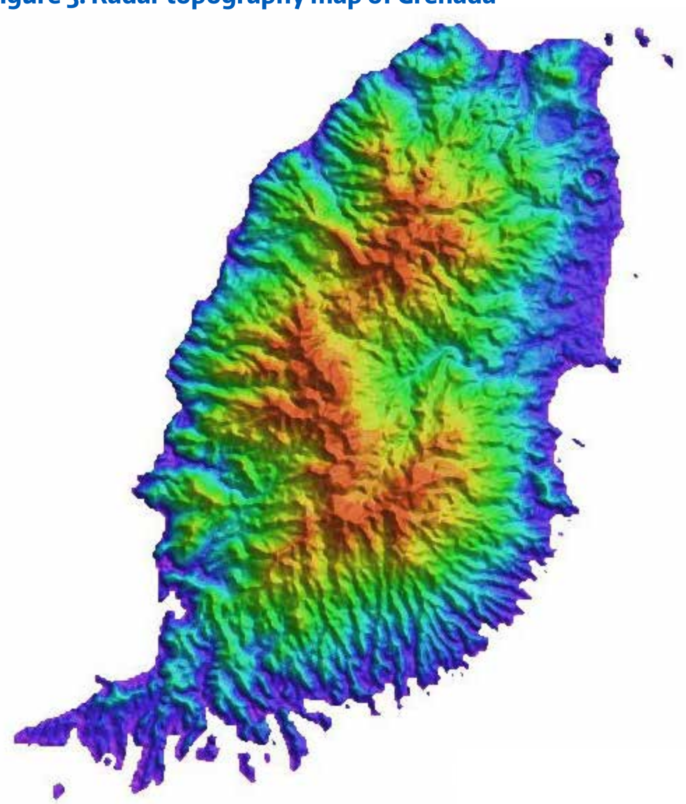
3.1 Contamination from natural sources

Surface water sources account for 95% of the water distributed through the network managed by NAWASA (NAWASA, 2018). Most of the catchment zones are located near the centre of the island at higher elevations (**Figure 2 and 3**) and are generally isolated from extensive human settlements. The principal catchment zones such as the feeders for the Annandale, Vendome, and Petit Etang treatment plants, are located in protected forest reserves which helps to ensure that the water sourced from these areas are generally unaffected by anthropogenic activity.

Regular monitoring of the basic water quality parameters confirms that the quality of water produced in Grenada mostly meets the guidelines stipulated by the WHO. Analysis of the data from the period 2010 – 2017 (**Figure 4**) shows average pH values with little variation between 7.70 ± 0.36 and 7.75 ± 0.40. These values, chemically categorized as neutral to slightly alkaline, fall well within the WHO guideline pH range of 6.5 and 8.5, and are typical of fast flowing unaltered lotic systems (Dirisu et al., 2018; WHO, 2017a).

Microbiological activity is also closely monitored with collected data showing an absence of *Escherichia coli* in close to 98% of analysed samples and total coliforms in 88% in 2010 and 94% in 2017 of all analysed samples (**Figure 5 and 6**). Given, however, that optimally total coliforms which is an indicator for pathogenic microbiological activity should

Figure 3. Radar topography map of Grenada



Highest elevations (orange), lowest points (dark blue).
Source: http:// caribbeanvolcanoes.com/radar- grenada/.
Retrieved Jan 2018.

be absent in 100% of samples, these results indicate an ongoing challenge in ensuring effective disinfection. The level of microbiological activity depends greatly on the type and efficacy of disinfection process used, which in turn is affected by specific water physical characteristics such as turbidity and chlorine demanding solutes. Chemical disinfection in the form of chlorination is used throughout the island. WHO guidelines stipulate that free chlorine should remain above a threshold value of 0.2 mg L^{-1} throughout the distribution system, optimally ≥ 0.5 mg L^{-1}, after at least 30 min contact time at a pH < 8.0 (WHO, 2017a). **Figure 7** confirms that samples taken along the distribution network generally contained free chlorine values above the guideline values, but with significant deviation from the mean, which could in part explain the aforementioned challenges faced in ensuring effective disinfection.

Though free chlorine is generally a good indicator for disinfection efficacy, the applicability of its interpretation can be affected by the physical properties of the water such as turbidity and chlorine-demanding solutes (WHO, 2017b). On average, turbidity levels (**Figure 8**) throughout the distribution system have consistently been above the WHO recommended level of 1 Nephelometric Turbidity Units (NTU), which singularly would negatively affect the efficacy of chemical disinfection (WHO, 2017a). Collected data showed mean values between 1.9 and 5.6 NTU between 2010 and 2017, with significant variation and single values as high as 190 NTU. These results indicate serious and currently unmet challenges in reducing turbidity. The prime source of high turbidity in untreated and treated water throughout the distribution system has been linked to the presence of silt and organic matter, the exacerbation of which is generally observed during heavy rainfall and top soil erosion during the wet season.

Figure 4. Mean pH values and std. dev. compared to WHO guideline values (2010-2017)

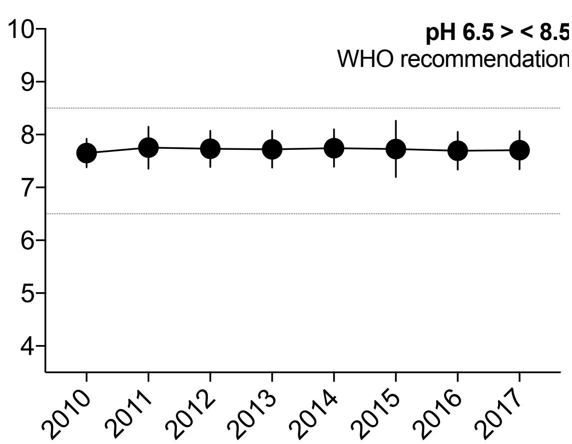


Figure 5. Mean % of samples with absence of total coliforms (2010-2017)

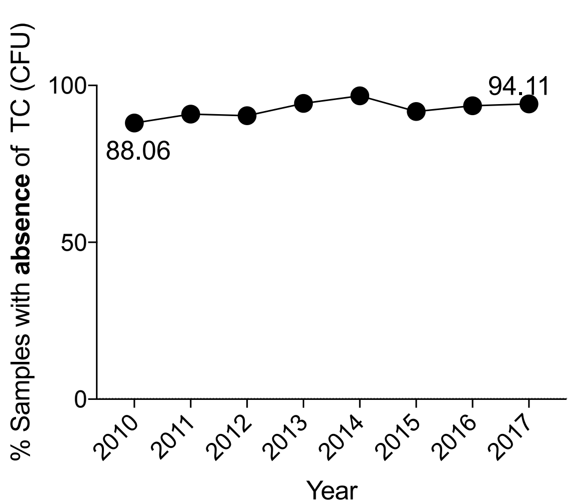
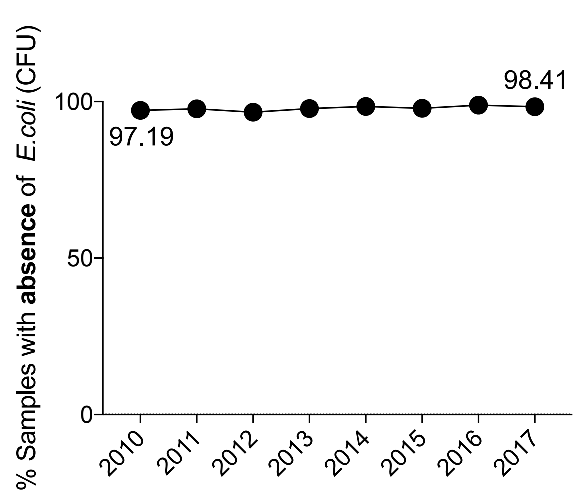


Figure 6. Mean % of samples with absence of *Escherichia coli* (2010-2017)



The impact of high turbidity levels on water quality is generally less severe when due to natural as opposed to anthropogenic contamination. Nevertheless, the continued inability to meet guideline values indicates the possible presence of pathogens, detached biofilms, and scales from oxidized distribution material or external sources of contamination (WHO, 2017b). Proposed solutions to this problem currently revolve around the use of improved filtration systems along with increased use of coagulating agents such as aluminium sulphate and chemical disinfectants such as chlorine.

These solutions, however, not only present important economic implications, but also potentially significant population and environmental health consequences. Elevated concentrations of sulphates can result in secondary reactions that produce potentially corrosive solutions which in turn threaten the integrity of metal structures throughout the distribution network (Knowles et al., 2015). Additionally, exposure to high concentrations of aluminium (Al) has been linked to neurotoxicity (Hsu et al., 2018; Klotz et al., 2017). Based on available data and the adoption of the precautionary principle, some international regulatory agencies including the United States Environmental Protection Agency and the European Environmental Agency, have set 0.2 mg L^{-1} as the maximum Al concentration level in potable water (EC, 2009; USEPA, 2010). While the WHO doesn't set a health-based value, it does recommend that Al levels be below 0.2 mg L^{-1} (WHO, 2017a). Although residual Al is not regularly monitored throughout Grenada's water distribution system, collected sample data showed that 6% of all samples exceeded the guideline value. High Al concentrations were observed principally in water from treatment plants that handle very turbid waters due to surface runoff from soils with high silt content, highlighting the complex dynamic between water quality parameters.

Increasing the use of chlorine as a disinfectant can result in the formation of undesirable disinfection by products (DBPs) including trihalomethanes (THMs), which studies have associated with numerous negative health effects including reproductive toxicity and carcinogenesis (Iszatt et al., 2014; Li and Mitch, 2018; Rahman et al., 2014). THMs formation is the result of chemical reactions between the halogens used in disinfection (generally chlorine) and organic matter found in untreated water (Xie, 2004). In waters disinfected with chlorine, chloroform is usually the most common THM found. However, bromine, a physicochemically similar halogen, is quite ubiquitous in nature. It is usually found in bromide salts alongside other common salts, notably sodium chloride. When present, bromine not only reacts more readily with organic matter than chlorine forming brominated THMs, but also results in an additive toxic effect with the chlorinated THMs.

Figure 7. Mean free chlorine (Cl-) values and std. dev. compared to the WHO guideline value (2010-2017)

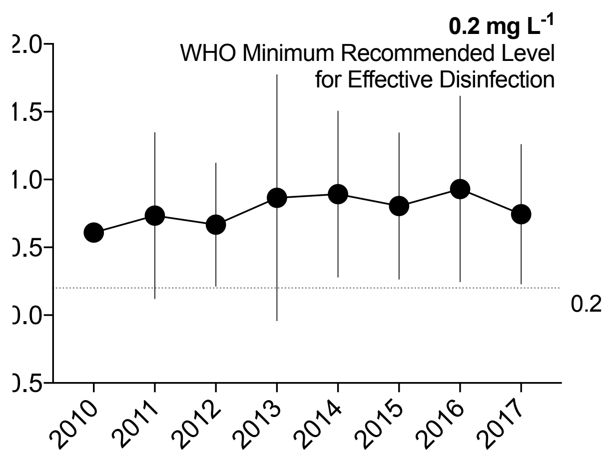
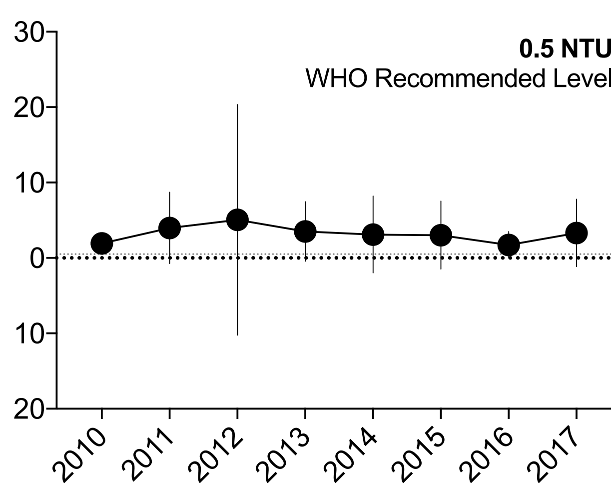


Figure 8. Mean turbidity (NTU) values and std. dev. compared to the WHO recommended guideline value (2010-2017)



THMs are not regularly monitored in Grenada, Carriacou, and Petite Martinique. Given the high potential for containing high concentrations of bromide and chloride salts in groundwater sourced in the southern region of Grenada and in the desalinated water distributed on the islands of Carriacou and Petite Martinique, regular monitoring for THMs is recommended. During 2017, 28 samples were analysed for chloroform. Of those 28 samples, the presence of chloroform was confirmed in 18 samples with concentrations ranging between 8 and 111 µg L^{-1}, well below the WHO guideline value of 300 µg L^{-1}. However, the WHO recommends continuous monitoring of the three other commonly found brominated THMs –bromoform, bromodichloromethane, dibromochloromethane (WHO, 2017a). This data can be used to establish a total THM standard calculated with the sum of the ratios of each THMs' concentration and their respective guideline values, thus taking into account the additive toxic effect. Although there is a current lack of capacity to quantify these THMs regularly, acquiring such capacity should take priority as the ongoing increase in the exploitation of ground and sea water inherently increases the risk exposure to THMs.

3.2 Contamination from anthropogenic sources

Due to the location of surface water sources, water distribution for associated catchment zones has been largely unaffected by anthropogenic contamination. Agricultural activity represents the single largest threat to water quality as industrial activity in any of Grenada's catchment zones remain negligible. Though limited in number, laboratory analyses have been done on samples over the past seven years to determine the presence and concentration of three chemicals of health significance in drinking water associated with anthropogenic contamination (WHO, 2017a). In all cases, copper (Cu), nitrates (NO_3^-) and nitrites (NO_2^-), typically associated with agrochemicals, were found to be under WHO guideline values of 2 mg L^{-1}, 50 mg L^{-1} and 3 mg L^{-1} respectively. These values are based on short-term and long term effects of exposure to these chemicals (WHO, 2017a).

In some areas not protected by the Forest Soil and Water Conservation Act (1984), there is an increasing presence of small scale agricultural activity, most notable in the catchment zones of the parishes of St. John and northern St. Andrew. Farmers in these areas have been known to indiscriminately use chemical fertilizers and pest management techniques that ultimately affect water quality. These catchment zones, however, benefit from a natural buffer system which include steep gradients and high throughput water volume resulting in dilution and low residence times of potential contaminants. Nevertheless, with increasing agricultural activities in these areas, this natural buffer system can be overwhelmed thus, continuous and regular monitoring hence required.

Groundwater sources on the island of Grenada currently supply 5% of the total distributed drinking water and is primarily utilized in the southern areas of the island. This water source, however, faces unique challenges when compared to the surface sources. Though the Forest Soil and Water Conservation Act (1984) inherently protects some of the watersheds that supply the subterranean sources, the absence of zoning regulations limits the protection afforded by law. In recent times, extensive anthropogenic activity has been observed in the catchment zones in the southern region of the island, including housing settlements, industrial activity and large-scale farming. Stakeholders are particularly concerned with the possible presence of chemicals associated with fertilizers and pesticides used on the farms. Additionally, housing settlements with inadequate waste management such as malfunctioning septic systems increase the risk of organic matter and microbiological contamination of groundwater. Although soils naturally depurate most organic contaminants (Vangronsveld et al., 2009), most of the borehole wells in Grenada are shallow with a maximum depth of only 150ft, and so leachate residence time in the soil is reduced thus limiting its buffering capacity.

Of the 94 WHO chemicals of health significance in drinking-water, legal, technical and economic resources only permit the infrequent analysis of five (NO_2^-, NO_3^-, Cl^-, Cu and $CHCl^3$). Notably absent are the aforementioned brominated trihalomethanes, toxic metals and persistent organic compounds including many currently used pesticides associated with much of the agricultural activities in several water catchment zones. Available results show that WHO guideline values are being met with tested chemicals, however, the infrequency of sampling limits the relevancy of these results.

Improved oversight of NAWASA, as stipulated by the Water Quality Act (2005) by the Ministry of Health, necessitates that the Sanitary Authority be made fully functional so that it can better monitor and analyse the quality of water produced by NAWASA. This regulatory body can also ensure that the frequency at which sampling is done is increased so as to ensure consistent quality water production. Additionally, adequate zoning policies are needed in catchment zones not currently protected as reserves to prevent anthropogenic contamination.

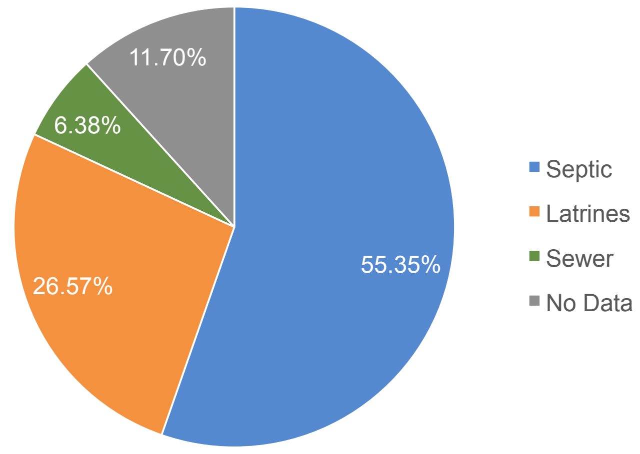
3.3 Wastewater management

According to data collected in 2015 by a WHO/UNICEF Joint Monitoring Programme for Water Supply (2017), 89.3% of the population in Grenada, Carriacou and Petite Martinique has access to basic sanitation services, which includes septic tank systems, pit latrines and public sewer systems (**Figure 9**). This is slightly higher than the average 85% access for the Latin American and Caribbean region. Septic systems are used by 55.35% of the population while 26.57% of the population still uses pit latrines as their main means of human waste disposal. Ground water can potentially be contaminated by malfunctioning septic systems near the catchment areas, particularly in the southern region of the island. With the continued increase in the size of the population living in this region of the island, this has prompted NAWASA to carry out preliminary sampling and laboratory analyses to quantify this risk. Initial results indicate that the quality of ground water sources has so far remained largely unaffected by the increasing number of faulty septic systems.

Finally, approximately 6% of the population has access to sanitation services provided by two sewerage systems, the St. George's/Carenage/Lagoon Road Sewerage System which serves the city center and nearby areas, and the Grand Anse Sewerage System which serves the South George area, including most of the major hotels which are located in this part of the island. With both systems, wastewater is collected from domestic and commercial users, screened (> 6mm) to remove large solids, rags and debris, then pumped into the sea through outfalls that extend 350m at an approximate depth of 25m (CDB, 2016). Presently no secondary treatment is being done, however, plans are underway to look at bring this capability to the island.

Several rehabilitation and upgrading programs have suggested the development of additional sewerage systems for the Greater St. George's area and Grenville (CDB, 2016). An expansion of the South St. George system has also been suggested and is currently under evaluation. This expansion would specifically target the areas near True Blue, St, George, an area that is currently undergoing significant development by St. George's University and supporting services. Though leaks in the piping system of the South St. George outfall have been reported, quantitative analyses of the water quality in the potentially affected area have not been published. The risk of severe environmental degradation thus exists, and continued monitoring and evaluation of possible remedial actions is recommended. Remedial actions currently being explored include the installation of a waste water treatment plant using secondary (biological) treatment processes to service the South St. George area. This area was chosen due to the rapid increase in urban development and the direct negative impact degradation of the marine ecosystem can have on the tourism sector.

Figure 9. Population coverage of sanitation services based on facility type



Source: (WHO/UNICEF, 2017)

4. Socioeconomic Aspects

Potable water distribution and sewerage services as provided by NAWASA are intended to be economically sustainable by means of a tariff structure, however, the mechanisms to ensure full operating cost recovery are not currently in place. Lack of economic sustainability is an inherent threat to the ability of NAWASA to provide these important services to the population.

Access to clean water is indispensable for socioeconomic development. Being a socially essential service, good water quality management must include community involvement. Initiatives focused specifically on increasing awareness of the importance of water quality in the community, however, to date have been limited. NAWASA through radio, television and social media has made efforts to sensitize the population on the importance of water as a resource through informational presentations. The effect of these presentations though may be anecdotal at best, as quantitative improvements in use and conservation is attributed primarily to the introduction of tariffs and a metering programme (ECLAC, 2007). These latter programmes have resulted in notable improvements in water use efficiency and a paradigm shift from viewing water as an entitlement to viewing water as a valued resource.

Under the current administrative structure, NAWASA has an estimated 43,031 customer accounts, a service coverage of approximately 90% which provides an estimated 97% of the population access potable water. Grenada can be found on the list of 100 countries categorized as having "improved water sources" as per target 7C of the Millennium Development Goals (CDB, 2016; World Bank, 2017). Grenada is categorized by the United Nations as a Small Island Developing State in terms of economic development and by the United Nations Development Programme as a country with High Human Development with a positively trending index of 0.754 (UN, 2014; UNDP, 2010). These rankings indicate satisfactory progress has been made to improve life expectancy, education, and wealth of the population. However, the UNDP also monitors other indicators such inequality which can be used to adjust the HDI for a better approximation of the socioeconomic status of the population. This data, along with the data needed to calculate the gender development index (GDI) and multidimensional poverty index (MPI), are absent for Grenada.

The relationship between these indicators and overall water security is well explored. Men and women are generally placed in differentiated positions in their ability to deal with issues related to water security due to patriarchal norms, inequities, and inequalities (Myrttinen et al., 2018). This would also play an integral role the prevailing attitudes towards water quality. On the other hand, the MPI currently used to more accurately gauge poverty includes a "standard of living" dimension under which access to safe drinking water is an explicit indicator. This relationship between poverty and access to water here in Grenada is highlighted in a study done by Neff (2013) as cited by Forde & Neff (2015), where the resilience of residents to issues related to water security including intermittent service and poor water quality depends greatly on economic status. Continued research is needed as the collected data would ensure the ability to calculate these indices placing stakeholders in a better position to identify and mitigate deprivations in specific dimensions of the system with more effective resources allocation, ensuring social equity and economic sustainability of water distribution (UNDP, 2016).

Economic sustainability and social equity in the context of water as a resource are considered pillars of integrated water resource management (Lenton and Muller, 2012). Though inherent in the objective of the NAWASA Act (1990), focus on water resource management commenced in 2006 at a Working Group held in Jamaica (Government of Grenada, 2007b), with important products of this collaboration including a Road Map Toward Integrated Water Resources Management Planning for Grenada and Draft National Water Policy. The lack of adequate financing, government in-continuity and an inadequate institutional framework, however, has made implementation an ongoing challenge. Many core activities of integrated water resource management, especially development of specific policies, laws and regulations, improved water resource assessment and capacity building to implement the above have not yet being undertaken.

These systemic inefficiencies in water quality monitoring, water-use efficiency and overall water resources management place Grenada in the unique position of having met the target 7C of the Millennium Development Goals (World Bank, 2017), but challenged to meet the targets of 6th Sustainable Development Goal: Clean Water and Sanitation, especially the implementation of integrated water resources management (UN, 2015). Though the principles of the met MDG target are partly applied to some SDG 6 targets, there is still a need for major improvements across the board. The implementation, however, of existing policies and legislation including the National Water Policy and all stipulations in the Water Quality Act (2005) would significantly contribute to Grenada's ability to meet those targets.

5. Conclusions and recommendations

Categorised as a country that has a high human development and having met target 7C of the Millennium Development Goals, Grenada is well on its way to ensure its entire population has access to clean water. Over the years, significant improvements have been made in water management resulting in many positive impacts on the wellbeing of consumers. The 35 water supply facilities supply 97% of the population with clean drinking water.

Although significant progress has been made in filtration and disinfection technologies, major improvements in the water sampling and analysis programme is warranted. Currently 89 of the 94 WHO identified chemicals of health significance are not being monitored, representing a significant gap in the data needed in ensure water supplied to the population is indeed safe to use and consume. This lack of monitoring and testing capacity is common in many of the small island developing states within this region of the World, highlighting the importance of regional collaboration and resource pooling for better water resource management across the region.

Focus needs to be placed on the passing, implementation and enforcement of local legislation pertaining to water management. Properly enforced zoning regulations will go a long way in reducing the adverse impacts of contamination of surface and ground water sources. In recent years, notable improvements have been made in the legislative framework resulting in better water resource management. The Water Quality Act of 2005 in particular, has provided the mandate for the formation of a multi-stakeholder Sanitary Authority which is given the charge to oversee the quality of water intended for human consumption. Financial constraints, however, have prevented this board from becoming fully operational. A National Water Policy was drafted in 2007, which provided a comprehensive road map for better water management, however financial constraints again proved to be the limiting factor. As such, these legislative frameworks can provide a solid foundation for the assurance of adequate water management, but the evident lack of implementation renders them ineffectual.

Finally, a more concerted focus on maintenance, rehabilitation and upgrading of current water distribution systems, wastewater disposal systems, including the construction of new wastewater treatment plants is recommended, in order to ensure the continued integrity of the land and water ecosystems of the tri-island state of Grenada, Carriacou and Petite Martinique.

6. References

Allen, C.D., Diller, S.L., Zabarauskas, T., 2014. Grenada: the Spice Isle, in: Allen, C.D. (Ed.), Landscapes and Landforms of the Lesser Antilles. Springer International Publishing AG, Salt Lake City, pp. 243–265. https://doi.org/10.1007/978-94-017-8628-7

AQUASTAT, 2014. Country Overview: Grenada.

Brink, K.H., Robinson, A.R., 2005. The Global Coastal Ocean: Regional Studies and Syntheses. Harvard University Press.

CDB, 2016. Water Supply Expanision and Sewerage Improvement Project - Grenada. Wildey, St. Michael.

Dirisu, A., Olomukoro, J., Thadeus Imoobe, T., 2018. Limnochemical Characterization of Lotic and Lentic Ecosystems in Agbede Wetlands. Turkish J. Fish. Aquat. Sci. 18, 585 595. https://doi.org/10.4194/1303-2712-v18

EC, 2009. ANNEX 3 to the Commission Staff Working Document accompanying the Report from the Commission in accordance with Article 3.7 of the Groundwater Directive 2006/118/EC on the establishment of groundwater threshold values Information on the Groundwater Thresh. Brussels, European Union. https://doi.org/10.1017/CBO9781107415324.004

ECLAC, 2007. Overview of the water profile and the capcity of national institutions to implement integrated water resources management: Antigua and Barbuda, Dominica, Grenada. Port of Spain.

FAO, 1998. Forestry Policies in the Caribbean: Reports of 28 selected countries and territories. Food and Agriculture Organization of the United Nations; European Commission. Directorate-General for Development.

Forde, M., Neff, B., 2015. Impact of development on water supply and treatment in Grenada, in: Vammen, K., de la Cruz Molina, A. (Eds.), Challenges of Urban Waters in the Americans. A Vision From the Academies of Sciences. IANAS The Inter-American Network of Academies of Sciences, Cuernavaca, Mexico, pp. 2–25.

Government of Grenada, 2007a. Draft National Water Policy.

Government of Grenada, 2007b. Road Map Toward Integrated Water Resources Management Planning for Grenada.

Government of Grenada, 2005. Water Quality Act, CAP. 334B. Grenada.

Government of Grenada, 2001a. National Report: Integrating Management of Watersheds and Coastal Areas. St. George's.

Government of Grenada, 2001b. Waste Management Act, CAP 334A. Grenada.

Government of Grenada, 1990. National Water and Sewerage Authority Act, CAP. 208. Grenada.

Government of Grenada, 1984. Forest Soil and Water Conservation Act, CAP. 116. Grenada.

Hsu, H.-W., Bondy, S.C., Kitazawa, M., 2018. Environmental and dietary exposure to copper and its cellular mechanisms linking to Alzheimer disease. Toxicol. Sci. https://doi.org/10.1093/toxsci/kfy025

Iszatt, N., Nieuwenhuijsen, M.J., Bennett, J.E., Toledano, M.B., 2014. Trihalomethanes in public drinking water and stillbirth and low birth weight rates: an intervention study. Environ. Int. 73, 434–439. https://doi.org/10.1016/j.envint.2014.08.006

Kingdom, B., Liemberger, R., Marin, P., 2006. The challenge of reducing non-revenue water (NRW) in developing countries - how the private sector can help : a look at performance-based service contracting, Water Supply and Sanitation Sector Board Disucssion Paper Series. Washington, D.C.

Klotz, K., Weistenhöfer, W., Neff, F., Hartwig, A., van Thriel, C., Drexler, H., 2017. The Health Effects of Aluminum Exposure. Dtsch. Arztebl. Int. 114, 653–659. https://doi.org/10.3238/arztebl.2017.0653

Knowles, A.D., Nguyen, C.K., Edwards, M.A., Stoddart, A., McIlwain, B., Gagnon, G.A., 2015. Role of iron and aluminum coagulant metal residuals and lead release from drinking water pipe materials. J. Environ. Sci. Heal. Part A 50, 414–423. https://doi.org/10.1080/10934529.2015.987550

Lenton, R., Muller, M., 2012. Integrated Water Resources Management in Practice : Better Water Management for Development. Taylor and Francis.

Li, X.-F., Mitch, W.A., 2018. Drinking Water Disinfection Byproducts (DBPs) and Human Health Effects: Multidisciplinary Challenges and Opportunities. Environ. Sci. Technol. acs.est.7b05440. https://doi.org/10.1021/acs.est.7b05440

McSweeney, C., New, M., Lizcano, G., 2006. Grenada. UNDP Clim. Chang. Ctry. Profiles.

Myrttinen, H., Cremades, R., Fröhlich, C., Gioli, G., 2018. Bridging Troubled Waters: Water Security Across the Gender Divide, in: Fröhlich, C. (Ed.), Water Security Across the Gender Divide. Springer International Publishing AG, pp. 3–14. https://doi.org/10.1007/978-3-319-64046-4_1

NAWASA, 2018. Water Treatment Process. Ministry of Communications, Works, Physical Development, Public Utilities, ICT & Community Development, St. George's.

Rahman, M.B., Cowie, C., Driscoll, T., Summerhayes, R.J., Armstrong, B.K., Clements, M.S., 2014. Colon and rectal cancer incidence and water trihalomethane concentrations in New South Wales, Australia. BMC Cancer 14, 445. https://doi.org/10.1186/1471-2407-14-445

UN, 2015. Transforming our world: The 2030 agenda for sustainable development. New York. https://doi.org/10.1007/s13398-014-0173-7.2

UN, 2014. World Economic Situation and Prospects 2014. United Nations Publications, New York.

UNDP, 2016. Human Development Report 2016, United Nations Development Programme. New York. https://doi.org/eISBN: 978-92-1-060036-1

UNDP, 2010. Human Development Report 2010 The Real Wealth of Nations : Pathways to Human Development. United Nations Development Programme, New York. https://doi.org/10.2307/2137795

USEPA, 2010. National Primary Drinking Water Regulations. Washington, D.C.

Vangronsveld, J., Herzig, R., Weyens, N., Boulet, J., Adriaensen, K., Ruttens, A., Thewys, T., Vassilev, A., Meers, E., Nehnevajova, E., van der Lelie, D., Mench, M., 2009. Phytoremediation of contaminated soils and groundwater: Lessons from the field. Environ. Sci. Pollut. Res. 16, 765–794. https://doi.org/10.1007/s11356-009-0213-6

WHO, 2017a. Guidelines for Drinking-Water Quality: fourth edition incorporating the first addendum. Geneva.

WHO, 2017b. Water Quality and Health - Review of Turbidity: Information for regulators and water suppliers. Geneva.

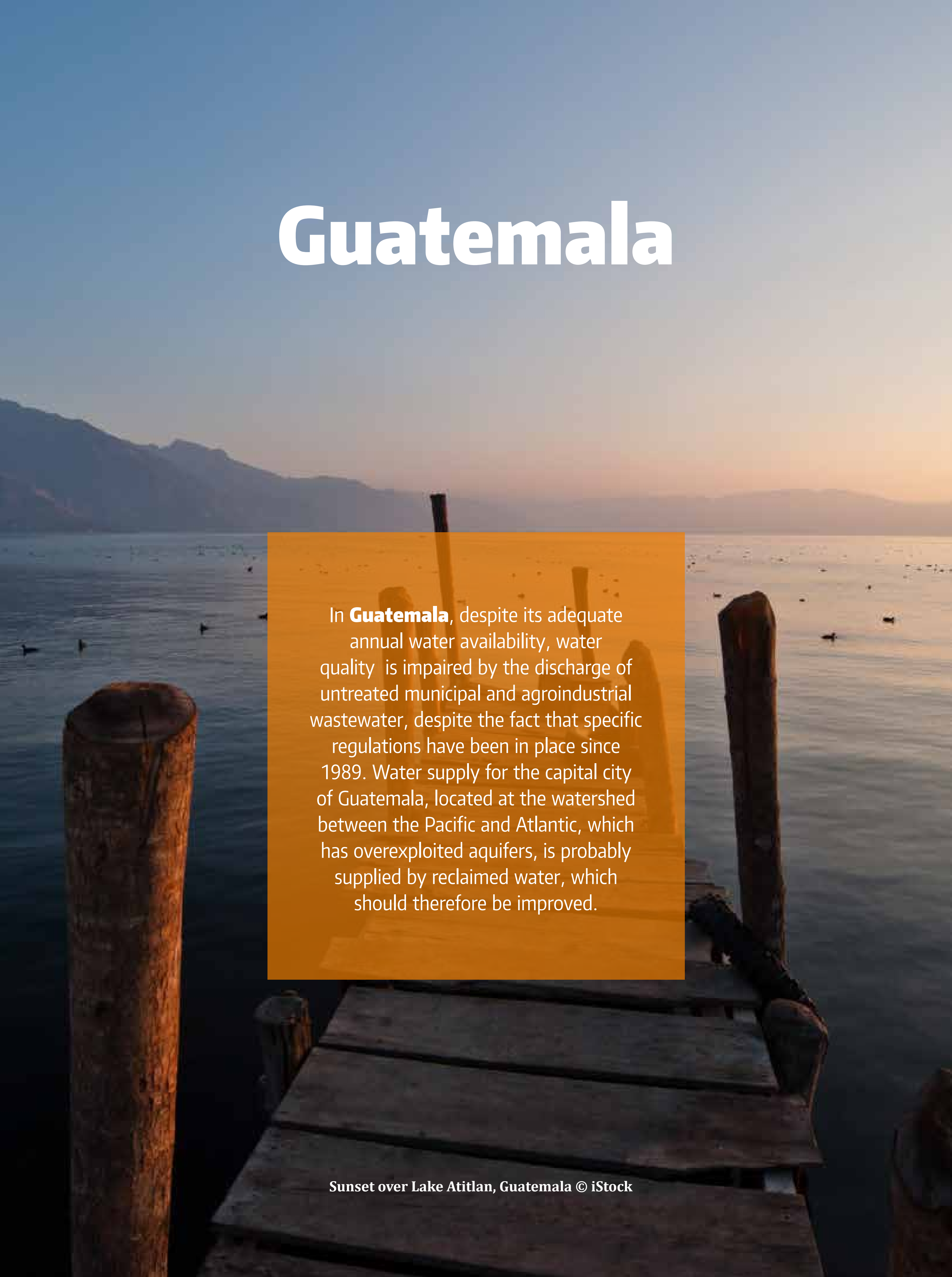
WHO/UNICEF, 2017. Joint Monitoring Programme for Water Supply, Sanitation and Hygiene; Estimates on the use of water, sanitation and hygiene in Grenada. New York.

World Bank, 2017. Improved water source (% of population with access) WHO/UNICEF. Washington, D.C.

Xie, Y.F., 2004. Disinfection byproducts in drinking water : formation, analysis, and control. Lewis Publishers, Boca Raton.

Guatemala

In **Guatemala**, despite its adequate annual water availability, water quality is impaired by the discharge of untreated municipal and agroindustrial wastewater, despite the fact that specific regulations have been in place since 1989. Water supply for the capital city of Guatemala, located at the watershed between the Pacific and Atlantic, which has overexploited aquifers, is probably supplied by reclaimed water, which should therefore be improved.



Sunset over Lake Atitlan, Guatemala © iStock

Water Quality in Guatemala[1]

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Ángela Méndez, Ligia Díaz, Pablo Mayorga and Norma Gil

Abstract

In Guatemala, the deterioration of water quality is already a major problem despite the fact that specific regulations have been in place since 1989, which require compliance with standards to ensure the quality of the effluent discharged into water bodies. There is a lack of political will and institutional strength to exercise compliance with the regulations, and solving them now will require major financial investment. The effects on public health, the aquatic ecosystems and the economic activities of the country are evident.

Introduction

Guatemala is located in the far north of the Central American isthmus limited by Mexico, Belize, Honduras and El Salvador (**Figure 1**). It has an area of 108,889 km^2 and an average annual water availability of 97,200 million m^3 (MARN, 2015). The country has extremely rugged topography with elevations from sea level to 4,200 meters, producing six climate regions, three slopes (Pacific, Caribbean Sea and Gulf of Mexico), 38 basins, 138 bodies of water and 34 volcanoes (see **Figure 1**).

On June 30, 2014, the population ascended to 15.6 million, of which 50% were under 25 (INE, 2016). Guatemala has a multi-cultural, multi-ethnic society (comprising four groups: Maya, Xinca, Garifuna and Ladinos), and multilingual society (composed of 23 linguistic communities). In 2014, 38.8% of the population self-identified as indigenous, four of the communities represent an 80% of the total and 23.7% are monolingual in Mayan language (INE, 2016).

Although Guatemala is the largest economy in Central America, it is one of the Latin American countries with the greatest social inequality, with high poverty levels, particularly in rural areas and among indigenous populations. According to ENCOVI 2014, the percent-

1. The water quality report in Guatemala was presented to members of AGUALIMNO and guests on November 6, 2017, in the auditorium of the Guatemalan Association of Sanitary and Environmental Engineering (AGISA).

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age of total poverty in Guatemala was 59.3%, with 23.4% living in extreme poverty (INE 2016).

1.1 Context

The country has had a Law for the Protection and Improvement of the Environment since 1986 (Law 68-86) and Regulations for the Discharge and Reuse of Wastewater and Sludge Disposal (Government Agreement 236-2006) to prevent the deterioration of water quality due to discharges of municipal, urban and agroindustrial wastewater. The 2006 Agreement repealed two previous regulations issued in 1989 and 2005. In other words, the country has had regulations in place to prevent, control and protect water quality for nearly thirty years .

However, according to Siguí (2016), the 2006 regulations have several shortcomings. They are ineffectively implemented and in many aspects, they failed to improve what had been stipulated in the 1989 and, above all, 2005 regulations. The current regulation requires lower water quality of the final effluent from the entity producing it, fails to distinguish between the receiving water bodies and the types of industry, doesn't include the measuring of the chemical oxygen demand or parasites. Term of compliance is longer (the previous one granted six years in two stages, whereas now there are four stages of 5 years each, the last one being to 2024, and there have also been two extensions of two years each to the municipalities for compliance). The cat-

Figure 1. Morphometry of the country, neighboring countries, slopes and main bodies of water (lakes and lagoons) and volcanoes (eruptive foci)

egories for the re-use of wastewater were reduced, the periodicity for the Ministry of Environment and Natural Resources (MARN) to control wastewater discharges is not defined and the Ministry of Public Health and Social Assistance (MSPAS) is exempted from undertaking these controls, among other shortcomings.

Within this context, the chapter on Water Quality in Guatemala shows that despite having the regulations and public entities to enforce them, its application has been ineffective, as evidenced by the degree of contamination of the majority of the country's water bodies.

This chapter was written using the results of scientific research, which quantify and describe the status of the country's water bodies and the efforts being made to improve its management.

1.2 Main causes of water quality problems

According to Castellanos (2013), the country's environmental problems have reached a critical level, although this is not evident for the majority of the population. Consequently, the deterioration of the environment and the services it provides will continue to increase until this way of thinking changes.

One of the main causes of the deterioration of water quality is the lack of governance reflected in the indifference of citizens and the lack of compliance with the related laws, as indicated in the previous paragraph; the population must be informed about the importance of water quality for human health and ecosystems (Siguí, 2016).

The lack of compliance with regulations and standards by the institutions that must ensure water quality by law is due to the weak institutional framework. For example, MSPAS lacks the capacity to comply with the Health Code provisions in relation to water quality for human consumption, while MARN is unable to comply with Law 68-86 and Government Agreement 136-2006 regarding wastewater treatment and monitoring the quality of surface water bodies, because it lacks the resources to do so and ensure that the generators provide adequate treatment.

Another cause of the current status of water quality in the country is the lack of treatment of municipal and urban wastewater and the insufficient treatment of those that are treated, compounded by the fact that the operation and maintenance of treatment systems is not always adequate. The same happens with the wastewater from agro-industry, which is discharged untreated or with insufficient treatment.

Waste from agrochemicals used in agriculture is a non-point source of deterioration in water quality. However, there are no regulations to control non-point sources of contamination of the country's water bodies.

1.3 Objectives of the chapter

The objective of the chapter is to inform decision makers and public officials, the private sector, academics and civil society of the causes of the deterioration of water quality in the country, so that once we are aware of the situation, we can all contribute to its solution. Poor quality water affects the health of the population, especially that of children, aquatic ecosystems and their biological diversity, as well as affecting economic activities due to the previous treatment that must be undertaken so that it can be used.

2. Institutional authority and water quality governance

2.1 Legal framework

Ordinary regulations exist for environmental issues, such as the Law for the Protection and Improvement of the Environment (Decree 68-86), the Law on Protected Areas (Decree 4-89), the Forestry Law (Decree 101-96) and the Framework Law to Regulate the Reduction of Vulnerability, Compulsory Adaptation to the Effects of Climate Change and the Mitigation of Greenhouse Gases (Decree 7-2013). Environmental issues are the responsibility of the MARN, which must coordinate with the municipalities and private sector in the country (Article 20 of the Law on the Protection and Improvement of the Environment) to ensure the sustainability of national development.

The Government Agreement on the Regulation of the Discharge and Reuse of Wastewater and Sludge Disposal (236-2006), published in 2006, establishes the criteria and requirements to be met for the discharge and reuse of wastewater as well as for sludge disposal. This is designed to ensure

Table 1 Water supply systems with adequate levels of residual chlorine

Province	Water supply systems with adequate levels of residual chlorine	Total water supply systems monitored	% Water supply systems with adequate levels of residual chlorine	Total water systems registered	% Water systems monitored
Alta Verapaz	5	55	9	682	8
Baja Verapaz	14	45	31	393	11
Chimaltenango	72	167	43	661	25
Chiquimula	5	38	13	554	7
El Petén	15	114	13	210	54
El Progreso	17	43	40	169	25
Escuintla	30	191	16	226	85
Guatemala	235	371	63	898	41
Huehuetenango	16	214	7	1491	14
Izabal	6	67	9	316	21
Jalapa	3	46	7	236	19
Jutiapa	24	296	8	374	79
Quetzaltenango	6	41	15	515	8
Quiché	91	345	26	1292	27
Retalhuleu	9	59	15	154	38
Sacatepéquez	89	153	58	156	98
San Marcos	34	90	38	651	14
Santa Rosa	22	66	33	217	30
Sololá	1	6	17	608	1
Suchitepéquez	12	69	17	282	24
Totonicapan	25	46	54	131	35
Zacapa	2	10	20	213	5
General Total	**733**	**2532**	**29**	**10429**	**24**

Source: MSPAS, 2017.

that through the improvement of the characteristics of these waters, it will be possible to establish a continuous process that will: a) protect receiving waters from the impacts resulting from human activity; b) restore receiving waters undergoing eutrophication; and c) promote the development of water resources with an integrated management vision. This regulation is also designed to establish the mechanisms for evaluation, control and monitoring so that the MARN can promote water conservation and improvement. The Regulation establishes that MARN is responsible for its implementation. As mentioned earlier, the Regulation has several shortcomings and the issuance of a new one based on scientific research has been proposed (Siguí, 2016).

The COGUANOR NGO 29001:99 standard contains the values of the maximum acceptable limits and maximum permissible limits for chemical compounds, sensory characteristics, biocides and bacteriological limits, as well as the required concentrations of chlorinated water and bacteriological analysis methods, linked to the water quality standards that must be met for human consumption.

Article 38 of the Health Code stipulates that one of the preventive actions to maintain health is to guarantee potable water for the population, and adequate excreta disposal. Likewise, Section II of this article refers to the ways of guaranteeing access and universal coverage to drinking water, establishing the relationship between the MSPAS and the Municipal Development Institute (INFOM) and other organizations to promote a “priority policy of public necessity that guarantees access and universal coverage of the population to drinking water services with an emphasis on actions by communities themselves to ensure sustainable water management”. The same code states the obligation of municipalities to supply drinking water to communities located in their territorial jurisdiction, which is also contained in the Municipal Code.

2.2 Relations with academia and NGOs

Determining the quality of the water for supplying populations is the responsibility of municipalities, the MSPAS, water committees at the rural level and neighborhood associations which provide the service, since they are supplied by their own mechanical wells. Determining the water quality of the receiving bodies is the responsibility of public entities such as the authorities in charge of the four main lakes basins in the country (Atitlán, Amatitlán, Petén Itzá and Izabal), institutions such as the Private Institute for Research on Change Climate (ICC) and Non-Governmental Organizations (NGOs) that co-manage protected areas – the Defenders of Nature Foundation (FDN), in the Sierra de Las Minas, Bocas del Polochic and Sierra de Lacandón; FUNDAECO in Cerro San Gil, Punta de Manabique- and private nature reserves.

Universities, both public (San Carlos) and private (Rafael Landívar and Del Valle) also determine water quality in theses and research projects on various water bodies in the country. In March 2017, the Guatemalan Association of Limnology and Lake Management (AGUALIMNO), created in 2015, in coordination with the authorities of the lakes, universities and the private sector - simultaneously sampled six different water bodies in the country (Atitlán, Amatitlán, Petén Itzá, Chichoj, Petexbatún and El Pino).

2.3 Monitoring and database

Water quality is monitored by several entities, both public and private, either to determine whether it is suitable for human consumption or to identify its natural conditions.

In relation to the monitoring of water quality for human supply purposes, at the national level, MSPAS - sometimes in coordination with certain municipalities and INFOM - monitors urban water sources, as well as certain points of the distribution network for domestic consumption. Monitoring rural water sources and their distribution network is almost exclusively the responsibility of the MSPAS, which has a database.

Table 1 shows the percentage of water supply systems with adequate levels of residual chlorine in the 22 departments of the country in 2016. As can be seen, only 29% of the water supply systems monitored in the 22 departments have adequate levels of residual chlorine, which is extremely low. Even in the Department of Guatemala the percentage is 63%.

Monitoring the quality of natural waters, affected by human and economic activities, is the responsibility of the authorities for the main lake basins in the country (AMSA, AMSCLAE, AMASURLI and AMPI), academia and NGOs. These entities have databases.

Monitoring the quality of municipal and agroindustrial wastewater, point sources, must be undertaken by the pollution generating entity through the technical studies required by Regulation 236-2006. The MARN is in charge of receiving the technical studies and having the database. The MARN takes approximately 300 samples of the discharges from pollution-generating entities a year.

3. Main problems impacting water quality in the country

3.1 Eutrophication

Lake Amatitlán receives mostly untreated wastewater from the southern sector of Guatemala City and other municipalities in the metropolitan region (381 km^2). Mosquera (2015) analyzed the water quality of the lake and the tendency between 2008 and 2013 in order to evaluate the effect of the measures of the Environmental Program (PRACLA), financed by the Inter-American Bank (IDB) during that period. Due to the previous degree of contamination of the lake, the trophic state was maintained between 2008 and 2013, meaning that it is eutrophic according to Vollenwieder (1968). According to recent data, it is hypereutrophic (M. Dix, personal communication).

Lake Atitlan has deteriorated due to the increase in nutrient concentrations, which encourage the growth of algae and therefore reduce the clarity of the water. At present, most of the wastewater generated by the 300,000 people in the basin is discharged into the lake (407 liters/second). The phosphorus and nitrogen present in wastewater are accelerating the eutrophication of the lake. Pathogens from wastewater also increase the degradation of the water quality (Chandra *et al.*, 2013).

Eutrophication processes have also been observed in the waters of some of the other lakes (Izabal, Petén Itzá) and lagoons (Chichoj, El Pino, among others).

3.2 Natural contaminants

There are 33 volcanoes in the country, some of which are active. Volcanic activity and geology are sources of arsenic and other heavy metals. Pérez-Sabino *et. al.* (2015) carried out four samplings at 14 sites in 2014, in the main tributary rivers and in Lake Atitlán, as well as at the entrance to and exit from the wastewater treatment plant, in Panajachel, the municipal capital located within the basin of this lake, to determine arsenic and mercury concentrations. The concentrations of the former in all the samples were over 20 ug/l, higher than the maximum level allowed for drinking water (10 ug/l), according to the water quality standard for human supply in the country, COGUANOR (NGO 29001), meaning that water from Lake Atitlán and its tributaries is unsuitable for human consumption, although it is used by several communities. The presence of arsenic is due to the geology of the basin, located in a volcanic zone.

3.3 Cyanobacteria

López *et al.* (2015) took 120 samples from Lake Amatitlán in the photic and aphotic zone and the hypolimnion, during the dry and rainy seasons in 2013 and 2014, identifying 36 phytoplankton taxa (ten of cyanobacteria), *Microcystis* spp., and *Dolichospermum* spp. being the taxa with the highest densities (61,000-208,000 cel/ml and 24,000-31,000 cel/ml, respectively). The study concludes that there is a clear dominance of cyanobacteria in the photic zone, which decreases in the aphotic zone and hypolimnion. Moreover, large amounts of cyanobacterial biomass do not greatly influence phytoplankton diversity.

In Guatemala, since 2016, the Atitlán Study Center laboratory has had the capacity to determine the concentration of cyanotoxins (microcystin LR, YR and nodularin combined, saxitoxin, cylindrospermopsin and anatoxin-a through ELISA tests) in water samples. Cyanotoxin concentrations are routinely analyzed when there are confirmed blooms in lakes Amatitlán and Atitlán. To date, microcystins have been found in concentrations of over 1 µg/L, generally at specific sites in Amatitlán, together with low levels of anatoxin-a in *Dolichospermum* blooms. In Atitlán, there have been no recordings to date of levels above those recommended by the WHO (1 µg/L for microcystins and 3 µg/L for anatoxin-a).

Toxicity bioassays were conducted with *Thamnocephalus platyurus* (Mayorga, 2014) on the cyanobacteria bloom in Lake Atitlán in 2009, using the methodology of Törökné (1999). The mean lethal concentration (LC50) of the biomass from the center of the lake in 2009 was 0.077 mg/L, which is extremely toxic, according to the Törökné classification. Biomass collected on another occasion showed no known cyanotoxin content, so it is believed that what happened in 2009 may have contained cyanotoxins that have not yet been described or extremely toxic (potentially medicinal) bioactive substances. In 2013, the LC50 of biomass from the same place was 2.13 mg/L (toxic sample according to the Törökné criterion). Extracts of *Microcystis* from another lake in Guatemala (Mayorga, unpublished data) caused an LC50 of 0.26 mg/L.

3.4 Agrochemicals

Coc and Vanegas (2015) evaluated the effect of various land uses on erosion and sedimentation, and concluded that the crops caused erosion rates that were twice (between 16.65 and 28.53 t/ha) those reported for secondary forests (between 10.14 and 12.72 t/ha). Accordingly, residue from the agrochemicals used in rubber cultivation and annual agriculture would be transported in the run-off processes, in addition to reducing soil fertility.

3.5 Heavy metals

Mercury is a toxic, persistent and bioaccumulative pollutant (UNEP, 2013, cited by Pérez-Sabino et al., 2015), which is biomagnified in the trophic network, and one of the heavy metals with the greatest toxic potential. Methylmercury is a potent neurotoxin with the ability to penetrate the membranes of living beings and represents a risk to reproductive and neurological health (Scheuhammer, Meyer, Sandheinrich & Murray, 2007, cited by Pérez-Sabino et al. 2015). The main route of human exposure to methylmercury is through the consumption of contaminated fish, which can cause health problems such as reduced field of vision, mobility problems, mental deterioration, paralysis and death (Bisinoti & Jardim, 2004). Pérez-Sabino *et. al.* (2015) reported the presence of mercury in almost all the sampling sites of Lake Atitlán, in concentrations of up to 3.81 µg/L, the maximum limit allowed for drinking water being 1 µg/L, according to the COGUANOR standard (NGO 29001).

3.6 Deforestation

Castellanos (2013) indicates that in the past 25 years, the country lost 20% of its forest, despite the implementation of the incentive program. To date, $202 million USD have been invested, reforesting approximately 150,000 ha (INAB 2016).

In addition to the loss of tree coverage, the change in land use, without soil and water conservation measures, produces erosion and sedimentation. In Guatemala, 46% of land is used correctly, 25% is overused and the remaining 29% is underused: The potential erosion rate in over-used areas is eight times greater than in underused areas (IARNA, 2009, cited by Coc and Vanegas, 2015). FAO (cited by Coc and Vanegas, 2015) defines light soil erosion as less than 10 t/ha/year, moderate soil erosion as between 10 and 50, high soil erosion as between 50 and 200 and very high soil erosion as above 200 t/ha/year.

3.7 Salinization

The lower parts of certain basins of the Pacific slope (Figure 1) have salinity levels above 0.5 mg/l, a value which the Guatemalan standard for drinking water (COGUANOR NGO 29 001), establishes as brackish and is indicative of saline intrusion. Saline intrusion occurs as a result excessive pumping (overexploitation of aquifers) and prolonged droughts in the alluvial fan of the Coyolate, Acomé and Achiguate rivers (ICC, 2017).

3.8 Wastewater

The contamination of water bodies, caused by the discharge of untreated urban and agroindustrial municipal wastewater, is a serious problem for the large part of the population supplied by unimproved water sources (Lentini, 2010). Mosquera noted that according to MSPAS figures, 90% of national waters are contaminated with feces (Prensa Libre, 2017:18).

Siguí (2016) indicated that conventional wastewater treatment, including disinfection, fails to eliminate parasites. Disinfection of treated effluent when combined with organic matter forms trihalomethanes, which are considered carcinogenic, while residual chlorine is harmful to aquatic life.

As indicated above, arsenic and mercury concentrations in the surface water of Lake Atitlán and its tributaries were higher than the limits recommended by the country's drinking water standard. Plans are underway to transfer the wastewater generated in the Lake Atitlán basin to reduce the nutrient load. However, according to Pérez-Sabino *et al.* (2015) since in addition to transferring nutrients, this process would also transfer arsenic and mercury, contaminating the soil and crops in the area which would receive this water, the viability of the project should be considered in the analysis. A similar case would occur with the re-use of the surface waters of Lake Amatitlán, without adequate treatment, to supply the city of Guatemala and its area of influence, the Metropolitan Region of Guatemala (RMG), since the waters of the lake have also reported concentrations of metals above the drinking water standard.

3.9 Leaching to groundwater and surface water bodies

Leachates from controlled landfills of municipal solid waste and residues are a source of ground and surface water contamination. Municipal wastewater and solid waste from the largest cities in the country - such as the Metropolitan Region of Guatemala (RMG) - are deposited in Zone 3 of Guatemala City, which has no leachate collection or treatment. In the remaining municipal capitals (of which there are a total of 333), wastewater and solid waste are also discharged with no control of leachates.

Some of the country’s industries and agroindustries have leachate collection and treatment systems, such as, for example, the ashes from coal combustion in the thermoelectric sector.

Table 2. Temperature change and annual average precipitation for Guatemala under a scenario of high greenhouse gas emissions

Variable	2020	2030	2050	2070	2100
Temperature °C	0.8	1.0	2.0	2.9	4.7
Rain %	-1.5	-1.3	-12.7	-14.2	-26.8

Source: Castellanos (2013), with data from ECLAC, 2010.

3.10 Eco-toxicological studies of surface, marine and underground water

Mayorga (2009) conducted eco-toxicity and eutrophizing potential tests on the fresh and marine waters in the country, reporting toxicity at a few points -usually mild and not constant- and that the potential for eutrophication, reflected in the excessive growth of the bioassay with unicellular green algae, was the main threat to the water bodies evaluated, because of the excess of inorganic nutrients.

Mayorga (2016) conducted toxicity tests in groundwater in the valley of Guatemala City, reporting that 8 of the 10 wells presented toxicity to one or more of the test organisms used. The well with the most toxic water complies with the COGUANOR 29001 drinking water standard. It is obviously necessary to increase potable water supply coverage in the country and investments should be made to achieve this, but it must also be of adequate quality. The parameters established by the COGUANOR standard are adequate, but not sufficient due to emerging contaminants (drugs, endocrine disruptors and nanoparticles) and others, as a result of which they do not ensure that the water is of good quality. As indicated, most of the groundwater samples taken from mechanical wells that supply water complied with the COGUANOR potability standard, but were toxic to various aquatic organisms. This indicates that there are toxic substances present in groundwater that are not detected by the conventional physicochemical and microbiological analyses required (AGISA, 2016).

3.11 Emerging pollution

Emerging contaminants are classified as products used for various everyday activities, which have been found in bodies of water without losing their activity, so it is thought that they can directly or indirectly affect aquatic biota and humans (Hernández, 2013). In a sampling of the Las Vacas and Villalobos rivers, sub-basins of the Caribbean and Pacific waters of the country respectively, Hernández reported acetaminophen, caffeine, dexketoprofen, phenylephrine and ibuprofen. The only analyte with values below the limit of detection was sodium diclofenac. Of the five analytes found, phenylphrine had the highest amount in both rivers in comparison with caffeine, which had the lowest averages in both rivers.

3.12 Microbial diseases

The prevalence of *Helicobacter pylori* infection is associated with poor sanitary conditions, lack of water chlorination, unhygienic food preparation and overcrowding. Consumption of unpurified water among other risk factors is significantly associated (p <.001) with the existence of anti-*H Pylori* IgG. antibodies. Other contributing factors are not being healthy (p = .041), the presence of current diarrhea (p = .003) and the type of health service available (p = .003). In 2010, a frequency of infection of 51% for children aged 5 to 10 was reported, showing that the infection is present in the child population from an early age and, that if children do not receive treatment, it will persist throughout their lives (WGO, 2010, cited by Matta *et al.*, 2017).

3.13 Climate Change

During the period from 1950 to 2014, 16 neutral years have been registered, together with 25 with La Niña events and 24 with El Niño events (MARN, 2015). These phenomena impact on the variation of precipitation, heat and temperature and therefore surface and groundwater quantity and quality.

Temperature and rain projections due to climate change indicate that the country will gradually become drier and warmer, as shown in tables 2 and 3, meaning that the country's inhabitants will have to adapt to living with less water availability (Imbach *et al.,* 2012, cited by Castellanos, 2013). **Ta-**

ble 2 shows that the reduction of rainfall will increase from 2050 onwards, with decreases of more than 10% of the current average annual precipitation and that demand will rise, since the population will increase to 28 million (Castellanos, 2013).

Table 3 shows that water demand is growing at a rate of nearly 10% per year, which reduces the surplus of available water by 28%, without taking into account any decrease in its availability. The volume of contaminated water will increase at a rate of 3.5% per year and will continue to pollute receiving waters (Castellanos, 2013).

4. Social and economic aspects

4.1 Health

Lack of access to safe water and minimum sanitation conditions are factors that negatively affect people's health (IARNA-URL, 2012).

The second cause of infant mortality in the country are diarrheal diseases (8.3% in 2012, according to MSPAS, cited by Castellanos, 2013); 20.2% of children under six years of age suffered from diarrhea (INE, 2016). In 2016, the MSPAS report showed that 402,965 people nationwide were affected by gastrointestinal problems, particularly diarrheal diseases.

The health system is segmented and fragmented, resulting in social exclusion and inefficiency, respectively. Public expenditure on health in the period from 2001 to 2007 was 1.2% of GDP, the lowest in Central America (MARN, 2015).

4.2 Poverty

The lack of drinking water and sanitation services mainly impacts the poorest sectors in the country. Having inadequate water and sanitation services adversely affects health and well-being: the time invested in water collection, transportation and provision in poor households and the increase in days of absence from work due to diseases associated with unsafe water consumption, affects the possibility of securing family income.

In 2006, 67.2% of children under six living in poverty suffered from diarrhea. In 2008, 49.8% of children under five suffered from chronic malnutrition. Diarrhea is the cause of 18.4% of the mortality of children under the age of five (MARN, 2015), and remains one of the 10 leading causes of morbidity and mortality nationwide (MSPAS, 2016).

4.3 Education level

In Guatemala, which has medium human development and historical backwardness, the average schooling of its general adult population in 2014 was 5.6 years: 6.0 years in men and 5.3 in women, and 4.0 years in the indigenous population. In 2014, total literacy was 79.1%: 74.0% in women and 84.8% in men, and 57.6% in indigenous women (INE, 2016). Public spending on education in 2013 was approximately 2.8% of GDP (MARN, 2015).

4.4 Gender

According to Foster and Araujo (2004, cited by Ducci, 2007), 74% of activities involving water fetching, treatment, cleaning and household cleaning in Guatemala are undertaken by women and girls. It is estimated that the average time spent on these activities is 5 to 6 hours per day (RASGUA, 2007, cited by Ducci), which prevents women from engaging in other activities, such as the possibility of entering the formal labor market.

The lack of adequate health services in schools leads to school dropout, rates of which are higher in

Table 3. Water balance for Guatemala in 2005 and 2025 for the driest month. All data are given in millions of cubic meters

Item	2005	2025 trend	% change 2005-2025
Availability	2,645	2,645	0
Demand	336	988	+194
Balance	2,309	1,656	-28
Contaminated water	183	312	+70

Source: Castellanos (2013), with data from the SEGEPLAN report, 2007.

the case of girls (MARN, 2015). At the same time, the presence of drinking water and sanitation services allows for greater privacy and security, which has a particular impact on women's well-being, since it reduces the likelihood of violence and sexual harassment (Bosch *et al.*, 1999).

4.5 Rural and urban areas

In 2014, 89.8% of the population living in the urban area had access to improved sources of drinking water supply compared to 64.2% of the population in rural settings. In 2014, 73.4% of the population living in the urban area had access to improved sources of drinking water supply compared to 11.6% of the population in the rural area. In 2014, 53.6% of the population living in the urban environment had water meters compared to 8.9% of the population in the rural area (INE 2016).

Seventy-four per cent of households undertake some form of treatment for the water they consume or purchase purified water (Foster and Araujo, 2004). Whereas in urban areas, over 20% of households buy purified water and nearly 15% boil it, in rural areas over 20% boil it and only 5% purchase purified water(Lentini, 2010).

4.6 Investment in water quality programs

The Department of Regulation of the Health and Environment Programs (DGRVCS) of the MSPAS has a water quality monitoring system for supply systems (SIGSA-SIVIAGUA), which in 2016 took control of 24% (2,532) of the total registered water systems (10,429).

AG 236-2006 requires that wastewater generators conduct analyses of the water quality of the treated effluents, prior to their discharge into the municipal collector or receiving waters, twice a year, as well as the respective technical study. In order to monitor the water quality of wastewater discharges, the Directorate of Watersheds and Strategic Programs of MARN monitors some of these to demonstrate compliance with AG 236-2006; The average number of samples per year is 300.

4.7 Economic activities

Agricultural activity account for 13.1% of GDP; mines and quarries for 0.7%; and electricity supply and water collection for 2.6%. Agriculture, livestock, forestry and fishing, as well as mines and quarries have shown dynamic behavior (MARN, 2015). There are several industries which, because of their location, do not have easy access to the water supply service, as a result of which they rely on ground and surface water. Excessive exploitation of groundwater leads to the deterioration of water quality and results in an increase in total dissolved solids (Van de Wauw, Evens & Machiels, 2010).

5. Coping with Sustainable Development Goal 6

On September 25, 2015, Guatemala, like 194 other countries, adopted the Sustainable Development Goals (SDG) with the Transform Our World Declaration: the 2030 agenda for sustainable development. SDGs assume the task of finalizing the issues that have yet to be fulfilled within the framework of the Millennium Development Goals (MDGs) and incorporate new issues to advance sustainable development (SEGEPLAN, 2017).

Paragraph 55 of the Declaration indicates that each country will set its own national targets. In January 2016, a new president began his four-year term in Guatemala. In this regard, CONADUR stipulated that the SDG agenda would be subject to analysis and adaptation to circumstances, within the framework of the country's development priorities. Accordingly, in 2016 a strategy was designed to link SDGs to the K'atun Nuestra Guatemala National Development Plan 2032 (PND) formulated in 2012, which made it possible to prioritize national goals in the first four years of the current government. **Table 4** highlights the progress of the indicators for the Goal 6 targets.

a. Universal, equitable access to safe, affordable drinking water for all. Table 5 shows access to water by the population in 2015.

b. Equitable access to adequate sanitation and hygiene services for all and put an end to open defecation, paying special attention to the needs of women, girls and people in vulnerable situations. Table 6 shows access to sanitation services in 2015.

c. Improve water quality by reducing pollution, eliminating dumping and minimizing the discharge of hazardous materials and chemicals, halving the percentage of untreated wastewater, and substantially increasing safe recycling and reuse.

As indicated above, although the country has a regulation that provides for the reduction of pollution, municipal wastewater is not treated in most municipalities. Agribusiness uses treated wastewater for fertigation.

d. Substantially increase the efficient use of water resources in all sectors and ensure the sustainability of the extraction and supply of fresh water to address water shortages and substantially reduce the number of people suffering from water shortages.

The Political Constitution of the country, enacted in 1985, orders law on water resources to be issued. Since that date there have been several bills, but a law has yet to be passed.

Table 4. Guatemalan Indicators for each of the SDG goals 6

Goals	Indicators
Goal 6.1 Achieve universal, equitable access to safe, affordable drinking water for all by 2030	**6.1.1** Proportion of the population with properly managed safe drinking water supply services. (Coverage shown in Table 5)
Target 6.2 By 2030, achieve equitable access to adequate sanitation and hygiene services for all and put an end to open defecation, paying special attention to the needs of women and girls and people in vulnerable situations.	**6.2.1** Proportion of the population that uses safely managed sanitation services, including a hand washing facility with soap and water. (Coverage shown in Table 6)
Goal 6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing the discharge of hazardous materials and chemicals, halving the percentage of untreated wastewater, and increasing recycling and safe reuse by [x]% worldwide	**6.3.1** Proportion of safely treated wastewater. (5%) **6.3.2** Proportion of good quality water bodies (Undetermined)
Target 6.4 By 2030, substantially increase the efficient use of water resources in all sectors and ensure the sustainability of the extraction and supply of fresh water to address water shortages and substantially reduce the number of people suffering from water shortages.	**6.4.1** Change in the efficiency of water use over time. (The irrigation system changed from flooding to spraying) **6.4.2** Stress level due to water scarcity: extraction of fresh water as a proportion of available freshwater resources. (In several of the Pacific basins, in the dry season, the stress level is high; basin committees)
Target 6.5 Implement the integrated management of water resources at all levels, including through cross-border cooperation, as appropriate by 2030.	**6.5.1** Degree of application of integrated water resource management (0-100). (Estimated 10%) **6.5.2** Proportion of the area of transboundary basins with an operating arrangement for cooperation in the field of water. (There are no arrangements)
Goal 6.a By 2030, expand international cooperation and the support provided to developing countries for capacity-building in activities and programs related to water and sewerage, including water collection and storage, desalination, efficient use of water resources, wastewater treatment and recycling and reuse technologies.	**6.a.1** Volume of official development assistance for water and sewerage that is part of a government coordinated spending plan. (In 2005, the operation of a first loan with the IDB began, which took years to spend. In 2013, Congress approved the spending of a second loan, of which almost nothing has been spent. There is another loan with the WB under review, before it is submitted to Congress)
Goal 6.b Support and strengthen the participation of local communities in improving water management and sanitation	**6.b.1** Proportion of local administrative units with established operating policies and procedures for the participation of local communities in water management and sewerage. (Several in the country)

Source: SEGEPLAN, 2017.

Table 5. Coverage by source, time and water treatment in homes

Characteristics	Households			Population		
	Urban	Rural	Total	Urban	Rural	Total
Drinking water source						
Improved source	46.8	66.1	57.3	49.7	67.9	60.2
Indoor piping	23.0	17.5	20.0	23.6	17.6	20.2
By pipe in lot/land	21.8	38.8	31.1	23.9	40.3	33.3
Cistern / public tap	0.4	1.9	1.2	0.5	2.0	1.4
Another source with pipe	1.4	4.5	3.1	1.5	4.5	3.2
Protected spring	0.1	1.4	0.8	0.1	1.4	0.8
Rainwater	0.1	2.1	1.2	0.1	2.2	1.3
Non-Improved source	53.1	33.6	42.5	50.2	31.8	39.6
Public cistern / Public Tank	0.2	1.0	0.7	0.2	1.1	0.7
Mechanical or manual well (curb)	3.9	15.1	10.0	4.6	14.8	10.5
Protected spring	0.2	3.3	1.9	0.3	3.4	2.1
Tank truck / cart with drum	0.1	0.2	0.1	0.1	0.2	0.1
River / ditch	0.0	2.0	1.1	0.0	2.2	1.3
Lake or stream	0.0	0.7	0.4	0.0	0.8	0.4
Bottled water	48.7	11.3	28.4	45.0	9.3	24.5
Other source	0.1	0.3	0.2	0.1	0.3	0.1
Total	100.00	100.0	100.0	100.0	100.0	100.0
Time required to fetch water (round trip)						
Indoor water supply	97.1	83.1	89.5	96.8	82.5	88.6
Less than 30 minutes	2.5	13.0	8.2	2.8	13.3	8.8
30 minutes or more	0.4	3.9	2.3	0.4	4.1	2.5
Do not know / no information	0.0	0.1	0.0	0.0	0.1	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Water treatment before drinking a/						
Boiled	26.2	53.0	40.8	28.9	55.9	44.4
Bleaching agent or chlorine added	10.1	15.6	13.1	10.9	15.6	13.6
Filtered with cloth	0.4	0.8	0.6	0.4	0.9	0.7
Ceramic sand or other type of filter	4.8	3.7	4.2	4.7	3.6	4.1
Purified with sunlight	0.1	0.6	0.4	0.1	0.7	0.5
Other treatment	0.3	0.5	0.4	0.2	0.4	0.4
Untreated	13.4	21.5	17.8	14.1	20.8	18.0
% with appropriate treatment method /b	37.3	66.4	53.1	40.4	69.1	56.9
Number	**9,751**	**11,632**	**21,383**	**43,668**	**59,025**	**102,693**

a/ Since respondents were allowed to report more than one water treatment method, the sum of the different types of treatment may exceed 100 percent.
b/ The appropriate method for water treatment includes boiling, using chlorine, filtering or purifying with sunlight.
Source: ENCOVI, 2017

The Foundation for the Conservation of Water of the Metropolitan Region (FUNCAGUA) was recently created in the country to improve the potential recharge of aquifers in the Metropolitan Region of Guatemala (RMG); reduce runoff and, therefore, constant erosion and the risk of landslides due to extreme hydrometeorological events; generate greater awareness and education among the various water users on the problems associated with integrated water resource management and possible solutions; improve the capacity to manage financial resources in favor of water, soil and forest conservation; and monitor the environment in tandem with integral water management in the RMG.

FUNCAGUA regards the RMG as a territory comprising at least 12 municipalities (and an estimated population of around 4 million inhabitants) in 20 micro-watersheds, which contribute at least 701 million m^3/year of surface water and 140 million m^3/year of groundwater, coupled with the contribution of four micro-basins of the Xayá and Pixcayá rivers which, despite being located outside the RMG, represent an important source of surface water, with a contribution of 88 million m^3/year. These contributions are complemented by an indeterminate number of mechanical wells that exploit local aquifers. Public information from the Municipal Water Company of the Municipality of Guatemala (EMPAGUA) shows that all of its wells have decreased in level –from a depth of between 450 and 750 feet in the 1970s to 1200-1500 feet near the decade of 2010, with a decrease in productivity in the amount of liters per second (FUNCAGUA, 2016) -.

e. Implement the integrated management of water resources at all levels, including through cross-border cooperation. UNEP supports countries in monitoring and reporting on SDG 6 and

Table 6. Access to indoor sewerage service by area of residence

Characteristics	Households			Population		
	Urban	Rural	Total	Urban	Rural	Total
Improved installation, not shared						
With discharge into sewage network	65.5	11.7	36.3	64.6	10.7	33.6
With discharge into septic tank	8.4	18.7	14.0	8.7	17.7	13.8
With discharge into latrine	9.2	41.0	26.5	11.0	44.7	30.4
Improved ventilated latrine	0.0	1.2	0.7	0.0	1.3	0.8
Total	83.2	72.5	77.4	84.3	74.4	78.6
Shared Installation a/						
With discharge into sewage network	9.9	2.1	5.7	8.8	1.8	4.8
With discharge into septic tank	1.3	2.8	2.1	1.2	2.3	1.8
With discharge into latrine	2.1	9.5	6.1	2.1	8.4	5.7
Improved ventilated latrine	0.0	0.2	0.1	0.0	0.2	0.1
Total	13.3	14.6	14.0	12.1	12.6	12.4
Installation not shared						
Discharged, but not into sewerage, septic tank, or latrine	2.1	2.6	2.3	2.2	2.5	2.4
Latrine without lock	0.1	0.5	0.3	0.1	0.6	0.4
No service/scrub/field	1.3	9.7	5.9	1.3	9.9	6.2
Total	3.4	12.8	8.5	3.6	13.0	9.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Número	**9,751**	**11,632**	**21,383**	**43,668**	**59,025**	**102,693**

a/ Services that would be considered "improved", if they were not shared by two or more households. Source: ENCOVI 2017 developed the methodology for the step-by-step monitoring of indicator 6.5.1 . In October 2017, a workshop was held to apply this methodology.

Nearly 75% of Guatemala's annual water availability goes to neighboring countries. However, due to the lack of a legal framework, there are no bilateral negotiations between countries.

The Groundwater Governance in Transboundary Aquifers (GGRETA) Project undertook the first phase between 2013 and 2015, which consisted of evaluating the transboundary aquifer in a region between El Salvador, Honduras and Guatemala, known as El Trifinio (UNESCO, 2016). The Esquipulas and Ocotepeque-Citalá aquifers do not yet have a problem of depletion due to the overuse of groundwater, but if it continues to be used in a disorderly manner, without having the guidelines that allow adequate management, it could experience this problem in the medium term. Moreover, a water deficit has been observed that can be partly attributed to the effects of climate variability and change, an increase in the duration of the dry season and periods of heavy rains that do not allow water infiltration to contribute to the recharge of aquifers. Priority should be given to capacity building in El Salvador and Honduras, which share the Ocotepeque-Citalá aquifer and in Guatemala, for the Esquipulas aquifer (UNESCO, 2016).

f. Protect and restore ecosystems related to water, including forests, mountains, wetlands, rivers, aquifers and lakes

The ICC, the National Forestry Institute (INAB) and the National Council of Protected Areas (CONAP), together with private owners, have worked to protect and restore the natural mangrove forest on the Pacific slope, in the areas of Tiquisate, Sipacate -Naranjo, Blanca Cecilia and Tahuexco, and to monitor these efforts. Areas restored with red mangrove (*Rhizophora mangle*), together with the Sipacate-Naranjo conservation area, are also being evaluated (ICC, 2017).

The INAB grants forestry incentives for the protection of natural forests in areas with very high and high water recharge, and water sources.

g. Expand international cooperation and the support provided to developing countries for capacity-building in activities and programs related to water and sewerage, including water collection and storage, desalination, efficient water resource use, wastewater treatment and recycling and reuse technologies.

The Association of Municipalities of the Naranjo River Basin (Mancuerna) is an association of municipalities that has been working to ensure water for the present and future generations for 14 years. The mission of Mancuerna is to promote the integrated water resource management through its strengthening, and its vision is that by 2020, municipalities will have restored water governance.

The Spanish Cooperation Agency (AECID) has contributed funds for Mancuerna, and other communities such as Manctzoloyá and Copán Chortí.

International cooperation in the country supports capacity building. The Global Water Partnership (GWP) has cooperated with rainwater storage and storage projects in schools in the urban area of the municipality of Guatemala, in conjunction with the municipality and Fundación Solar.

6. Successful experiences in improving the quality and quantity of water

As indicated above, in the period 1950-2014 (45 years) there were 25 years with precipitation below the historic annual average. The last prolonged drought, in 2014 and 2015, was reflected in lower flows in the rivers, especially those on the Pacific slope, where agricultural activities with intensive water consumption (sugarcane, palm oil and bananas) are carried out and there are several communities that use water from rivers for domestic purposes.

In the dry season (January to May) of 2016, the flow of the Madre Vieja, Ocosito and Achiguate rivers, from the Pacific slope, was insufficient to meet demand, which led to conflicts between the agroindustries and the communities. In order to resolve them, in 2016, 32 technical committees were formed: a socio-political technical committee, made up of communities, municipal authorities, non-government organizations and companies; a business committee, made up of the irrigators; and another technical one, made up of the related public entities, the government, the municipalities and the ICC. The achievements of the technical working sessions were: to obtain a user inventory, the results of measurements at strategic points, and they also managed to ensure that water from the rivers emptied into the Pacific Ocean. In 2017, ten basin committees were formed, with the support of a coordinator and six teams of technical personnel and equipment (ICC, 2017).

There have been other positive experiences in the country, such as when users of a river basin contributed financial and in-kind resources to maintain the volume and quality of the water. Guerra and Alvarado (2006) and Guerra and Reyes (2008) describe the experience of payment for environmental services in the basins of the Sierra de Las Minas towards the San Jerónimo valley and the Ixtacapa sub-basin, respectively.

From 2015 to 2017, the INAB promoted and strengthened five payment mechanisms for environmental services (PSA) in different parts of the country: Olintepeque and Concepción Chiquirichapa in Quetzaltenango; Esquipulas Palo Gordo in San Marcos; El Durazno National Farm, San Jerónimo, Baja Verapaz; and Los Amates Izabal (INAB, 2017).

In addition, the Probosques Law stipulates that “The INAB, in collaboration with the beneficiaries and other interested parties, shall promote the operation of compensation mechanisms for the directors of projects that produce ecosystem and environmental services associated with forests" (Art. 19, Decree 2-2015).

Water Quality (WQI) and Pollution (PUI) Indices

In the country there are no water quality indices to determine the temporal and spatial variability of water bodies. Aldana and Zacarías (2014) designed one WQI and three PUI (organic matter, suspended solids and mineralization) for the Cucabaj River, located in the municipality of Santa Cruz del Quiché, Department of Quiché, because it is one of the three main sources of supply for more than 9,000 inhabitants of the urban area. The water quality parameters used to determine the WQI were: percentage of oxygen saturation, fecal coliforms, pH, biochemical oxygen demand, nitrates, phosphates, temperature, turbidity and dissolved solids. The results of the monitoring from April 2012 to January 2013 made it possible to classify the quality of the resource as medium-good, ranging from contaminated to slightly contaminated by organic matter due to the amount of total coliforms, meaning that it should be given potabilization treatment. It is also regarded as necessary to develop, use and compile biological indexes, such as macroinvertebrates, phytoplankton and eco-toxicological bioassays, which are more sensitive to changes in water quality, in order to obtain rapid results in the event of water pollution.

7. Conclusions and Recommendations

Water quality deterioration is already a major problem and, solving it will require heavy financial investment. The effects on public health, the aquatic ecosystems and the economic activities of the country are evident. Despite the fact that specific regulations have been in place since 1989, which require compliance with standards to ensure the quality of the effluent discharged into water bodies, they have only been partially implemented. It seems that the history of developed countries, whose water bodies deteriorated at some stage, after which they had to invest large amounts of financial resources to recover them, will be repeated in Guatemala. However, we do not have the financial resources to do so or the political will and institutional strength to enforce the law, as a result of which it seems that its resolution will be very long-term or perhaps only partial. In addition, it is not lack of treatment technology, but rather lack of investment that prevents the improvement of water quality in water bodies.

Moreover, the general population must recognize that wastewater treatment has a cost and that the polluter must pay for this process. However, all the municipalities in the country subsidize the water supply service for human consumption and therefore lack the financial resources to provide adequate service, far less treat the wastewater generated. There is therefore a need to sensitize the population to the need to comply with the legislation through education programs through the creation of a new curriculum, prioritizing water quality and its understanding for students and the population in general, among other actions.

Van de Wauw et al. (2010) indicated that the lack of a detailed baseline study and the limited monitoring efforts to date show that the country's legislation can be improved, and that the terms of reference for environmental impact (EIA) and monitoring studies should be similar to those undertaken in developing countries. On the other hand, the fact that public data and information made this study possible demonstrates the importance of the public provision of reliable and independent data. This raises the need to organize a truly independent, transparent and scientifically established monitoring system in order to meet those requirements.

Bibliographical references

Aldana, M.L., y Zacarías, E.E. (2014). Índice de calidad de agua del Río Cucabaj ubicado en el municipio de Santa Cruz del Quiché, Quiché y la influencia en los costos del tratamiento de potabilización. *Revista Ciencia, Tecnología y Salud,* Vol. 1, Núm. 1. pp. 21-34. ISSN:2410-6356

Asociación Guatemalteca de Ingeniera Sanitaria y Ambiental (AGISA) (2016). *Conclusiones y Recomendaciones del VI Congreso Nacional de Ingeniería Sanitaria y Ambiental.* Ciudad de Guatemala: AGISA, 2 al 4 de junio de 2016. Cap. 8, p. 18.

Bisinoti, M.C., & Jerdim, W.F. (2004). O comportamento do metilmercúrio (MetilHg) no ambiente. *Química Nova* 27(4), 593-600.

Bosch, C., Hommann, K., Sadoff, C. y Travers, L. (1999). *Agua, saneamiento y la pobreza.* Washington, DC: Banco Mundial.

Castellanos E.J. (2013). ¿Cómo estará el entorno ambiental en Guatemala en las siguientes décadas? *Revista de la Universidad del Valle de Guatemala,* Núm. 26, pp. 51-55.

Chandra, S., Dix, M., Rejmánková, E., Mosquera, V., Girón, N. y Heyvaert, A. (2013). *El estado ecológico actual del lago Atitlán y el impacto de la entrada de aguas residuales: recomendación para exportación de las aguas residuales de la Cuenca para restaurar el lago.* Presentado a la Autoridad para el Manejo Sustentable de la Cuenca del Lago de Atitlán. Sololá, Guatemala.

Coc, E.F. y Vanegas, E.A. (2015). Efecto del uso de la tierra sobre la erosión y sedimentación de los suelos en El Estor, Izabal. *Revista Ciencia, Tecnología y Salud,* Vol. 2, Núm. 1. pp. 39-45. ISSN:2410-6356

Dirección de Investigación en Derechos Humanos (2014). *El acceso al agua potable como un derecho humano en Guatemala.* Guatemala: Procurador de los Derechos Humanos.

Ducci, J. (2007). *Acceso al agua potable, saneamiento y pobreza.* IV Encuentro de Expresidentes de América Latina. Foro social de Sao Paulo 2009. Recuperado de www.corporacionescenarios.org

Foster V. & Araujo C. (2004). *Does infrastructure reform work from the poor? A case study of Guatemala.* Washington, DC: World Bank.

Fundación para la Conservación del Agua en la región Metropolitana de Guatemala (FUNCAGUA) (2016). *Plan de Conservación.* Guatemala: FUNCAGUA.

Guerra, A.E. y Alvarado, M.S. (2006). *De la Sierra de Las Minas al valle de San Jerónimo: acciones locales para la gestión integrada del agua.* Costa Rica: CATIE; Guatemala: Fondo del Agua del Sistema Motagua Polochic.

Guerra, A.E. y Reyes, L. (2008). *Experiencia de participación y contribuciones de los recursos naturales en la subcuenca del Río Ixtacapa.* Guatemala. Lecciones y reflexiones. *Revista Mesoamericana de la Conservación,* Año 1, Núm. 2. ISSN: 1998-0493 = Yu´am.

Hernández, E. (2013). *Análisis de Contaminantes Emergentes de Tipo Farmacéutico (Acetaminofeno, Cafeína, Dexketoprofeno, Diclofenaco sódico, Fenilefrina e Ibuprofeno) en el Agua del Río Las Vacas (municipio de Guatemala) y Río Villalobos (municipio de Amatitlán).* Tesis para obtener el título de Químico. Universidad de San Carlos de Guatemala, Guatemala.

Instituto de Investigación y Proyección sobre Ambiente Natural y Sociedad (IARNA-URL) (2012). *Perfil ambiental de Guatemala 2010-2012. Vulnerabilidad local y creciente construcción de riesgo.* Guatemala. ISBN: 978-9929-587-71-7

Instituto Nacional de Bosques (INAB) (2016). *Boletín Estadístico 1998-2016.* Departamento de Incentivos Forestales. Guatemala.

Instituto Nacional de Estadística (INE) (2016). *Encuesta Nacional de Condiciones de Vida 2014.* Tomo I. Guatemala: INE.

Instituto Privado de Investigación sobre Cambio Climático (2017). *Informe de Labores 2016.* Guatemala: ICC. 97 pp.

Lentini, E. (2010). *Servicios de agua potable y saneamiento en Guatemala: beneficios potenciales y determinantes del éxito.* Santiago de Chile: CEPAL.

López, M., Barrillas R. y López J. (2015). *Estructura, composición y dominancia de las cianobacterias en el Lago de Amatitlán y su relación con la pérdida de diversidad de fitoplancton.* Guatemala: Escuela de Biología, Universidad de San Carlos de Guatemala y Autoridad para el Manejo Sustentable de la Cuenca y del Lago de Amatitlán.

Matta, V. L., Lange-Cruz, K.J., Medina-Samayoa, N. G., Martínez-Castellanos, E.M., Hidalgo-Letona, E.L., Nave, F., Schneider-Paiz, R.E. (2017). Cambios en la frecuencia de infección por *Helicobacter pylori* en niños guatemaltecos durante 10 años. *Revista Ciencia, Tecnología y Salud,* Vol. 4, Núm. 1. ISSN:2409-3459

Mayorga, P. (2009). Toxicidad y potencial eutroficante de aguas dulces y marinas en Guatemala. En *Guatemala: Servicios y productos ambientales.* Citado en IARNA/URL (2009). *Perfil Ambiental de Guatemala 2008-2009: las señales ambientales críticas y su relación con el desarrollo.* Guatemala: Universidad Rafael Landívar, Instituto de Agricultura, Recursos Naturales y Ambiente. Serie Perfil Ambiental No. 11, p. 136.

Mayorga, P. (2014). *Determinación de la toxicidad de un extracto acuoso de biomasa de cianobacterias colectadas en el centro del Lago de Atitlán en agosto 2013, con el crustáceo anacostraco* Thamnocephalus platyurus. Presentado en el 1er Congreso Nacional de Geociencias Ambientales, Antigua Guatemala, 27 y 28 de noviembre de 2014.

Mayorga, P. (2016). *Toxicidad de agua subterránea en el Valle de Guatemala.* Presentado en el VI Congreso Nacional de Ingeniería Sanitaria y Ambiental. Ciudad de Guatemala: AGISA, 2 al 4 de junio de 2016.

Ministerio de Ambiente y Recursos Naturales (MARN) (2015). *Segunda Comunicación Nacional sobre Cambio Climático Guatemala.* Guatemala: MARN. 224 pp.

Ministerio de Salud y Asistencia Social (MSPAS), Instituto Nacional de Estadística (INE), ICF International (2017). *Encuesta Nacional de Salud Materno Infantil 2014-2015.* Informa final. Guatemala: MSPAS/INE/ICF.

Mosquera, V. (2015). Análisis de la calidad de agua 2008-2013: Lago de Amatitlán (sin referencia).

Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura (UNESCO) (2016). Programa Hidrológico Internacional (PHI) de la UNESCO, en el marco de las actividades del Programa Global de Iniciativas del Agua (GPWI) de la Agencia Suiza para el Desarrollo y la Cooperación (COSUDE).

Pérez-Sabino, F., Valladares-Jovel, B., Hernández, E., Oliva, B. Del Cid, M., Jayes-Reyes, P. 2015. Determinación de arsénico y mercurio en agua superficial del lago de Atitlán. *Revista Ciencia, Tecnología y Salud,* Vol. 2, Núm. 2. pp. 127-134. ISSN:2410-6356

Prensa Libre. 16 de noviembre de 2017:18.

Scheuhammer, A.M., Meyer, M.W., Sandheinrich, M.B., & Murray, M.W. (2007). Effects of environmental methylmercury on the health of wild birds, mammals and fish. *Ambio*, 36(1), 12-18.

Secretaría de Planificación y Programación de la Presidencia (SEGEPLAN) (2016). *Estrategia de articulación de la Agenda de Objetivos de Desarrollo Sostenible con el Plan y la Política Nacional de Desarrollo K´atun. Nuestra Guatemala 2032.* Guatemala: Comisión de Alineación, Seguimiento y Evaluación/Consejo Nacional de Desarrollo Urbano y Rural.

Secretaría de Planificación y Programación de la Presidencia (SEGEPLAN) (2017). Estructura de la Estrategia de implementación de las Prioridades nacionales de desarrollo. Guatemala: SEGEPLAN/Sistema de Consejos de Desarrollo.

Secretaría de Planificación y Programación de la Presidencia (SEGEPLAN) (2017). *Objetivos de Desarrollo Sostenible. Metas priorizadas.* Guatemala: SEGEPLAN/Sistema de Consejos de Desarrollo.

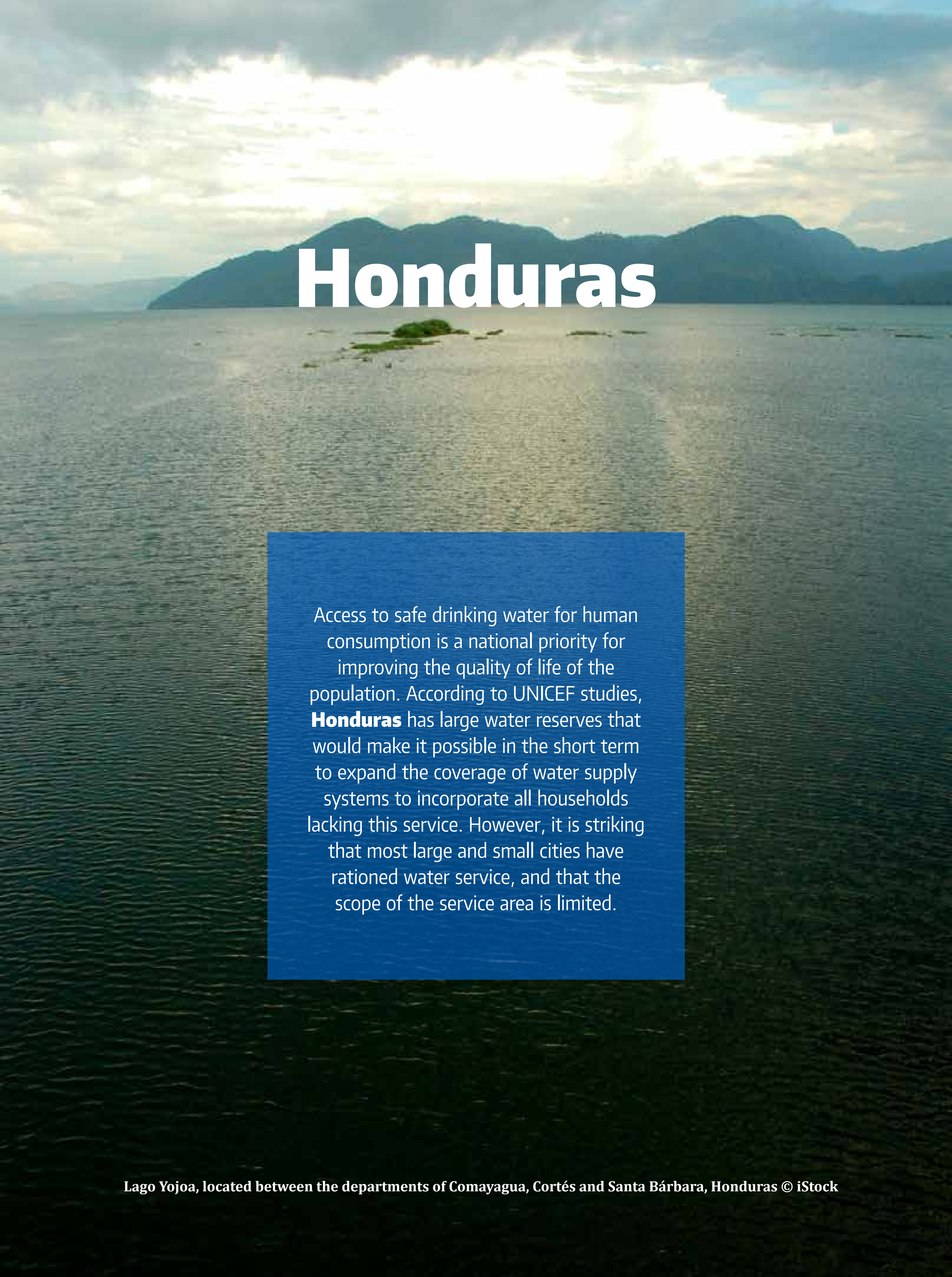
Siguí, N. L. (2016). ¿Por qué continúa la contaminación de aguas en Guatemala? *Revista Ciencia, Tecnología y Salud,* Vol. 3, Núm. 2. ISSN:2410-6356.

Törökné, A.K. (1999). A new Culture-Free Microbiotest for Routine Detection of Cyanobacterial Toxins. *Environmental Toxicology,* 14(5): 466-472.

United Nations Environment Programme (UNEP) (2013). *Global Mercury Assessment 2013: Sources, emissions, releases and environmental transport.* Geneva, Switzerland: UNEP Chemicals Branch,.

Van de Wauw, J., Evens, R. y Machiels, L. (2010). ¿Está la sobre extracción de agua subterránea y la reducida infiltración contribuyendo a problemas de salud relacionados con el Arsénico cerca de la mina Marlin (Guatemala)? En *Goldcorp out of Guatemala.* Recuperado de https://goldcorpoutofguatemala.com/reports-studies/informes-estudios/

Honduras



Access to safe drinking water for human consumption is a national priority for improving the quality of life of the population. According to UNICEF studies, **Honduras** has large water reserves that would make it possible in the short term to expand the coverage of water supply systems to incorporate all households lacking this service. However, it is striking that most large and small cities have rationed water service, and that the scope of the service area is limited.

Lago Yojoa, located between the departments of Comayagua, Cortés and Santa Bárbara, Honduras © iStock

Water Quality in Honduras

Marco Antonio Blair, Pedro Ortiz, Mirna Argueta and Luis Romero

Introduction

Access to safe drinking water for human consumption is a national priority, since it influences and is a factor in improving the level and quality of life of the population. In the past fifteen years, Honduras made significant progress in relation to access to drinking water and sanitation, achieving the targets set in Goal 7 of the MDGs.

In this document, an analysis is conducted of the status of water quality in Honduras, based on bibliographic reviews, interviews and field experiences. Chapter 1 describes the general aspects of Drinking Water and Sanitation (DWS), coverage and problems affecting water quality. Chapter 2 reviews water quality governance and the institutional and legal framework, among other aspects. Chapter 3 analyzes the main problems impacting water quality in the country. Chapter 4 deals with the social and economic aspects of water quality. Chapter 5 addresses the capacity of the country to face the SDG-6 challenges of the New UN 2030 Agenda. Chapter 6 describes the country's successful experiences in improving water quality through watershed restoration and protection plans. Lastly, Chapter 7 presents the main conclusions and recommendations drawn from the review of drinking water quality.

1. General aspects

Since the mid-1980s, Honduras has made significant progress in water and sanitation service coverage, estimated at 86% for access to drinking water and 78% for access to sanitation. However, according to the 2013 Population and Housing Census (INE, 2013), the population growth rate is 2.0% per year, which creates a continuous gap in the coverage of public services, particularly water and sanitation.

The transformation of the DWS sector has involved the formulation and approval of policies in the sector, the development of national strategies and plans, and the definition of sectoral objectives and goals. Accordingly, the growth of access to these services has been accompanied by the state's decision to modernize the sector through the enactment of the Framework Law for the Potable Water and Sanitation Sector in 2003 (SESAL, 2003).

1.1 Background

The review of the basic background information applicable to this study is explained below.

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1.1.1 Location and demographics

Honduras (112,492 km^2) is located between 12° 58' and 17° 30' North Latitude; and 83° 45' and 89° 22' West Longitude (MOSEF/GIZ/GFA, 2013).

1.1.2 Demographics

According to data from the Population and Housing Census 2013, Honduras had a total population of 8.3 million that year, distributed among 2.2 million dwellings, including 4,990 collective dwellings. The population is extremely young, with 24.9% of the population between the ages of 10 and 19 and 23.2% of the population under 10. A summary of the data of interest for the particular purposes of this document is given in **Table 1**.

1.1.3 Drinking water service coverage

Drinking water service coverage in the country has significantly increased in recent decades, and, as can be seen from the **Table 2**, household coverage amounts to 85.2%.

1.1.4 Sanitation service coverage

Sanitation service coverage has significantly increased in recent decades, although not at the same rate as the potable water sector. Coverage amounts to 54.9% of the total population, showing a 30.3% gap in homes that receive water, but lack an appropriate system for their wastewater disposal. **Table 3** shows coverage data by urban and rural settings.

On the basis of data from the table, and with an average endowment of 210 LPPD, nationwide domestic wastewater production is almost 361.2 million m^3 per year, 57.9% of which corresponds to urban settings and 42.1% to rural settings.

1.2 Main water quality problems in the country

Water and sanitation service coverage has significantly increased, although the same cannot be said of water quality. According to updated records from the 2015 SESAL, the main problems affecting water

Table 1. Honduras, Population and Housing 2013

Sphere	Population total	Men	Women	Housing
National	8,303,772	4,052,316	4,251,456	2,158,042
Urban area	4,436,223	2,095,408	2,340,815	1,189,753
Rural area	3,867,549	1,956,908	1,910,641	968,289

Source: XVII National Population Census and VI Housing Census 2013, INE.

Table 2. Honduras, Drinking Water Coverage 2013

Sphere	Housing total	With sewerage	Without sewerage
National	2,158,042	1,838,527	319,515
Urban area	1,189,753	1,026,247	163,506
Rural area	968,289	812,280	156,009

Source: XVII National Population Census and VI Housing Census 2013, INE.

Table 3. Honduras, Sanitation Coverage 2013

Sphere	Housing total	With sanitation	Without sanitation
National	2,158,042	1,184,324	973,718
Urban area	1,189,753	583,051	606,702
Rural area	968,289	601,273	367,016

Source: XVII National Population Census and VI Housing Census 2013, INE.

quality are related to organoleptic and bacteriological characteristics.

1.2.1 Deforestation

One of the main problems in the country is the growing deforestation that increases the rate of deterioration of forests in several of the watersheds with unfavorable consequences for water quantity and quality.

a. Legal and illegal deforestation occurs because of the commercial exploitation of wood, in the case of entrepreneurs engaged in the business of wood, whereas in the case of settlers in the basin, it is due to the extraction of firewood as cooking fuel. Owing to deforestation, there has been an increase in erosion, with an enormous dragging of sediment and organic matter that makes river channels silt up, altering the turbidity and color of the water, as well as its smell and taste.
b. Burning and forest fires in Honduras are another factor that affects water quality, increasing the temperature of water bodies, especially water supply reservoirs.
c. Migratory agriculture is another factor that affects water quality due to the destruction of the forest together with intensive livestock farming. This traditional practice of clearing portions of the forest and burning it after the harvest to "clean" the land in order to prepare it for next planting is cyclical, since after a certain amount of planting and harvesting, peasants leave the land and migrate to another area that is subsequently subjected to the same process of deforestation.
d. Extensive livestock, small livestock and poultry farms, as well as shifting cultivation also constitute a major source of pollution in the country, because all the wastewater discharges generated in haciendas are discharged into the environment, without control, including feces from livestock and farms.
e. The harmful bark beetle plague that attacks pines has caused serious damage to the forest, forcing the trees affected to be cut down, causing a serious negative impact on the environment. According to data from the Institute of Forest Conservation (CONADEH/MOSEF-UE/Gobierno de la República de Honduras/ICF, 2016), this plague affected 381.3 thousand hectares of coniferous forest in the center of the country. The most significant impact of the pine bark beetle is on forests in water producing areas, since this affects life itself due to the right to water and sanitation.

1.2.2 Wastewater discharge

Inadequate excreta and wastewater disposal constitutes another of the main and most serious factors that contribute to the deterioration of water quality, leading to the proliferation of disease and an increase in morbidity and infant mortality in the country. Waterborne diseases remain the leading cause of morbidity and the second main cause of infant mortality.

The population without sanitation service is equivalent to 45.1% of all households, with a 30.3% gap in households that receive water, yet lack an appropriate system for the disposal of their wastewater. This represents a discharge of untreated domestic wastewater of 361.2 million m^3 nationwide, 209.3 and 151.9 million m^3 of which are discharged in urban and rural settings respectively. Wastewater discharges are affecting the estuaries, seas and lagoons of both coasts, damaging these ecosystems.

1.2.3 Rationed service and pressure deficiencies

According to UNICEF studies carried out in 2017 through its office in Honduras, the Country has large water reserves that would make it possible in the short term to expand coverage of water supply systems to incorporate all households lacking this service. In most large and small cities, however, water service is rationed, and the scope of the service area is limited by the deficiency of pressure in the network. Moreover, as many water bacteria withstand high pressure, this situation gives rise to the generation and survival of bacteria in the pipeline and even post-chlorination bacteria.

The population that benefits from a water supply through water treatment plants amounts to 51% in the urban area and 14% in the rural area, meaning that the remaining population receives water service that has only been disinfected with chlorine.

1.3 Objectives and scope of the chapter

The main objective is to publish the result of the status of the potable water sector in terms of quality, analyzed from the point of view of academia, with the aim of establishing baselines or starting points to focus policies and strategies at the level of central government and municipal governments, in accordance with the Water and Sanitation Framework Law and its Regulation, issued in 2003, which establishes the entire institutional and legal framework for the significant improvement of water quality.

2. Water quality authorities and governance

The Framework Law of the Potable Water and Sanitation Sector and its General Regulations establish the bases for the modernization of the sector, whose main objectives include ensuring the quality of water and its potability, guaranteeing that its consumption is healthy for people.

2.1 Institutional framework

In general terms, this new Law modifies the authority and governance of the sector related to drinking water and sanitation, as shown in **Table 4**.

The sector has the Honduran Association of Water Systems Management Board (AHJASA), a grassroots organization, whose objective is to improve water quality in member communities, and strengthen the development of emerging associations through training and national integration, providing advisory services and organization processes for JAA. It also has a Training Center and special operation and maintenance modules. It offers chlorine, chlorinators, chlorine comparators and technical assistance to monitor service quality among other functions.

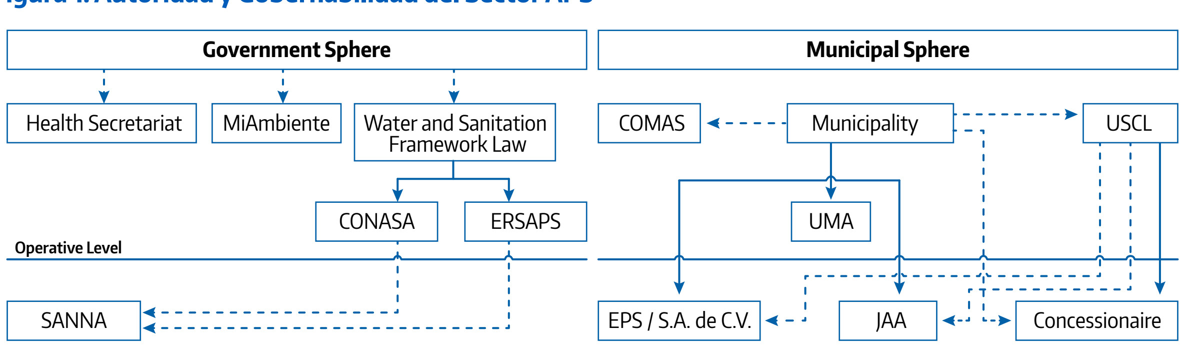
Figure 1 shows the hierarchy of authority within the institutional framework in accordance with the Framework Law.

Table 4: Institutionality and Governance Sector PHC

Sphere	Institution	Service Provider
Government	Health Secretariat SERNA (MiAMBIENTE) Comisión Nacional de Agua y Saneamiento (CONASA) Ente Regulador de los Servicios de Agua y Saneamiento (ERSAPS)	SANAA
Municipal	Municipality (Head of PHC services) Comisión Municipal de Agua y Saneamiento (COMAS) Unidad de Supervision y Control Local (USCL) Unidad Municipal Ambiental (UMA)	Municipal Public Services Office Ente Prestador de Servicios (EPS) Junta Administradora de Agua (JAA) Limited company Concessionaire

Sourse: *Plan de Vigilancia de la Calidad del Agua en los Municipios Priorizados en el Plan Nacional de Enfermedades Desatendidas*, OPS/OMS/SESAL, October 2012.

Figura 1. Autoridad y Gobernabilidad del Sector APS



Sourse: *Plan de Vigilancia de la Calidad del Agua en los Municipios Priorizados en el Plan Nacional de Enfermedades Desatendidas*, OPS/OMS/SESAL, October 2012.

Depending on the modality of service provision, the APS EPSs are grouped in **Table 5**.

2.2 Legal framework

Legal instruments that emphasize support of the legislation in the sector include the following:

- The Constitution
- General Law of the Environment and its Regulations
- Health Code
- Environmental Health Regulation
- Framework Law on Drinking Water and Sanitation, and its Regulations
- National Technical Standard for Drinking Water Quality, NTN-AP
- Technical Standards for Wastewater Discharges into Receiving Bodies and Sewerage, NTAR-AS

The supreme authority governing the legal framework related to water quality, including water quality monitoring, is the Ministry of Health.

2.2.1 Health Code

The Health Code authorizes SESAL, "through the corresponding body, to carry out the sanitary control and monitoring of waters and to establish the desirable and admissible characteristics it must have". It also authorizes it to regulate everything related to the management and disposal of excreta, sewage and rainwater, as well as the surveillance and technical control of sewers and their effluent.

2.2.2 National Technical Drinking Water Quality Standard, NTN-AP

The goal of the Standard is, "to protect public health by establishing the appropriate or maximum levels that be achieved by the components or characteristics of water that may pose a risk to the health of the community and problems in water supply systems".

This Standard establishes that SESAL will undertake the sanitary control and monitoring of waters and establish their desirable and admissible characteristics. The NTN-AP establishes the maximum admissible parameters of drinking water quality, sampling frequency and the most appropriate analysis methodologies or routines. It is possible to establish a monitoring program based on frequency.

2.2.3 Environmental Health Regulation

This Regulation (SESAL, 1998) seeks to develop the set of rules to enforce compliance with the provisions related to water quality, stating that it has to meet physical, chemical and biological characteristics, according to the NTN-AP.

The Regulation emphasizes environmental health by ensuring the application of technical standards and the solution of specific environmental health or environmental sanitation problems. It prohibits the discharge of wastewater of any type and size, on the banks of rivers, streams, lakes, lagoons, reservoirs, winter streams and the proximity of water wells for human consumption, as well as the beaches of seas and estuaries near cities.

2.2.4 Technical Standards for Wastewater Discharges into Receiving Bodies and Sewerage

As indicated in its initial articles, enforcement of these standards is the responsibility of SESAL, SERNA and the Ministry of the Interior and Justice, with the aim of regulating the discharge of wastewater into receiving bodies and sanitary sewage, and encouraging the creation of programs for the minimi-

Table 5. EPS Governance Modality

Level of care	Authority	Service Provider
Central government	SANAA	Three Regional Administrators
Municipal governments	Municipality	Municipal Department of Public Works Municipal Public Services Department Municipal Division of Water and Sanitation Municipal Water and Sewerage Board
	Service Provider	Decentralized Municipal Unit Limited Company with Variable Capital Concessionaire
Community Level	Water board	Local Water Board

Source: *Manual para la Identificación e Implementación de Acciones Tercerizantes para EPS de APS*, ERSAPS, marzo de 2011.

zation of waste, the installation of treatment systems and the disposal of wastewater discharged into the environment.

Protection of both surface and groundwater sources is the fundamental goal of this regulation, since protecting sources from contamination due to the dumping of wastewater is crucial to environmental health and therefore to the preservation of the quality of the water destined for human consumption, domestic use and agroindustry.

2.3 Relations with NGOs and universities (scientific research)

Most of the coordination between NGOs, universities and water project developers is undertaken by RAS-HON.

a. RAS-HON is an instance of dialogue and consultation between all its member institutions, comprising all the organizations and institutions and collaborators of a social, private, national and international public nature that implement and develop plans and projects in the water and sanitation sector of Honduras. RAS-HON has Centro Hondureño de Recursos de Conocimiento e Información en Agua y Saneamiento (CHRECIAS), as an executor to comply with knowledge and information management strategies, particularly in regard to water quality.
b. The Water for All Foundation (FUNDAPAT), created as an initiative of the UNICEF, SANAA, the Chamber of Commerce and Industry of Tegucigalpa and the Media Association (AMC), has successfully extended potable water services to 105,000 people in 104 communities.

2.3.1 Universities

Of the existing universities, only UNAH and the Universidad Panamericana Agricola Zamorano form part of RAS-HON, with very little contribution are water quality issue.

UNITEC has a water quality laboratory which undertakes quality analysis of water and wastewater, among other functions. However, its main role is commercial and it does not have a data bank. UNICAH offers an Environmental Engineering degree program yet lacks a water quality laboratory where the teaching of quality analysis methodology and the creation of data banks can be implemented.

2.3.2 Scientific research

Scientific research is scarce and marginal, and only undertaken in the event of emergencies, and depending on the use of water in which this type of situation occurs.

The Center of Studies and the Control of Contaminants (CESCCO) is a Directorate of the Ministry of Energy, Natural Resources, Environment and Mines,[1] whose mission is to be the highest-level technical-scientific body in Honduras, in terms of environmental pollution. It engages in research, the provision of laboratory service, environmental monitoring and the management of chemical products, in order to strengthen the environmental management of Honduras based on the principles of responsibility, honesty, ethics and integrity.

Within the institutional sphere, only the EPS of APS, which have the greatest human and material resources capacity, undertake water quality analysis for quality control purposes, such as SANAA and Aguas de San Pedro, among others. These companies usually assess water quality for the design and construction of new water treatment plants and the expansion of existing ones.

There is no evidence of scientific research by universities, although the Pan-American Agricultural University, undertakes water quality monitoring to control drinking water quality.

2.4 Monitoring and database

a. In accordance with the Water and Sanitation Framework Law and its Regulation, ERSAPS[2] performs the function of regulation through Unit for Supervision and Local Control (USCL), which is responsible for ensuring compliance with water quality monitoring, through the quality analysis that the EPS of APS must perform, and for providing these records to the central office of ERSAPS, where a data bank is kept for each municipal USCL.
b. CESCCO has a water quality laboratory for human consumption, through which it conducts commercial monitoring activities in a timely manner and when emergency cases arise. Through this laboratory, it provides analytical

1. http://www.miambiente.gob.hn/cescco/

2. http://www.ersaps.hn/

services in the physicochemical area for various types of water: surface, ground and wastewater. Although CESCCO has the best capacity in terms of monitoring, there is no evidence of the existence of data banks.

c. Only institutionally strong EPS, from the point of view of human and economic resources, have the capacity to monitor and create data banks such as SANAA, ASP, Aguas de Cortes, Aguas de Choloma and Servicios Aguas de Comayagua (SAC).

3. Main problems impacting water quality

In general terms, at the national level, the monitoring of surface streams and groundwater for the identification of problems that impact drinking water quality in Honduras has only been possible through the water quality analysis carried out by institutions that have developed water supply projects that include the installation of water treatment plants.

Another type of analysis routinely undertaken by SANAA involves monitoring the quality of raw water in the reservoirs for water supply in the capital of the country.

3.1 Eutrophication

The main causes of the rapid eutrophication in Honduras are deforestation, forest fires and abundant agricultural activity in basins designated as water supply reserve areas. Deforestation has increased the production of sediment due to erosion, while forest fires create abundant ash and coal waste, and agricultural activity has led to the production of organic waste with a high nitrogen content and its derivatives: phosphates, carbonates and chlorides.

These problems, like those emerged in the Los Laureles Reservoir for example, in the capital city for water supply, raised the need to include an aeration process in the water treatment plant with previous pre-chlorination and alkalization to adjust the quality of the raw water (Aceituno, 2016) and a floating device of raw water was built for direct intake from the epilimnium.

Thermal stratification has been observed in lakes, lagoons and reservoirs, and there has been a proliferation of water lily or water hyacinth, which has been controlled, mainly in reservoirs destined for water supply.

3.2 Natural contaminants

The natural pollutants with the greatest effect on water quality in the country are hurricanes, which transport various materials and elements to certain areas, causing pollution.

Although hurricane *Mitch* left sufficient sequelae to undertake significant research, there are still no field records based on laboratory analysis to determine and classify the natural pollutants affecting water bodies, including air currents. During the cyclonic rain season, these air currents drag elements that cause pollution, erosion and toxic plants, among other effects.

Specific evaluations carried out in projects for water supply from surface streams and drilling wells for groundwater, as well as hydroelectric projects, have found contamination from iron, magnesium and manganese (Aceituno, 2016).

3.3 Pollution

The main cause of the pollution of water sources is the abundant discharge of untreated domestic and industrial wastewater into the environment, which is greater in major cities, particularly on the North Coast, where the industrial zone is located.

According to CESCCO studies,[3] there are 19 severely polluted rivers, the Chamelecón River, located in the Sula Valley, being the most polluted one due to the large volume of industrial discharges it receives. The Choluteca River, which crosses the capital city, has high levels of pollution from discharges, which are mostly domestic. Both rivers become septic in the summer season when the base flow of the rivers decreases, leading to a greater concentration of the pollutant load. Dissolved oxygen measurements undertaken of the Choluteca River by SANAA between 1982 and 1986 showed that the recovery capacity is 14 km, which reflects the level of contamination.

3.4 Agrochemicals

Contamination by agrochemicals in Honduras is mainly due to the use of pesticides employed to prevent, repel or control pests of animal or vege-

3. http://www.miambiente.gob.hn/cescco/

table origin during the production, storage, transportation and distribution of agricultural products. Contamination of the soil and groundwater affects crops, livestock and drinking water and in the case of human consumption, entail health risks, resulting in eutrophication and water pollution.

To date there are no epidemiological records of agrochemicals related to water quality, and only CESCCO has conducted research on specific environmental pollution problems in general, enabling response actions to be undertaken by the competent authority.

3.5 Heavy metals

The main source of contamination from heavy metals in Honduras is opencast mining, for the extraction of gold, for which mercury and chromium are used. Since there is no adequate control or management of these metals, the discharge of these elements into the environment forms deposits at the lowest points of the places where mining takes place, which infiltrates groundwater with a risk of contamination.

Traces of cadmium and lead have been found in groundwater sources in the central zone of Honduras (Aceituno, 2016), while arsenic has been found in groundwater sources in parts of the North Coast in banana growing areas where aerial spraying has been used to apply pesticides. Although there have been major studies by CESCCO on heavy metal pollution, the level of research still lacks the intensity and interest to form a database that will permit advanced studies to design strategies and policies in this regard.

3.6 Deforestation

Deforestation is a serious problem that increases due to forest clearing, burning and forest fires, shifting cultivation and intensive livestock, and more recently, the bark beetle pest. Accordingly, the deterioration of forests in the largest and most important watersheds of the country has increased with unfavorable consequences for water quantity and quality (MOSEF/GIZ /GFA, 2013). Due to deforestation, the impact of the rain during Hurricane *Mitch* caused a large dragg of sediment. There are still no records of the impacts on the different hydraulic parameters that make it possible to evaluate water quality before and after Hurricane *Mitch*.

Figure 2. Free discharge of raw wastewater

Source: http://contaminacionenhonduras.blogspot.com/p/agua_653.html

In terms of forest burning and forest fires, only annual inventories are available, but there is still no evaluation of their consequences on water quality. The same is true of migratory agriculture, intensive livestock farming, and the growing poultry and fish farming industries.

3.7 Salinization

Although there are no detailed studies based on field research in Honduras, it has been found that this problem of salinization occurs mainly in coastal areas, where it is necessary to establish controls for the use of groundwater, its quality, the degree of pollution and the impact of climate change on them.

In the southern part of the country, saline intrusion problems have been detected due to the use of groundwater for agricultural activities, causing pollution as a result of its over-exploitation for irrigation and industry (MOSEF/GIZ /GFA, 2013).

3.8 Wastewater. Lack of treatment plants, poor management of existing plants. Cities and municipalities without treatment plants

The main rivers and creeks have been severely contaminated as a result of human activity and population growth, as well as increasing urbanization and industrialization coupled with the new phenomenon of the urbanization of rural areas.

According to the analysis of sanitation service coverage in 2015, 361.2 million m^3 of wastewater is produced nationwide, but only 50% of the volume of wastewater from the urban area is treated, in other words, 104.6 million m^3. This means that 256.7 million cubic meters are directly discharged into the environment, without any treatment. A total of 40.7% of wastewater is discharged in urban areas, while 59.3% is discharged in rural settings (MOSEF/GIZ /GFA, 2013).

One of the main causes of pollution of rivers and streams is the direct discharge of raw wastewater into the environment, see **Figure 2**, which has become a serious problem that has yet to be solved by the competent authority.

According to National Plan of Water and Sanitation PLANASA (CONASA, 2014), there is a major deficit of wastewater treatment plants (PTAN) nationwide. The treatment system consists mainly of stabilization ponds with the primary and secondary treatment stages, preceded by preliminary treatment. There is no official audit inventory on the current status of existing PTANs, which lack good management due to the absence of operation and maintenance programs.

Nationwide, the Choluteca, Chamelecón and Ulúa rivers are most seriously contaminated by wastewater discharges. These rivers receive sewage from the cities of Tegucigalpa and Sula Valley, respectively, industrial waste, agrochemicals used and manufactured in the basins, garbage deposits on their banks and sediment.

3.9 Lixiviation into groundwater and surface water bodies

In Honduras, the problem of contamination by Lixiviation is due to crematoria, landfills or open garbage dumps, which do not have control systems, waterproof rafts, or channeling or control systems that prevent leakage into the environment and enable subsequent waste treatment. Since this problem is directly related to the size of the population and the industrial development of each city, this type of contamination is most severe in the capital city and the Metropolitan Area of Sula Valley, followed by cities with populations of over 100,000 inhabitants (CONASA/PPIAF/BM, 2005).

In some cities, the amount of leachate in garbage dumps is so high that it quickly forms lagoons in places where the soil is impermeable, constituting a form of natural treatment, which has prevented it from trickling into slides or natural channels that cause surface contamination.

Leaching has also been identified in open pit mining, widely practiced in the South and Central Eastern areas of the country, where gold is extracted in an artisanal way, and chromium, mercury and lead have been identified.

3.10 Emerging pollution

The largest source of production of emerging pollutants in the country are hospitals, dental clinics and pharmaceutical laboratories, which lack proper control for the management and safe disposal of the wastewater they produce. Pharmaceutical waste is disposed of in internal evacuation systems, sewers or sewers connected to the municipal sewerage network –when it does exists.

Blood plasma, blood, alcohol, bone and meat waste and residue from chemical products from pills and serum are discharged into the places where surgical equipment is cleaned and in some major hospital centers, there are traps for the removal of solids (MOSEF/GIZ /GFA, 2013). Wastewater is discharged into the municipal networks where there is a sewerage system and, failing that, into the environment.

There are still no records or field studies of this type of pollution from contaminants emerging from surface water sources.

3.11 Other: nanomaterials

The past five years have seen a new class of emerging pollutant identified as nanomaterials, materials with morphological properties smaller than one micron, in at least one dimension, including micro-plastics or nano-plastics. Since this new class of contaminants and their contaminating effect is scarcely known in Honduras, there is no research on this area, except for the studies begun by the National Academy of Sciences (ANC).

4. Social and economic aspects

According to the first paragraph of Article 21 of Framework Law, “the Central Government, the Municipalities, and the Water Management Boards will promote the management of resources for the development of drinking water and sanitation services, establishing priorities for the undertaking of projects, investment recovery criteria, and capital allocation, which will be determined on the basis of socioeconomic studies, taking into consideration their respective financial capacity".

The government has emphasized these areas of human development, as borne out by the actions it has taken for this reason. Thus, in 2004, it passed the Framework Law for the Potable Water and Sanitation Sector and its Regulations, the first recital of which states, "that it is the state's obligation to enforce laws to promote the economic, political, social and cultural well-being of Hondurans". Subsequently, in 2006, it launched the strategic plan called Plan Estratégico de Modernización del Sector Agua Potable y Saneamiento PEMAPS (CONASA/PPIAF/BM, 2005), in which the strategies to meet the needs of the DWS sector in Honduras stand out. In 2011, it drafted the proposal for the National Policy for the Water Sector and Sanitation, and in 2014 it developed PLANASA

Since 2009, the country has had a Law for the Establishment of a Country Vision 2010-2038 and the National Plan 2010-2022 (Presidency of the Republic, 2010), approved by Legislative Decree 286/2009, which establishes eleven strategic guidelines that define the direction of public policies, and, therefore form the basis of the sectoral policy, and the plans and programs to be developed.

4.1 Health

Nationwide, water-borne diseases are the main cause of morbidity and the second leading cause of infant mortality. Sanitary deficiencies in the quality of drinking water services play a serious risk to health, such as lack of continuity in service, in more than 90% of cases according to the Sectorial Board (CONASA, 2014), and chlorination deficiencies, since only 44% of the systems provide adequate chlorination.

The main regulations include the Health Code, approved by Legislative Decree No. 65-91 of June 14, 1991, which states that the Ministry of Public Health -now SESAL-, through the corresponding body, will undertake the control and sanitary surveillance of the waters and stipulate the characteristics they must have.

Through Agreement No. 084 of July 31, 1995, through SESAL, the Central Government enforced the Technical Standard for the Quality of Drinking Water.

4.2 Poverty

Poverty seriously affects the water supply, since those living in poverty usually have less access to drinking water. However, this is not true in Honduras, because as indicated earlier, according to the aforementioned data, 14.8% of the population lacks potable water service, 13.7% of which corresponds to the urban area and 16.1% to the rural population (INE, 2013).

The population that lacks drinking water in their homes includes not only poor people, because in rural areas there are people with financial resources that enable them to live comfortably, yet who lack water in their homes; whereas in urban areas there is a high percentage of the population located in developing neighborhoods that lack economic resources, yet have access to drinking water, through indoor connections, public taps, unconventional service by tanker trucks, or individual or community drilled wells.

It is estimated that the marginalized population in the main cities of the country amounts to an average of 47% (INE, 2013), and that this figure is higher in the Municipality of the Central District.

4.3 Educational attainment in communities. Education programs and curriculums

Basic knowledge in the field of water is extremely broad since it covers health, agriculture, aquaculture, industry, energy and ecosystems.

a. At the community level, through FHIS, training programs are developed for the Operation and Maintenance of aqueducts in communities where water projects are implemented. This training, carried out through Local Water and Sanitation Board (JAS), includes water disinfection through chlorination, and the care of sources to prevent the quantitative and qualitative deterioration of water.
b. SESAL developed the Water Security Plan (PSA) (PAHO, 2012), compiled by SANAA with the support of PAHO and the Honduras Chapter of the Inter American Association of Sanitary Engineering (AIDIS). PSA operators are environmental health technicians (TSA), who should be qualified water laboratory technicians. PAHO has strengthened the capacities of the EPS by training human resources with the

support of AIDIS, particularly in the water quality component.

c. The AHJASA maintains its training program for the development of training events, seminars, workshops, meetings and assemblies at the local, municipal, departmental, and national levels.

d. Within its program of studies, the Universidad Católica de Honduras (UNICAH) offers an undergraduate degree program in Environmental Engineering, which includes the design of water treatment plants and disinfection, yet lacks the practical aspect of water quality monitoring.

4.4 Gender

The predominant role played by women in the household economy and the raising and education of their children has been acknowledged, which is why, in this context, it is increasingly accepted that women have an important role to play in water management and that this role should be reinforced through a gender mainstreaming strategy.

To date, Zamorano EAP (Joya, 2017) is the only institution known to have incorporated women into the use, management and conservation of natural resources and water governance, with a water quality component.

In the National Institute of Women (INAM), Diagnostic Report (2007), a review of policies, strategies and the sectoral and gender legal framework, found that the gender approach is included in the national or macro, institutional or meso, and community or micro levels, in response to international commitments and sectorial and gender indicators in the PRSP contracted by the country.

The participation of AHJASA through the Water Boards is opening up the possibility of the participation of women in up to 50% in water disinfection activities.

4.5 Rural and urban areas

According to the definitions established by INE, on the basis of the Population Census of 1974, the characteristics of urban and rural areas are as follows:

a. Urban area means any populated area in the 2013 Census based on at least one of the following criteria:
   1. Population of 2,000 or more inhabitants.
   2. Populated center that was urban in the 2001 Census.
   3. Population of between 1,500 and 1,999 people, with at least one of the following characteristics: a) urbanized; b) teaching center; c) health center; d) at least 10% sewer availability.

b. A rural area is any populated center that fails to comply with the above definition.

Despite the previous categorization, the characteristics applicable for each area do not fully apply in Honduras since some of them intersect transversally. Thus, in urban areas, particularly large cities, there are peri-urban areas that typically have rural characteristics such as a lack of water and sanitation services, whereas in rural areas these services have increased, with a greater emphasis on drinking water, and where there is no electricity, unconventional supply systems have been implemented, such as hand-made wells with manual pumps.

In peri-urban areas, inhabitants often resort to buying water in tank trucks that are suspected of selling water of dubious quality. Accordingly, it is in these marginalized population belts that diarrheal diseases and others associated with the consumption of contaminated water often emerge.

In the rural population, water obtained from surface sources is of good quality, but deteriorates with inadequate handling because users use unsafe containers and store water inappropriately for its subsequent consumption. Due to this situation, in rural areas it is common to find common diseases such as diarrhea and others associated with the consumption of contaminated water, including parasitism. The greatest social problems due to poor quality water consumption occur in scattered rural areas, estimated to house 15% of the total rural population (INE, 2013).

4.6 Water quality investment programs

a. During the period 2009-2015, the Government of Honduras, through SANAA, in collaboration with the Spanish government, through the Spanish group SETA, installed and commissioned 31 water treatment plants in the same number of communities, with the aim of improving the quality of water supplied to reduce the morbidity and mortality rate due to waterborne diseases, and to strengthen economic development by improving the health and quality of life of the population (CONASA, 2014).

One conventional plant, 29 modular plants and a desalination plant were installed in the Island of Útila, which provide a volume of 80,000 m^3 of good quality water to an estimated population of 600,000. The program included the supply of 20 chlorination plants in the same number of communities.

b. The investment program for water quality infrastructure planned by CONASA (2014) in PLANASA, for the period 2018-2022 amounted to $22.2 million USD for the purification of 880 LPS and $224,000 USD for the disinfection of 180 LPS.

c. With the support of Cornell University of New York, the Water for the People NGO and AHJASA, a cooperation program was set up with donation funds for the installation of water treatment plants in small urban areas, with appropriate technology, using sand filters and benefiting 30,000 inhabitants.

4.7 Industry, mining, and agriculture and conflicts related to water quality caused by these factors

Climate change has caused extreme effects on the country's water resources, such as altering rainfall patterns, which, due to the presence of the El Niño phenomenon, has caused droughts with the consequent reduction of water flows in rivers and the deterioration of water quality.

a. A large amount of industrial products, particularly in the food industry, require large amounts of water for processing. Nevertheless, the industry is also a source of contamination because it requires water as a means of diluting and cleaning contaminated areas.

The main industry in the country is the food or agroindustry, which demands water of good quality, safe for human consumption. Companies usually take water from the municipal network if they are located within the urban perimeter, which is why it is supposed to be good quality water, whereas agroindustries located in non-urban areas have purification systems enabling them to use good quality water from groundwater sources.

Although there is no updated inventory, it is believed that 50% of the metalworking industry owns its own system with water from an underground source, as does the maquila industry, whose main sector is clothing manufacture (MOSEF/GIZ /GFA, 2013).

b. In most mining operations in the country, water is obtained from underground sources, streams, rivers, lakes or through commercial water service providers. Since almost all the areas where mines are located have a water shortage, it is understandable that communities and local authorities usually oppose such activity, since they use the water from these sources, and seek to control most of the water pollution caused by mining companies.

According to the Instituto Hondureño de Geología y Minas (INHGEOMIN), until 2009, 426 mining exploitation concessions had been granted, the greatest demand being in the Departments of Olancho (76), El Paraíso (55), Choluteca (44), Francisco Morazán (42) and Santa Bárbara (35). In the case of Olancho, iron deposits are usually exploited, for which groundwater sources are used.

Mining activity in Honduras constitutes a major source of contamination from heavy metals, and the lack of control by the competent authority has led to environmental pollution particularly of rivers and streams, deforestation of the environment where they are located and loss of aquatic habitats.

c. The demand for water for Honduran agriculture creates serious problems in the regions located in the South, Southeast and Southwest of the country, especially in the so-called dry corridor, where the rainfall regime has periods of severe drought that have worsened in the past four or five decades. This demand is being alleviated by the construction of reservoir ponds or "water harvests" that capture rainwater in limited quantities.

In the northern part of the country, where concessions were granted to banana companies, there is a well-developed irrigation infrastructure that permits the capture of surface water by diversion dams and water distribution channels.

Although agriculture experiences serious problems of contamination of water sources over a wide radius due to the use of pesticides for pest control by aerial fumigation, there is still no scientific study on this problem of contamination due to agricultural activities.

d. Another important aspect that influences the social and economic aspects of water quality, for example, is that Honduras is one of the most vulnerable countries to climate change, whose effects contribute to exacerbating environmental degradation and increasing vulnerability to climate change, as a result of which environmental sustainability in the development of the country is particularly urgent.

Although Honduras' Ecological Footprint has decreased in recent decades and remains relatively stable, its biocapacity has also decreased considerably. The Environmental Performance Index measured by Yale University[4] classifies Honduras among the countries with a "modest performance" yet with a tendency to deteriorate.

The country faces several environmental challenges which, together, contribute to aggravating the situation of poverty, reducing health levels, increasing vulnerability to natural disasters and/or increasing food insecurity. These challenges are related to deforestation, soil degradation, desertification, access to water, water and air pollution, management of solid and toxic hazardous waste, erosion and coastal degradation, and biodiversity reduction, among other effects.

5. Facing up the Sustainable Development Goal 6 (SDG-6)

Access to drinking water and sanitation remains one of the greatest challenges to be faced in Honduras since thousands of its inhabitants still lack access to safe sources of water for human consumption and decent sanitation services.

In 2003, the country reformed the APS Sector with the aim of promoting the quality of life in the population and the consolidation of sustainable development as a generational legacy, based on the Framework Law for the Drinking Water and Sanitation Sector. This law is a major milestone, since it recognizes drinking water and sanitation as a national development sector, promoting its transformation with the construction of a new institutionality that creates a separation of functions and the clear definition of its roles: a) regulations, policies and planning; b) regulation and control; and c) service provision.

In order to meet the challenges of the United Nations Sustainable Development Goal 6 "Clean Water and Sanitation of the 2030 Agenda",[5] Honduras has the tools contained in: (a) PEMAPS; (b) PLANASA; (c) the National Policy for the Potable Water and Sanitation Sector of Honduras (CONASA, 2013), which establishes the strategic guidelines, implementation mechanisms and investments required to comply with goals established in the Law for the Establishment of a Country Vision 2010-2038 and the Adoption of a National Plan 2010-2022 for Honduras, in accordance with the institutional framework established in the Framework Law for the Drinking Water and Sanitation Sector, where the principles focusing on the *human being and its equitable and integral development* are regarded as important.

In order to periodically monitor and evaluate the scope of the goals and the fulfillment of the sectoral reform objectives, CONASA, with support from Program of Water and Sanitation, PAS-World Bank, designed the Monitoring of Country Advances in Drinking Water and Sanitation (MAPAS), whereby a Scorecard was drawn up for the new sectoral challenges and their links with the SDGs, to evaluate the route through which the country converts financing into sustainable drinking water and sanitation services for each of the four subsectors: rural water, urban water, rural sanitation and urban sanitation. This route evaluates three major sectoral dimensions: a) institutional framework, b) sectoral development, and c) sustainability.

5.1 Universal, equitable access to safe, affordable drinking water

The decentralization adopted by the government assumes equity between the various parts of its

4. https://epi.envirocenter.yale.edu/2018/report/category/hlt

5. http://www.hn.undp.org/content/honduras/es/home/post-2015/sdg-overview/goal6.html

own territorial space and, from this perspective, seeks to achieve the universality of equitable access to potable water service with a focus on social inclusion. According to PLANASA, the government has a strategy of decentralizing services, designed to provide support and monitor the decentralization process of services still under SANAA's responsibility, towards municipalities. Likewise, municipalities must create providers with autonomous technical, financial and administrative management, taking into account the priorities and specific conditions of the various categories in these localities.

In order to implement this strategy, PLANASA (CONASA, 2014) has planned the development of a $22.2 million USD investment program for water purification and disinfection in municipalities that currently provide services within the framework of the new Water and Sanitation Law. In accordance with the constitutional mandate that establishes the human right to water, the Honduran State, through ERSAPS, regulates the connection prices (supply rate) set by providers so that costs are not transferred above the real cost of the latter and do not constitute a barrier to access for the poorest sectors of the population. This includes the micro-measurement program that will allow fair collection based on consumption.

In projects to expand drinking water networks, programs and projects must ensure that providers supply temporary drinking water services to the surrounding population, which for technical reasons are not part of the project, such as water condominium networks with public pools, collective storage tanks or tanker truck service.

5.2 Access to adequate and equitable sanitation and hygiene

Like the treaty on drinking water access, the constitutional mandate establishes the human right to sanitation while the Honduran State, through ERSAPS, regulates the connection prices (supply rate) established by providers.

Additionally, the governing body will promote alternative and complementary sources to enable the low-income population to undertake the indoor connection of their sanitary installations from the dwelling to sewerage systems, through household connections.

In order to implement this strategy, and to achieve the objective of facilitating equitable access to adequate sanitation and hygiene services for all and ending open fecalism, PLANASA has foreseen the development of a $129.3 million USD investment program. for the expansion of sanitation coverage in the municipalities that currently provide services within the framework of the new Water and Sanitation Law, paying special attention to the needs of women and girls, and people in vulnerable situations.

5.3 Improve water quality by reducing pollution

SESAL is mandated to exercise surveillance, sanitary control and the promotion of water quality and discharges, especially water for human consumption as a priority activity for public health and it is their responsibility to play a leading role in this field, for which its structure includes a Health Surveillance Unit, Surveillance Directorate of the Regulatory Framework and the General Directorate of Normalization. For its operation, the institution has departmental sanitary regions comprising Verification, Statistical and Laboratory Units and Analysis Units (UDA), whereas at the municipal level there are environmental health technicians (TSA) responsible for surveillance, performing functions of daily sanitary control.

Thus, in order to improve water quality by reducing pollution, eliminating the direct discharge of raw wastewater into the environment, and minimizing the discharge of hazardous materials and chemicals, the construction of wastewater treatment plants has been proposed to initially halve the percentage of untreated wastewater and gradually eliminate discharges into the environment.

Based on the above, the goal according to PLANASA (CONASA, 2014) and the Nation and Country Vision Plan is to achieve 60% sewerage coverage including small cities, and 50% treatment of the total volume of wastewater collected.

The **Table 6** shows the investment needs for wastewater treatment.

5.4 Increasing the efficiency of water use

The principles that guide the National Policy for the Water and Sanitation Sector (CONASA, 2013) include the principle of *Efficiency*, which seeks to ensure that the provision of services be carried out efficiently, in other words, that services produce immediate results and there be no waste of resources, additional costs, loss of quality or user dissatisfaction.

The development of the infrastructure proposed in PLANASA is the strategy concerned with the rehabilitation and optimization aspects of the infrastructure, as well as the expansion of services. In this line of action, investments have been grouped into three large groups:

a. Water suitable for human consumption, with the necessary investment for treatment of surface water systems, and the installation of disinfection systems.
b. Hydrosanitary continuity and efficiency to increase the continuity of services, the rehabilitation of water systems and sanitation systems to enhance efficient water use, the installation of meters and a pilot plan for the installation of low consumption toilets.
c. Towards *the universalization of services*, which covers investments aimed at increasing drinking water production, as well as drinking water and sanitation service coverage, service coverage in rural areas and wastewater treatment, and the adequate management of sludge from treatment plants and in situ sanitation systems.

5.5 Integrated water resource management at all levels

In April 2017, the government of Honduras launched the Water, Forest and Soil Master Plan (ABS Plan) (Presidencia de la República, 2017) as an integral part of the 2010-2038 Country Vision and 2010-2022 National Plan (Presidencia de la República, 2010) and as an initiative to create guidelines that strengthen the integral management of water resources. The objectives of the ABS Plan are for local institutions and organizations to have technical and financial capacity for the implementation of integrated soil, water and forest management, and to achieve the comprehensive management of natural resources, by implementing integrated water resource management at all levels, including through cross-border cooperation.

Citizen participation and the social audit strategy is regarded as a transversal axis of the various guidelines contained in PLANASA, and is effective in the creation of the Service Provider's Board of Directors and the creation of COMAS and USCL. Social audits of co-responsibility are designed to guarantee transparency and accountability in the use of resources, and in the control and monitoring of water quality and services, thus achieving integral water resource management within the municipality.

Regarding the executive aspect, for the development of good water resource integration applicable throughout the country, and given that in the Law for the Establishment of a Country Vision to 2038 and the Adoption of a National Plan to 2022 the country is recognized as being predominantly urban, and is expected to double its population by 2040, it has been subdivided into six regions characterized by basins with similar characteristics.

5.6 Protect and restore ecosystems related to water

The ABS Plan, launched by the government of Honduras, contains policies and strategies designed to protect and restore water-related ecosystems, including forests, mountains, wetlands, rivers, aquifers and lakes.

Table 6. Investment to Expand Wastewater Treatment

Population Center	Population Range	Totals (US$)
Metropolitan Areas	Over 500,000	54,000,000.00
Major cities	Over 30,000	974,795.00
Small cities	5,000 to 30,000	2,073,712.00
Minor urban centers	2,000 to 5,000	446,430.00
Total		57,494,937.00

Source: PLANASA, Comisión Nacional de Agua y Saneamiento, noviembre de 2014.

The processes and strategic lines of the ABS Plan include:

1. Governance Process
   a. Local governance for integrated water, forest and soil resource management.
   b. Strengthening the legal-institutional framework and financial mechanisms.
2. Knowledge Management Process
   a. Information generation and management for decision making.
   b. Capacity building and skills development.
3. Process of Implementation of Sustainable Practices
   a. Conservation, protection, restoration and sustainable use of water, forest and soil.
   b. Development of infrastructure for water treatment, use and efficient reuse (rainwater, groundwater and wastewater).

5.7 Expand international cooperation and capacity development

The sectoral financing strategy, set forth in PLANASA and the National Policy on the Potable Water and Sanitation Sector of Honduras, includes the response to the objective of expanding international cooperation and the support provided for capacity building in activities and programs related to water and sanitation, including gathering and water storage, desalination, efficient water resource use, wastewater treatment and recycling and reuse technologies.

Financing operations in the sector, especially at the municipal level, is one of the central elements that will move the gears of the sector under the new decentralization and modernization approach. The aim is for there to be an adequate flow of resources to improve services, achieve providers that operate efficiently and sustainably, and create capacity in the municipality in order to boost its actions in communities to undertake local projects and extend coverage to backward areas, and ensure effective regulation.

The strategy proposes the development of the following elements:

a. The consolidation of funds in the sector coordinated and led by CONASA and its visualization in the general budget of the country; and
b. Promote the creation of a Honduran Drinking Water and Sanitation Fund.

Three levels are identified for financing the sector:

a. Sectoral level: establishment of the rules, modalities and instruments to finance the various components of costs and investments in this sectoral level.
b. Provider's level: establishment of financial and administrative mechanisms to enable providers to operate with solvency; and
c. Municipality level: what local governments can do by law to improve services.

Investment in the sector is carried out through a mixture of donations, loans, state investments, and the management of projects and programs, complemented by a certain level of contribution to operating costs by users through tariffs and in urban areas through investment costs.

Regarding the framework of Capacity Building, in rural areas water boards have performed well in at least 40% of the systems (Presidencia de la República, 2010). Technical assistance has played an important role in this. However, decentralization poses challenges regarding the structuring of technical assistance.

Most municipalities have low administrative, operational and strategic management capacity. They have few qualified human resources and incentives, significant staff turnover and face supply constraints in the local labor market.

5.8 Support and strengthen local community participation

In order to increase the participation of local communities in the improvement of water management and sanitation, providers will be supported in both institutional strengthening, and in their relationship and promotion of citizen participation and social audit, on the basis of mechanisms established by the sectoral authority.

Institutional strengthening includes management and managerial processes, technical, commercial, administrative-financial management and planning, participatory social management, risk and system vulnerability management. Municipalities will also be supported through the creation and strengthening of the Technical Municipal Office, (UTM), properly equipped, with mobilization logistics and an operational budget integrated with that of the municipality. Qualified services will be promoted through the implementation of the professional training of operational technical personnel and middle management, as well as a certification mechanism for professional consultants to provide technical assistance and advice to service providers and municipalities.

The Operating Manual for Intervention Models for Potable Water and Sanitation projects in Marginalized Peri-Urban Districts, Concentrated and Dispersed Rural Sector (PAS, 2002), prepared by the FHIS with the support of the World Bank, establishes strategies for the support and strengthening of citizen participation through community involvement in the development of water projects with an emphasis on water quality.

ERSAPS (2011) has compiled a Manual for the Identification and Implementation of Outsourcing Actions for the EPS of APS, whose objective is to become a support and consultation tool for EPS managers and executives. Outsourcing services is intended to reduce the bureaucratic size of EPSs, especially in the field of the operation and maintenance of DWS systems, making them more efficient in providing a quality service and providing a product -water- of very good quality.

6. Successful experiences to improve water quality

Over the past 14 years, all the actions developed to improve water quality have been oriented towards watershed management, taking into account climate change, whose effects on water resources are harmful in all countries. Honduras has taken its status as a country that is extremely vulnerable to the effects of climate change very seriously, which is why its efforts are oriented towards establishing a policy based on climate resilience strategy programs (CONASA, 2013).

Environmental protection and conservation is the responsibility of the state through the Secretariat of Natural Resources and Environment and municipalities. Providers are responsible for ensuring compliance with the quality standards required for drinking water and sanitation service provision, and must allocate the necessary resources for the environmental protection of areas where the sources or points of discharge are located.

6.1 River basin restoration/ protection plans

Under the 2016 Bonn-Latin America Challenge (GIZ/ Federal Ministry of Environment, Public Works and Nuclear Safety/CCAD/MiAMBIENTE, 2016), Honduras pledged to restore one million hectares, which is consistent with national goals and the Country Plan. In this commitment, Honduras highlights its interest in protecting the coasts and water supply for the local communities involved, which are predominantly indigenous and Afro-descendants, due to their high vulnerability to natural disasters, since Honduras is one of the most vulnerable countries according to the list of the Intergovernmental Panel on Climate Change (IPCC).

The 2016-2026 MiAMBIENTE Strategy sets out recommendations for the actions the government must implement to protect water resources and guarantee the sustainability of water quantity and quality. In the context of the Agenda Climática de Honduras and the ABS Plan, the government has designed the National Restoration Plan, that seeks to reforest one million hectares by 2030, with the support of UNDP, which has mobilized $20 million USD in non-reimbursable financial resources from the Adaptation Fund and the Global Environment Fund, in order to advance the restoration of 115,000 ha of forest landscapes in the next five years.[6]

The Adaptation Fund initiative is planning to restore 30,000 hectares of forest in the central forest corridor, affected by the southern pine beetle, which covers the Municipality of the Central District and other neighboring municipalities. At the same time, the Global Environment Fund initiative seeks to restore 85,000 ha of biological micro-corridors among 20 protected areas in the country and thereby conserve high biodiversity.

In order to continue supporting the efforts of the state to achieve its goals and actions in favor of restoration, UNDP is co-organizing an event parallel to the central event of the Bonn Challenge with

6. http://www.hn.undp.org/content/honduras/es/home/presscenter/pressreleases/2017/06/1-1/pnud-contribuir-en-lograr-el-11-de-la-meta-nacional-de-restauraci-n-de-bosques/

national and international actors to learn about and expand the financing mechanisms in this area of restoration in the country. This parallel event is funded by the UNDP Low Emissions Capacity Building Program with funds from the European Union and the German government.

6.2 Pilot experiences (Guidelines for policy makers, among others)

The government has launched the Water, Forest and Soil Master Plan or ABS Plan, which considers water resources, forestry and soil resources as the main axes for the establishment of an agroforestry policy based on sustainable productive landscapes, through a series of programs based on the national plan for mitigation and adaptation to climate change. It will include a National Reforestation Campaign called "Honduras Siembra Vidas", in accordance with the Bonn Challenge.

The water component of the ABS Plan focuses on more and better quality water in accordance with the Country Vision of the Master Plan, because water is the resource that attracts most attention because of its potential in the country.[7] The ABS Plan seeks to become a public policy that will make it possible to integrate the three issues from a "from local to national and global" perspective. This means that emphasis will be placed on work with communities so that they can implement actions designed to improve access to water, and conserve forests and soils.

The Master Plan will promote and encourage the good practices already being carried out in several communities in Honduras in terms of good water, forest and soil management.[8] For water quality, solid and polluting waste treatment and collection will be the immediate priority.

6.3 Education, training and public awareness

Sanitary education, derived from the provision of DWS services, is vital to the reduction of morbidity and mortality rates, by educating families by promoting more frequent bathing, scrupulous washing and handling of food, hygienic practices in excreta and solid waste management, and the need for environmental protection to contribute to a healthy, sustainable environment.

6.3.1 PEMAPS platform

The PEMAPS Development Platform proposes the modernization process that will make it possible to reach the best levels of coverage and efficiency in the provision of quality services to supply safe water for the population, implying a series of changes that will result in the definition of clear sectoral policies, provisions and regulations for the provision of services, technical standards and the use of new technological, technical and legal tools.

PEMAPS raises the issue of human resource training that is crucial to the good management of DWS service provision within EPSs. Its existence with the right quantity and quality guarantees better internal work capacity and facilitates the introduction of new participation schemes in service provision via *outsourcing* or other participatory alternatives. The strategy considered in PEMAPS is to strengthen human resources throughout the entire system.

6.3.2 Intervention models

At the level of training and public awareness, with the support of the World Bank, the FHIS prepared the *Operation Manual of the Intervention Models for Potable Water and Sanitation projects in Marginal Peri-Urban Districts, Concentrated and Dispersed Rural Sector*, which establishes the strategy for training EPSs and JASs through the formation of Committees with the integration of trained Technical Personnel and for the culturization of water through community involvement in activities to monitor drinking water quality.

Likewise, the Country Vision and Nation Plan establish 11 strategic guidelines that define the direction that guides public policies and are therefore the basis of the sectoral policy, and the plans and programs to be developed. These guidelines are linked to sectoral ones, which establish the framework considered in the formulation of PLANASA. The strategic guidelines of the Nation Plan established include education and culture as means of social emancipation, oriented towards health and environmental education.

7. http://www.hn.undp.org/content/honduras/es/home/stories/pnud-apoyara-a-la-implementacion-de-los-objetivos-del-plan-maest.html

8. http://www.presidencia.gob.hn/index.php/sala-de-prensa/170-plan-abs/2283

6.3.3 Healthy school and home

The joint work between SANAA and UNICEF resulted in the "Healthy School and Home" Project [9] in 1996 to address the fact that the implementation of DWS service infrastructure of needs to implement an education program parallel to the construction of this infrastructure, for which it was considered useful to apply methods that contemplated the direct participation of residents.

The "Healthy School and Home" Project has had a positive impact on the quality of life of members of the rural and peri-urban communities of Honduras, especially in their hygiene and environmental sanitation practices, and has become a model that is being replicated by various cooperation agencies and non-governmental organizations.

6.4 Other: Partnerships between water companies and communities

a. In 2013, the Honduran Association of Water and Sanitation Service Providers[10] was established with the purpose of achieving the development of the basic services in each of the integrated municipalities.
b. Under Article 20-A of the Municipalities Act, Decree No. 143-2009, the creation of the commonwealth "as associative modalities or an association of municipalities" is defined as a territorial entity subordinated to member municipalities, subject to public law and the exclusive manager and implementer of programs, projects and services of priority interest, which allows its members to address problems they are unable to deal with individually "(p. 18).

7. Conclusions and recommendations

7.1 Conclusions

a. Honduras has made significant progress in water and sanitation service coverage, estimated at 85.2% for access to drinking water and 55.0% for access to sanitation, achieving the UN SDG 2015 goals.
b. The problems that most affect water quality are deforestation, forest fires and the direct discharges of raw wastewater into the environment.
c. Governance of the country has changed positively with the approval of the Framework Law for the Potable Water and Sanitation Sector and its Regulations, and the support tools: PEMAPS, PLANASA and the National Policy for the Potable Water and Sanitation Sector, which has strengthened the institutional and legal framework of the sector, and also has the support of technical drinking water and sanitation standards.
d. The participation of NGOs mainly grouped together within RAS-HON plays an important role, complementary to the actions of the state in the supply of drinking water to a large sector of the urban and rural population.
e. Scientific research related to the quality of water for human consumption is still weak, and the role of universities in the subject has failed to elicit the interest it warrants from the competent authorities. Monitoring and creation of interest banks based on scientific research is, therefore, scarce, while existing efforts are isolated and lack continuity.
f. Among the problems that impact water quality, leaching and emerging pollutants have become relevant because they affect groundwater sources through infiltration. Emerging pollutants include nanomaterials such as nano-plastics, particles smaller than one micron with morphological properties.
g. Honduras has found that knowledge in the field of water and its quality is crucial to achieving success in the sustainability of water systems. The culturization of water contributes to good practices in its use and the conservation of its quality as a source of good health.
h. Honduras has prepared and continues taking actions to address the challenges of Goal 6 set out in the UN's New 2030 Agenda for Sustainable Development to guarantee the availability of water and its sustainable management and sanitation for all.
i. Honduras has developed excellent experiences in the water quality issue, beginning with the approval of the Framework Law of the Potable Water Sector and its Regulation, the formula-

9. https://www.wsp.org/Hygiene-Sanitation-Water-Toolkit/Resources/Readings/ UNICEF-Honduras.pdf

10. https://issuu.com/25965/docs/presentacion_ahpsas_rashon_ 2014.ppt

tion of a Country Vision, Nation Plan and work tools such as the ABS Plan and intervention models for water and sanitation projects.

7.1 Recommendations

a. Additional efforts must be made to sustain the achievements obtained in water and sanitation coverage, and complement pending tasks, so that there is no gap in the near future, and develop new works.

b. The country should implement the actions recommended in the MiBABIENTE Strategy and the ABS Plan for the restoration of forests, and the protection of watersheds, within whose planning the development of the country has been considered, taking into account PAP Honduras and the existence of associations as organizations of municipalities with the capacity to implement appropriate actions in the field.

c. All the recommendations made in the PEMAPS should be put into practice, PLANASA should be implemented and the National Policy on the Drinking Water and Sanitation Sector should be applied in order to firmly cement the new state of governance of the APS Sector, currently under development, and to consolidate the achievements obtained.

d. The Central Government must strengthen the institutional sector of NGOs, due to the role they play in attending an important sector of the population which the action of government authorities has not yet reached, such as the peri-urban zones of major cities, and concentrated and scattered rural settlements.

e. Resources should be allocated to scientific research, the monitoring of surface and ground sources identified for water supply, and the creation of data banks that include meteorological parameters, to be included in the strategies and policies of the National Water and Sanitation Plan, and adaptation to climate change, as stated in the MAPAS. CESCCO plays an important role in this field, since it has offices in various regions in the country.

f. Attention should be paid to the problem of contamination by leachates and emerging pollutants, and human resources should be trained to develop programs and projects for proper waste management and disposal that will not harm the environment. It is necessary to eliminate open air dumps, build sanitary landfills and control the discharges of process water in mines being exploited.

g. Education programs developed for health education, such as the Healthy School and Home Program, should be replicated and expanded, due to the success obtained. Health education programs, such as the Healthy School and House Program, should be replicated and expanded, due to the success obtained.

   The necessary resources should be invested, as proposed in PEMAPS and PLANASA to train educators and train and raise the awareness of citizens. The component of citizen participation and training proposed in the intervention models should be applied with greater intensity.

h. The government must rely on all the institutional infrastructure it created to achieve the goals set out in the 2015 MDGs, and strengthen it with trained personnel, and the allocation of sufficient financial resources to meet the challenges of SDG 6 raised in the UN 2030 Agenda for Sustainable Development.

i. The country must socialize the Country Vision of the Nation Plan and the ABS Plan, the Policies of the Drinking Water and Sanitation Sector, and the PLANASA and implement them, since they contain an ambitious development plan for Honduras, with solid foundations to achieve a better standard of living with health and education.

References

Aceituno, Laura (2016). Plomo, hierro y manganeso mayores contaminantes del agua en comunidades de Ojojona, Santa Ana y San Buenaventura determinaron estudiantes de la UNAH. UNAH, *Presencia Universitaria,* July 7 2016. https://goo.gl/dJVx8W

Asociación de Municipios de Honduras (1993). Ley de Municipalidades y su Reglamento. Publicado en *La Gaceta* el 18 de febrero de 1993. Available at: https://portalunico.iaip.gob.hn/portal/ver_documento.php?uid=MzczMjY3ODkzNDc2MzQ4NzEyNDYxOTg3MjM0Mg

CONADEH/MOSEF-UE/Gobierno de la República de Honduras/ICF (2016). *El gorgojo descortezador del pino y otras graves amenazas ambientales a la vida digna de los hondureños y hondureñas.* Tegucigalpa: ICF.

CONASA/PPIAF/BM (2005). *Honduras: Plan Estratégico de Modernización del Sector Agua Potable y Saneamiento (PEMAPS). Hacia una gestión descentralizada.* Tegucigalpa: Comisión Nacional de Agua Potable y Saneamiento.

CONASA (2013). *Política Nacional Sector Agua Potable y Saneamiento de Honduras.* Tegucigalpa: Comisión Nacional de Agua Potable y Saneamiento.

CONASA (2014). *Plan Nacional de Agua Potable y Saneamiento (PLANASA).* Tegucigalpa: Consejo Nacional de Agua Potable y Saneamiento.

ERSAPS/SEFIN/PROMOSAS/BM (2011). *Manual para la Identificación e Implementación de Acciones de Tercerización para Entes Prestadores de Servicios de Agua Potable y Saneamiento.* Tegucigalpa: ERSAPS.

GIZ/Ministerio Federal de Medio Ambiente, Obras Públicas y Seguridad Nuclear/CCAD/MiAMBIENTE (2016). *Desafío de Bonn-Latinoamérica 2016.* Panamá, 26 de agosto de 2016. El Salvador: REDD+ Landscape/CCAD).

Instituto Nacional de Estadísticas (INE) (2013). *XVII Censo Nacional de Población y VI de Vivienda.* Tegucigalpa: INE.

Instituto Nacional de la Mujer (INAM)/RAS-HON/WSP-LAC (2007). *La inclusión del enfoque de equidad de género en el sector de agua y saneamiento en Honduras. Diagnóstico y propuesta.* Honduras: INAM.

Joya Rodríguez, Crisly Massiel (2017). *Participación de mujeres en el uso, manejo y conservación de los recursos naturales y gobernanza del agua en la microcuenca río Marcala, Honduras.* Proyecto especial de graduación presentado como requisito parcial para optar al título de Ingeniera en Ambiente y Desarrollo en el Grado Académico de Licenciatura. Escuela Agrícola Panamericana, Zamorano, Honduras.

MOSEF/GIZ /GFA (2013). *Perfil Ambiental de País-Honduras.* Consultores: Juan Palerm, Ernesto Flórez Payarez, Hans Nusselder. Tegucigalpa: MOSEF.

OPS/OMS (2012). *Proyecto de Municipios y Comunidades Saludables. Plan de Seguridad del Agua (PSA) del Sistema de Abastecimiento de Agua Potable del Casco Urbano de la Ciudad de Siguatepeque.* Tegucigalpa: OPS/Aguas de Siguatepeque.

OPS/OMS/SESAL (2012). *Plan de Vigilancia de la Calidad del Agua en los Municipios Priorizados en el Plan Nacional de Enfermedades Desatendidas.* Tegucigalpa: SESAL.

Presidencia de la República (2010). *República de Honduras: Visión de País 2010-2038 y Plan de Nación 2010-2022.* Available at: https://eeas.europa.eu/sites/eeas/files/lc_10.pdf

Presidencia de la República (2017). *Plan Maestro de Agua, Bosque y Suelo (Plan ABS).* Available at: http://www.presidencia.gob.hn/index.php/plan-maestro

Programa de Agua y Saneamiento (PAS) (2002). *Manual de Operación Modalidades de Intervención para Proyectos de Agua Potable y Saneamiento en Barrios Peri-urbanos Marginados, Sector Rural Concentrado y Disperso.* Vol. 1. Tegucigalpa: FHIS/BM.

SESAL (1998). Reglamento General de Salud Ambiental. *La Gaceta Diario Oficial de la República de Honduras.* Núm. 28,593, June 20 1998. Tegucigalpa: Presidencia de la República de Honduras.

SESAL (2003). Ley Marco del Sector de Agua Potable y Saneamiento. Decreto N° 118-2003. *La Gaceta Diario Oficial de la República de Honduras.* Tegucigalpa: Presidencia de la República de Honduras.

Mexico

En las áreas de alta densidad poblacional, en el centro del país, se presenta la mayoría de los problemas de contaminación del agua por materia orgánica y contaminantes biológicos. El 89% de la carga total de contaminantes por DBO se genera en 20 cuencas hidrológicas que albergan 93% de la población y 72% de la producción industrial. Tan sólo las cuencas de Lerma, Pánuco, Bravo, San Juan y Balsas reciben 50% de las descargas de aguas residuales de la nación. La insuficiente infraestructura de tratamiento de agua residual municipal e industrial, así como las descargas no controladas a los cuerpos de agua, ocasionan serias repercusiones en la salud humana y en los ecosistemas acuáticos. En **México** esto se debe a la falta de normatividad, pero también, y en mayor medida, al incumplimiento de las normas vigentes y a la falta de vigilancia de su cumplimiento.

Pátzcuaro Lake from the pier of Ucazanaztacua, Michoacán © Photo by Daniel Moreno Alanís

Water Quality in Mexico[1]

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1. Introduction

Water quality is, in fact, an abstract term that only acquires practical meaning when associated with a particular use and the concentrations and values for measuring it are defined (Jiménez, 2001). This happens because the quality of water required for drinking, for example, is different from the quality required to make bricks. Thus, it may even turn out that the same compound in one case is polluting while in another it is innocuous or necessary. It is possible that toxicity values may be different. In Mexico, interest in water quality is relatively recent (dating from recent decades), since the initial concern was always related to the quantity of water. This interest has been reflected in the generation of a significant amount of information, which is presented below, dealing with institutional aspects, types of pollutants, quality problems and social aspects.

2. Water quality governance

2.1 Legal framework

Mexican legislation recognizes that water quality is important from a social, economic and environmental point of view. The regulatory framework is federal and is based on the Mexican Political Constitution (CPEUM, 1917). Article 4 states the right of every person to an adequate environment for their development and well-being; Article 25 is more explicit in pointing out the goal of integral and sustainable development for the country, as well as the need for the care and conservation of natural resources. Article 27 establishes that water is the property of the nation and stipulates the measures for preventing its deterioration and restoring the ecological balance. Likewise, the General Law of Ecological Equilibrium and Environmental Protection (LGEEPA, 1988) grants the Secretariat of Environment and Natural Resources (SEMARNAT), and the latter grants the National Water Commission the authority to implement water policy and regulatory, administration and monitoring mechanisms, whi-

*Chapter coordinators.

le municipalities have operational functions in terms of drinking water, sewerage and sanitation. The LGEEPA (1988) and the National Waters Law (1992), amended in 2004, indicate that planning, ecological zoning, environmental impact assessment, the concessions and allocations regime, wastewater discharge permits, collection of rights, self-regulation and the Official Mexican Standards (NOM) that establish specifications, conditions, parameters and permissible limits for the use of water and wastewater discharge are the instruments that materialize the constitutional precepts and national water policy. Their application is shown in **Figure 1.**

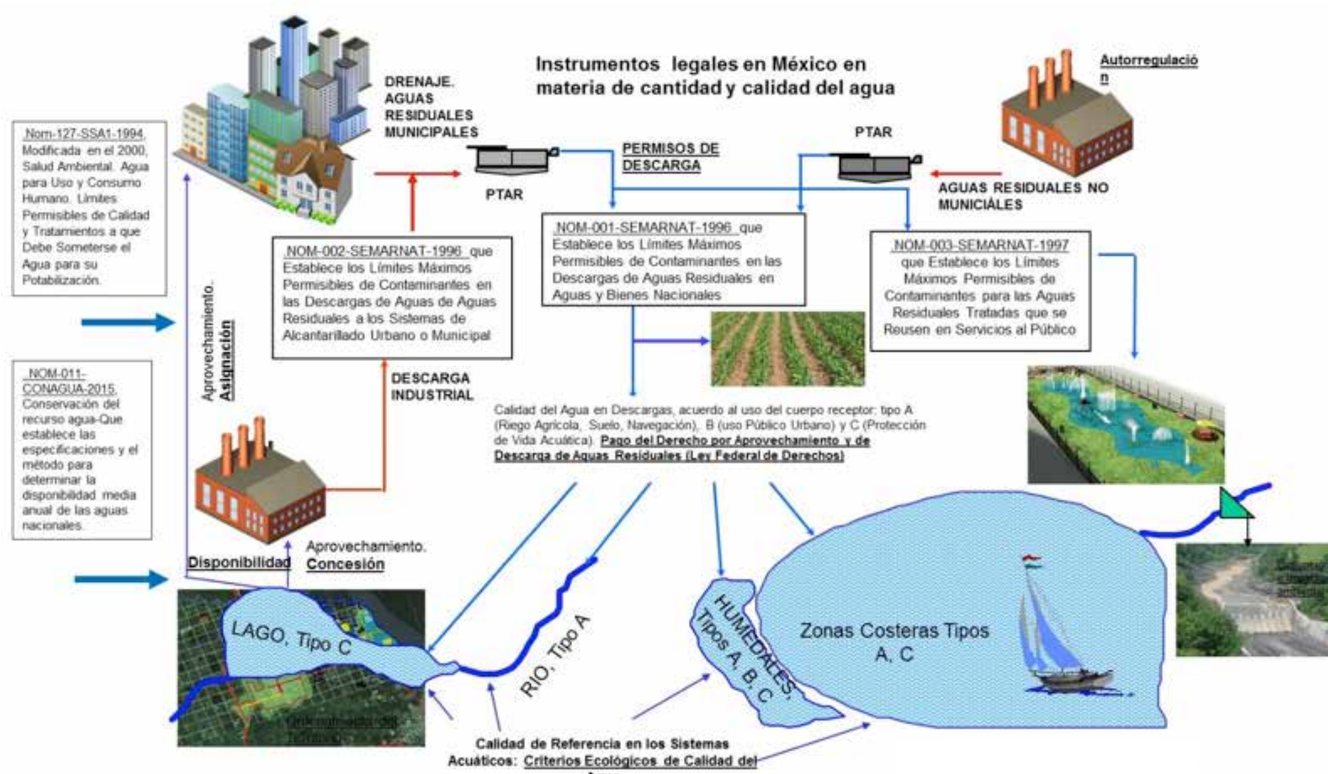
Unlike most countries, Mexican standards regulate the quality of discharges according to the use of the receiving body (water or soil), rather than doing so according to the type of discharge or capacity for assimilating contaminants. There thereby acknowledge that water is a renewable resource that is reused through the hydrological cycle and time (Jiménez, 1995 and 1996). This normative structure was established as a minimum basis to build capacity for compliance with it.

At present, there are several institutional challenges to addressing pollution problems, such as the following: (a) poor intra- and inter-institutional coordination; (b) lack of long-term water quality goals or for addressing specific problems; (c) continuous and increasing overexploitation of water; (d) a regulatory approach based solely on discharge control and with limited oversight; (f) lack of policies to prevent the generation of pollutants; (g) insufficient, inadequate wastewater treatment; (h) absence of control of diffuse contamination; (i) limited citizen participation; and (j) inefficient decentralization of functions and resources of the federation towards states, municipalities and users.

2.2 Social participation

Social participation, defined in the Law on National Waters, is achieved through the Basin Councils (Chapter IV) or the Water Advisory Council (Chapter V bis). The Basin Councils –consisting of at least 50% of users and citizen or non-governmental organizations- are jointly organized collegiate bodies for coordination, consultation, support, consulta-

Figure 1. Schematic representation of the regulatory framework for water quality in Mexico



tion and advice for better water management, the development of hydraulic infrastructure and the respective services, and the preservation of the resource. As for the Water Advisory Council (CCA), it is an autonomous consultation body composed of civil society, with an independent, proactive, plural and representative citizen perspective.

At present, the organization of users, that is, those who have a concession title, to a greater or lesser extent, is a reality in all the country's basins, but the participation of society in general is as yet incipient. The main obstacle to having this type of participation is the lack of resources, an obstacle that has been partially overcome through the will of citizens and the emergence of foundations. One example is the Gonzalo Río Arronte IAP Foundation (FGRA), founded in 2000, which had funded 204 projects by 2015. However, the resources that can be channeled by NGOs are still insufficient for achieving the full participation of civil society. Another relevant example of social participation in Mexico is the "Water for All, Water for Life" movement that integrates indigenous peoples, social organizations, workers, community water management systems and researchers committed to the construction of the democratic government of water and the territory. More than 420 researchers and organizations participated in this initiative in workshops held in 26 states in Mexico with the aim of preparing a new proposal for the Water Law. A third example is the citizen observatories that monitor drinking water and sanitation services, particularly in the cities of La Paz, Valle de Bravo, San Miguel de Allende, Xalapa and Tuxtla Gutiérrez.

2.3. Monitoring and database

Since 2012, the National Water Commission has systematically monitored the quality of the country's water resources. The National Water Quality Measurement Network covers 40 parameters at 5,000 measurement sites (**Figure 2**), including dams and lakes (840), rivers (2,041), coastal zones (939) and wells (1,180). The results are recorded in the Water Quality Information System (SICA, 2016), a databa-

Figure 2. National Water Quality Measurement Network

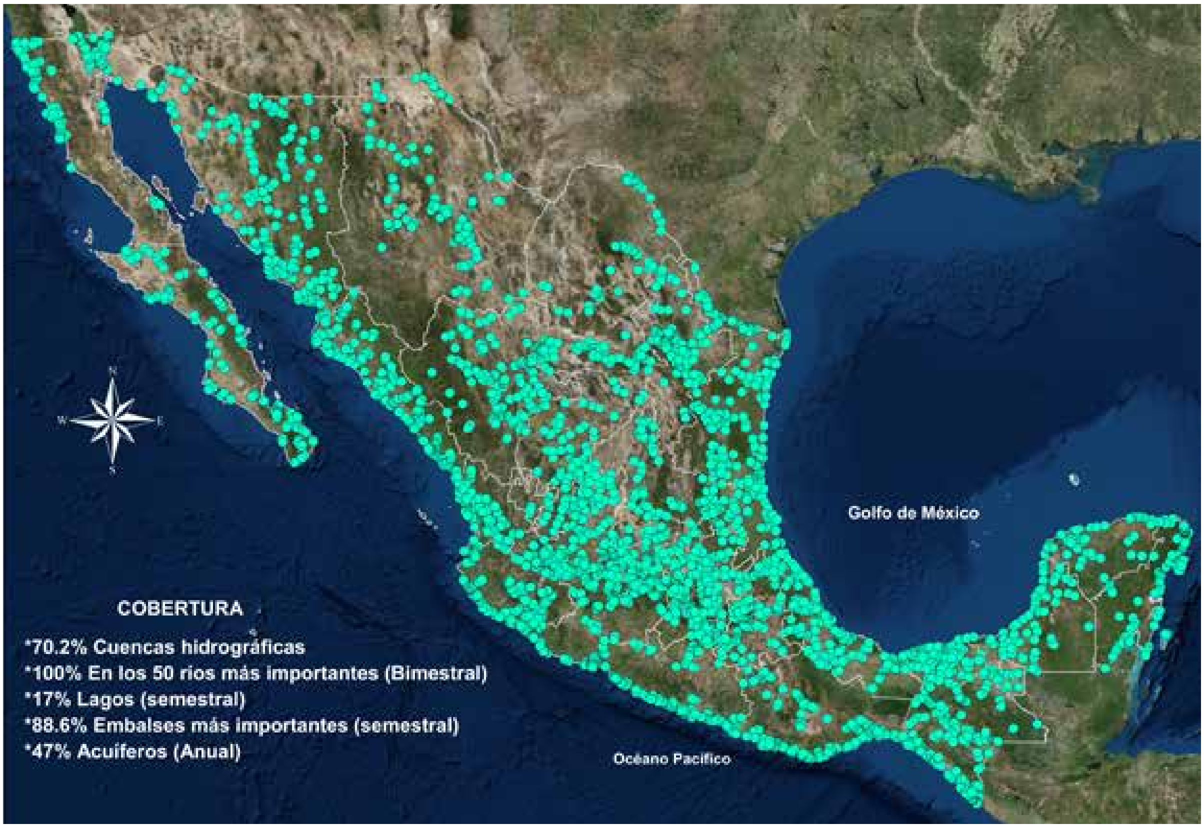
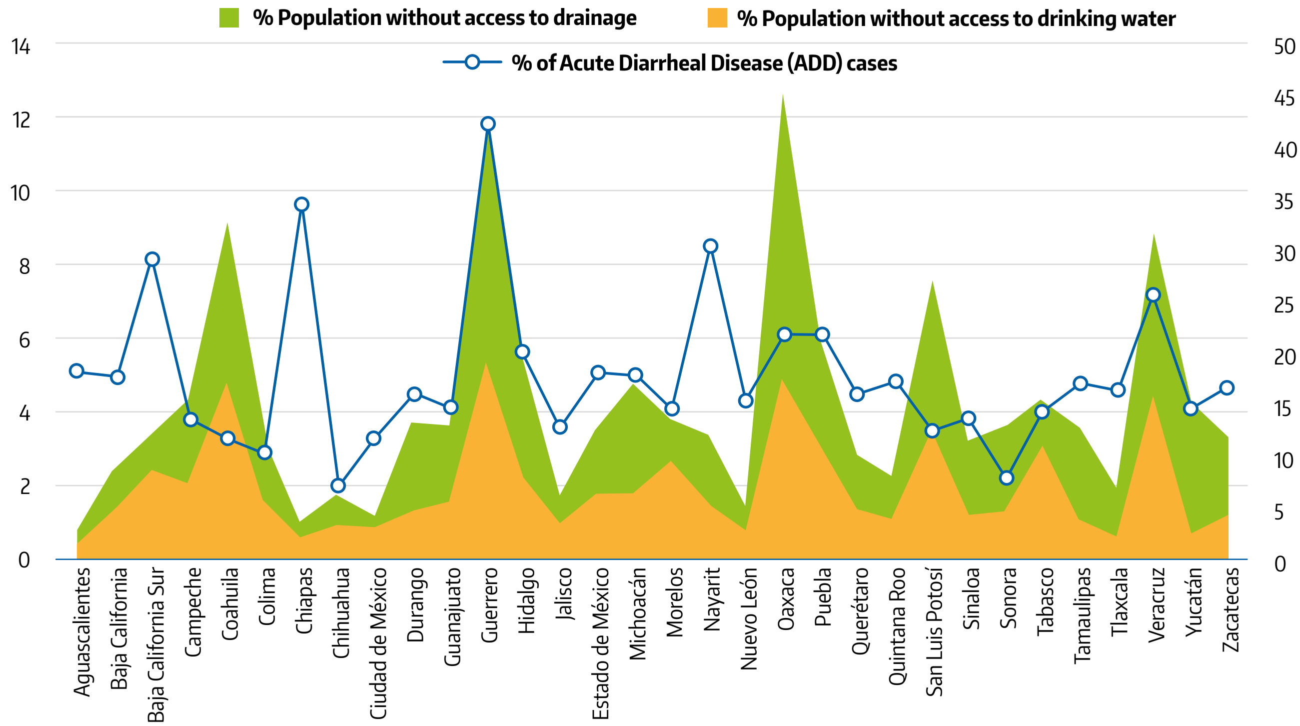


Figure 3. Incidence of diarrheal diseases and population without access to drinking water and sanitation



Source: INEGI, 2015.

se partially open to the general public, which is essential for planning and evaluating pollution prevention and control actions. According to SICA, for surface water, 92% of the sites have an excellent to acceptable quality in terms of BOD5 (Biochemical Oxygen Demand), 68% in terms of Chemical Oxygen Demand and 93% as regards total suspended solids. Eighty per cent of the sites have a content that is less than or equal to 1,000 fecal coliforms (NMP/100 ml). In areas identified as contaminated, sanitation, inspection of sources and administrative sanctions against polluting companies are promoted.

3. Country water quality

3.1 Situation of water resources

The problems of water resource contamination are serious, since available treatment systems remove 19% of the biodegradable matter (BOD5) generated by municipal discharges, which is equivalent to pouring 9.7 tons of BOD5 into the environment annually (CONAGUA, 2016).

3.1.1 Surface bodies

The inadequate municipal and industrial wastewater treatment infrastructure and uncontrolled discharges of 8% of the population into surface water sources (CONAGUA, 2016) cause microbiological, organic and nutrient contamination of water with serious repercussions for aquatic ecosystems and human health. Lack of drainage and treatment is related to a higher incidence of intestinal diseases, which affect up to 12% of the population in certain states in the country (**Figure 3**).

3.1.2 Groundwater

In Mexico, groundwater accounts for about 40% of the total volume of water concessioned for use in public supply (60.5%) and agricultural irrigation (35.5%) (CONAGUA, 2016b).

The importance of groundwater[1] is reflected in the magnitude of the volume used by the main users, since 38.9% of the total volume concessioned

1. Of the 348m^3 per second of water supplied in the country, it is estimated that 60.5% comes from underground sources (CONAGUA, 2016b).

for consumptive uses[2] (33,311 hm^3 per year to 2015) comes from groundwater, the largest user being the agricultural sector, which uses 35.9% of the total volume (CONAGUA, 2016a).

The groundwater system consists of 653 aquifers, of which availability is greater than exploitation in 498, 18 have problems due to marine intrusion, 32 contain brackish water and the remaining 105 are overexploited. Agriculture is a major cause of overexploitation, but also of groundwater pollution, mainly in the north and center of the country. Agriculture pollutes groundwater through fertilizers (nitrogen inputs) and pesticides used to increase crop productivity. Persistent pesticides have been found in aquifers throughout Mexico, for example, in Jalisco (Sandoval Madrigal, 2015), Yucatán (Metcalfe *et al*., 2011), Sonora (García de Llasera and Bernal-González, 2001), Sinaloa (García- Gutiérrez and Rodríguez-Meza, 2012), Guanajuato, State of Mexico (Vicenta Esteller and Díaz-Delgado, 2001) and Hidalgo (Downs *et al*., 1999). Although the Mexican Inter-Secretariat Commission for the Control of the Process and Use of Pesticides, Fertilizers and Toxic Chemicals (CICOPLAFEST) has restricted the use of certain pesticides since 1988, implementation of this policy has been difficult and inconsistent. Recently, the Program for the Monitoring and Evaluation of Persistent and Bioaccumulative Substances (STPB) for Watersheds and Aquifers was formed to quantify STPB, including pesticides, in the groundwater of Río Fuerte, Zacatepec, Tuxtla Gutiérrez, Cuernavaca and the Ocosingo Aquifer. However, a great deal of research is still required in this area to understand the extent of the problem (Hansen, 2012b).

Another important source of contamination of groundwater is saltwater intrusion. This process occurs when seawater infiltrates coastal aquifers, polluting them. The best known cases in Mexico are found in Baja California, Baja California Sur, Sonora and the Yucatán Peninsula. In the future, this phenomenon will be exacerbated by the combined effect of overexploitation and sea level rise as a result of climate change (Cardona *et al*., 2004, Metcalfe *et al*., 2011, CONAGUA, 2015). This process is similar to the intrusion of geothermal water that occurs in Puebla and other states in the north of the country, where groundwater is contaminated with sulfur and other dissolved solids (Flores-Márquez *et al.,* 2006).

Various processes and the geological environment can cause high concentrations of contaminants in the water supply, making it unsuitable for potable water, or other uses (such as irrigation and aquaculture). In Mexico, groundwater is naturally contaminated by arsenic (As) and/or fluoride (F-) in various places (Armienta and Segovia, 2008). In these mineral regions, arsenopyrite or scorodite release large concentrations of arsenic into the water, as has happened in Zimapán, Hidalgo, and possibly in Villa de la Paz, SLP (Armienta *et al*., 2001, Razo *et al*., 2004) . Another example is the interaction of thermal water with fluorite from volcanic rocks, which causes the contamination of drinking water with fluoride in San Luis Potosí (Carrillo-Rivera *et al*., 2002). In Hermosillo, Sonora, the presence of fluoride (F) is due to its release from granites (Valenzuela-Vásquez *et al*., 2006). In the central zone of Chihuahua, where there are high levels of both arsenic and fluorine, its presence is due to the interaction of water with rhyolites (Reyes-Gómez *et al*., 2013). The water-rock geochemical processes combined with thermal waters lead to high concentrations of F- and As in Juventino Rosas, Guanajuato, and in Los Altos de Jalisco (Hurtado and Gardea-Torresdey, 2004, Morales *et al*., 2015). The desorption of As in granular aquifers leads to contamination in the Comarca Lagunera (Durango, Chihuahua and Coahuila), which is also exacerbated by evaporation (Molina, 2004, Ortega-Guerrero, 2004). The Comarca Lagunera has seen significant health problems due to the chronic intake of water with As from 1958 (Cebrián *et al*., 1994). Mining waste is also a source of pollutants such as arsenic, but it is extremely difficult to detect as a source of pollution in areas naturally enriched with this element.

The problem of arsenic and fluoride contamination has been partially solved but only in certain areas. In Chihuahua, for example, reverse osmosis systems were installed to treat drinking water and offer it at low cost. However, not all the population uses this water, possibly because they must take containers to fill up with water. Elsewhere, the authorities mix contaminated water with good or better quality water, to dilute the content of As and F-. Another solution has been to replace groundwater

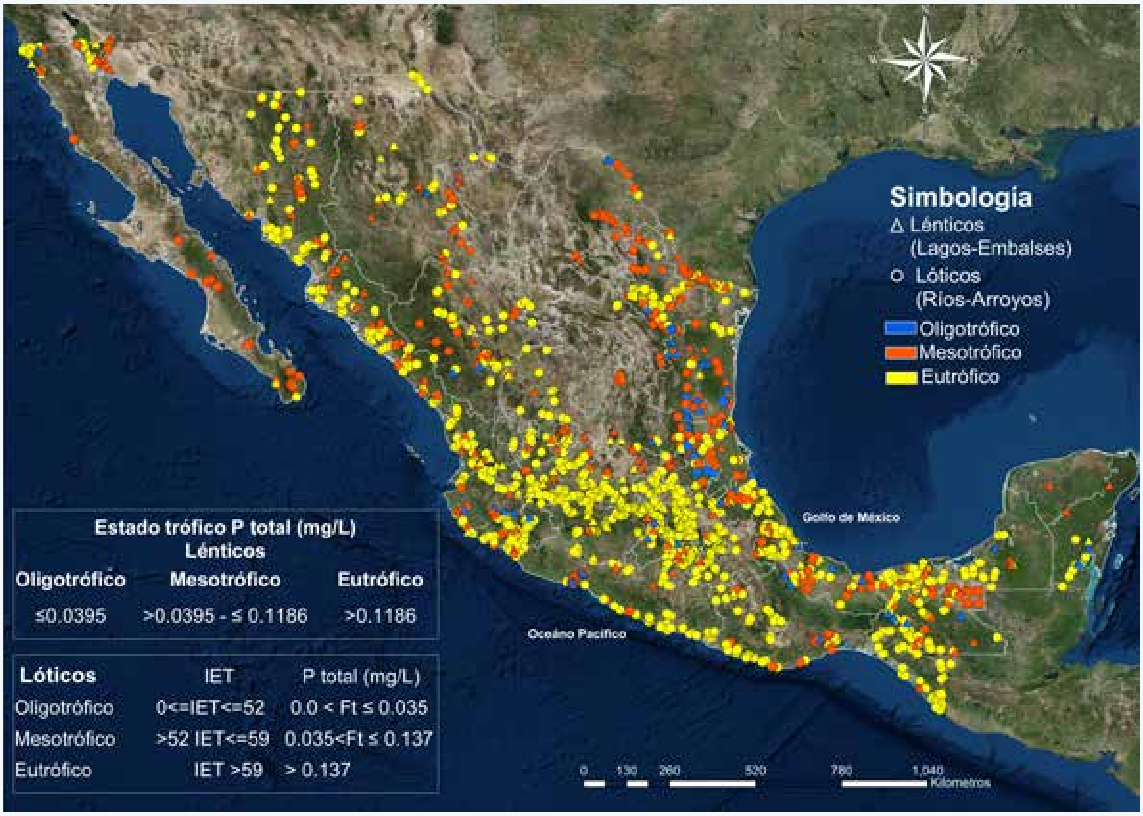
2. Consumptive use is the difference between the volume extracted and the volume discharged when undertaking an activity.

Table 1. Eutrophication

Eutrophication causes the depletion of water oxygen, the rapid increase of aquatic plants, fish mortality and risks to human and animal health due to the presence of toxins. According to SICA (2016), eutrophication is a major problem in Mexico. Using the CEPIS classification (2001) for lakes and tropical reservoirs, of 321 lentic water bodies evaluated from 2012 to 2016, 39% are eutrophic (with abundance), 44.2% mesotrophic (intermediate condition) and 16.8% oligotrophic (with shortages) (Figure 4). For tropical rivers and using the Carlson Index modified by Lamparelli (2014) for 1,963 measurement sites, 80.1% are eutrophic, 18.9% mesotrophic and 1% oligotrophic. Moreover, in 54% of these, detergents (SAAM) were found in concentrations above the Ecological Water Quality criterion for the protection of aquatic life of 0.1 mg/L (DOF, 1989).

Solving the problem requires purification processes that eliminate nitrogen and phosphorus from water (which is expensive), using cleaner production techniques, such as producing low-phosphorus detergents and controlling diffuse contamination, mainly due to the use of synthetic fertilizers in agricultural areas. An extreme case of eutrophication occurs in Lake Patzcuaro.

Figure 4. Eutrophication of water bodies in Mexico



with surface water, but this cannot be done in many arid or semi-arid areas where the problem exists. In Zimapán and other places, treatment systems have been set up to remove arsenic and sometimes also fluoride, but due to operating and maintenance costs, many municipalities operate the plants intermittently or simply abandon them. Both arsenic and fluoride can cause severe health damage (such as cancer, diabetes, hypertension, cognitive problems, dental and bone disorders and gangrene).

There are also pollution problems due to the incidental recharge of aquifers with wastewater, which contributes pathogens, heavy metals and emerging pollutants (Gallegos *et al*., 1999, Chávez *et al*., 2011), and aquifers may be contaminated with discharges from the mining industry. However, many new exploitation practices -such as shale gas extraction of - are not contemplated in the water quality regulations (De la Vega Navarro and Ramírez Villegas, 2015).

3.2 Status by type of pollutant

3.2.2 Organic and biological contamination

Most problems of contamination by organic matter and biological contaminants are found in areas with high population density, particularly in central Mexico. In fact, 89% of the total pollutant load per BOD in the country is generated in 20 basins that are home to 93% of the population and 72% of industrial production. The Bravo, Pánuco, Lerma, San Juan and Balsas basins receive 50% of the nation's wastewater discharges (CONAGUA, 2016).

In southeast Mexico, where the Balsas, Pacífico Sur and Lerma-Santiago-Pacífico hydrological administrative regions are located, agricultural activities are the main source of the economy. In this region, the main sources of contamination by organic matter are the sugar, tanning, paper mill and pork industries.

In the state of Sonora, in northwestern Mexico, the Yaqui and Matape rivers have severe problems of organic contamination in the lower parts of the basins, caused by urban, agricultural and industrial discharge. The contamination of the Yaqui River is aggravated by the presence of pesticides that come from nearby agricultural fields, as well as by high salinity caused by high evapotranspiration and/or marine intrusion (Vega-Granillo *et al*., 2011).

In the Lerma-Chapala basin, which is the largest in the country, although industries generate a low volume of wastewater, they discharge 130,500 tons/year of biochemical oxygen demand (BOD). Organic non-point pollution also comes from the El Bajío area, in the lower Lerma River, together with livestock waste, particularly from pig farms. The food industry in the area is also a source of non-point pollution, albeit to a lesser extent.

With respect to coliforms, most of the microbiological loads are found in the Lerma-Chapala and Balsas basins, particularly in the states of Michoacán, Jalisco, Guanajuato, Querétaro, Mexico, Morelos and Puebla, where most of the waste is untreated livestock and municipal wastewater (CONAGUA, 2016).

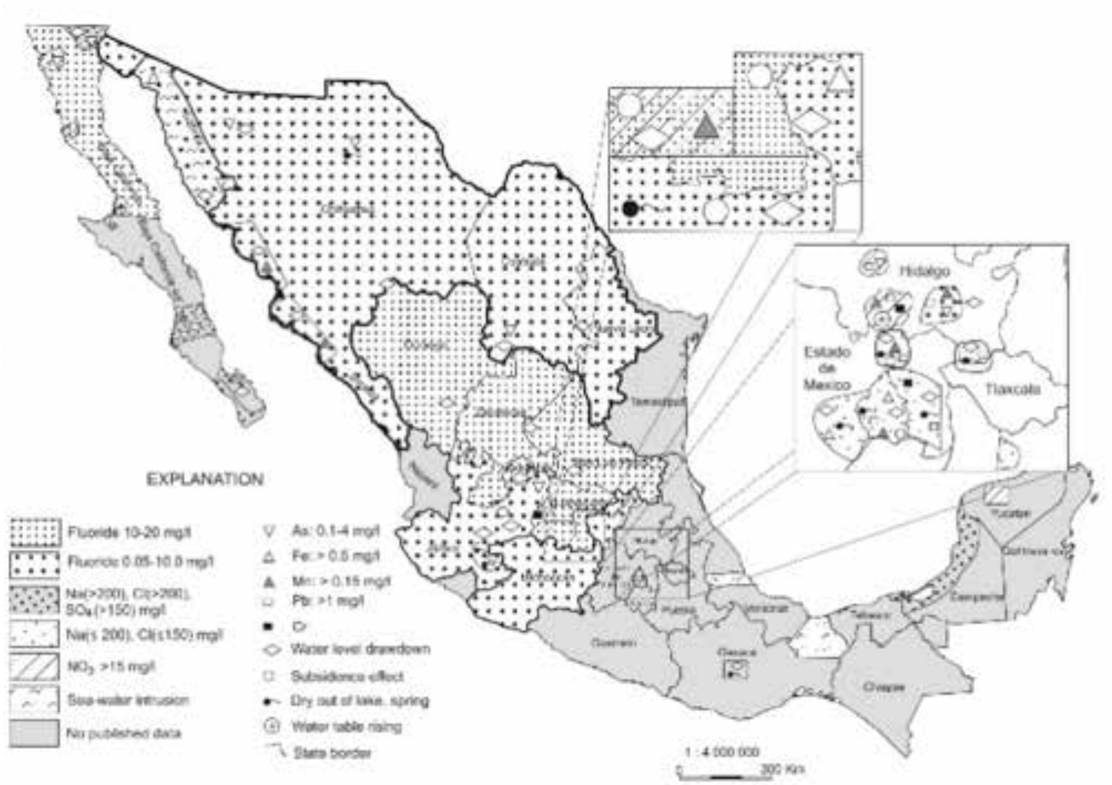
3.2.3 Agrochemicals

Agrochemical use is widespread in Mexico in both extensive and subsistence agriculture. On the one hand, the amount of fertilizers used in the country has become generalized, while at the same time, its use has intensified, from 62.3 kg/ha in 2002 to 83.6 kg/ha in 2014 (datos.bancomundial.org). Thus, in 2014 it accounted for a total of 4.2 million tons. A review of cases at the national level (Sánchez-Guerra *et al*., 2011) found that the problem is not only is the use of pesticides per se, but also their inadequate application. This has caused poisoning in agricultural workers and their families, causing a decrease in sperm counts and genotoxic effects, among other health problems. Unfortunately, the high marginalization of agricultural areas means that agricultural workers are unaware of the risks of their use. In addition to the above, Mexico continues to use pesticides that have been banned internationally. This is partly due to the fact that the list of dangerous pesticides (19 in total) has not been updated since 1991 by the Federal Commission for Protection against Sanitary Risks (COFEPRIS). At the same time, there is very little follow up on the existing regulations on the manufacture, import, storage, distribution, sale and application of agrochemicals of the Secretariat of Health (SSA), the Secretariat of Environment and Natural Resources (SEMARNAT) and the Secretariat of Agriculture, Livestock, Rural Development, Fishing and Food (SAGARPA).

The problem of contamination by water pesticides is already widespread in the country. On the one hand, in the states where intensive agriculture exists -such as Sinaloa, Sonora and Guanajuato-, the application of agrochemicals is also intensive. On the other hand, in places with subsistence agriculture, agrochemicals are also used, albeit on a smaller scale, but with even more precarious protection measures, causing water, soil and air contamination with the associated increase in risk to human and environmental health.

Like many cases in the country, the existence of a regulatory framework must be accompanied by an operational framework that facilitates its application. In addition, and in order to reduce their con-

Figure 5. Main sites with problems of groundwater quality due to their excessive industrial and urban use or where lack of understanding of how groundwater works creates quality problems due to their extraction



sumption, alternatives should be offered to producers, such as economic incentives to adopt the use of organic agriculture or Integrated Pest Management (IPM). It is extremely important to train field people about the risks associated with the pesticide management, both for human health and for the environment.

3.2.4 Metals and metalloids

Metals enter water systems from various sources such as smelting, refining and fuel burning, as well as leaks, waste water discharges, dumping and leaching from garbage. Some metals are highly toxic even at very low concentrations, such as lead, mercury, cadmium, chromium, copper, zinc, aluminum, beryllium, cobalt, thallium, vanadium, nickel and metalloids such as selenium and arsenic. The fate of these metal(oids) in bodies of water is governed by numerous processes that include sorption/desorption, precipitation/dissolution and complexation/dissociation. Some metal(oid)s are also sensitive to changes in an oxide/reduction state. Once in the water bodies, the metal(oid) is transported from the water column to the sediment by depositing particles of organic matter and iron and manganese oxides, where they are accumulated, meaning that the sediment acts as the destination of the metal(oid)s. In Mexico, governments, nongovernmental organizations, universities and research centers conduct metal(oid) sampling studies in water bodies. However, continuous metal(oid) monitoring programs have not been established and, therefore, there are no formal inventories of these pollutants or the risk of exposure they represent. Sediment monitoring is not an established practice either, although this makes it possible to determine the historical evolution of the contamination (Hansen *et al.*, 2013).

3.2.5 Salinization

Excessive groundwater extraction of is one of the causes of the calinization of groundwater in the country. According to various publications and theses (Carrillo-Rivera *et al.*, 2008) (**Figure 5**), this has mainly been observed in areas that obtain their groundwater supply from fractured rock in the Sierra Madre Occidental (such as the states of Aguascalientes, Baja California, Coahuila, Chihuahua, Durango, Guanajuato, Jalisco, San Luis Potosi, Zacatecas), or from a granular medium in very thick sedimentary basins (such as Mexico City) and coastal zones (such as Baja California, Sonora). The water extracted in different places often reaches alarming levels - above the water quality standard - in terms of total dissolved solids, sodium, fluoride, radioactivity or arsenic content, among others. The response of the type of groundwater and its content in salts, as well as its corresponding control before the water reaches the extraction pump, has been defined by applying the operation of the Tóthianos groundwater flow systems (SFTAS), a methodology which, although its application has been continuously published since the 1990s, should be included in a specific law to direct any environmental activity related to groundwater. Correcting salinization requires understanding the problem before acting using the SFTAS methodology. The objective is to understand how it will be possible to control the appropriate processes related to the increase in salinization before this effect occurs and is observed in an extraction well. However, this solution, being more economical and more respectful with the environment, attracts less attention than structural solutions that often create additional undesirable environmental effects.

Table 2: Is the Water Balance a solution?

Perhaps one of the difficulties of solving the issue regarding which scientific methods to use to solve the problem of groundwater salinization is to face the already established "method" of studying groundwater. This has been the standard procedure in many countries. In Mexico, it began in the mid-60s under the name of Geohydrology: the “water balance”, an approach that is purely static and in direct conflict with the systemic vision of groundwater functioning. The interpretation of groundwater data based solely on the hydraulic response is often inadequate because it overlooks chemical, biological and geological evidence. For example, the uncontrolled extraction of shallow groundwater in San Luis Potosí (north-central Mexico) leads to the blending of a cold, low fluoride and sodium flow, as well as a deep, fluoride-rich thermal flow, in different proportions. This has resulted in a mixture in the extraction well producing a flow with a high fluoride (≥4.1 mg · l-1) and sodium (≥60 mg · l-1) content, which is dangerous for human health and farming. The mixture of flows is carried out depending on the flow of extraction, local hydrogeology, as well as the design, construction and operation of the well. Understanding the groundwater flow system provides alternative solutions for controlling and regulating the flow of water from deep flows and taking advantage of the chemical reactions that control the solubility of fluoride, which can precipitate it before it reaches the extraction well.

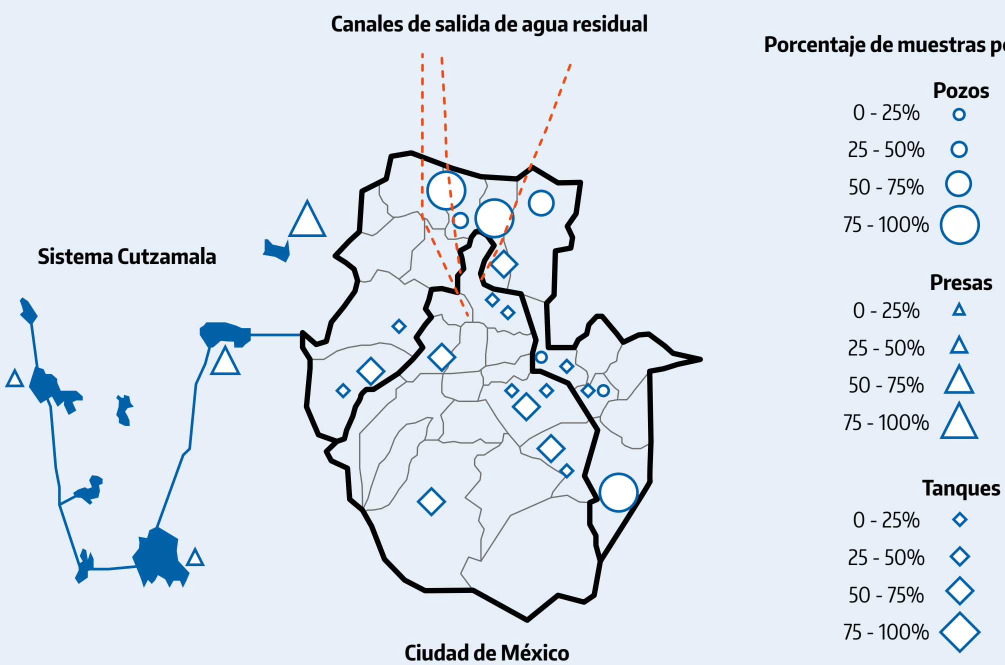
3.2.6 Emerging contaminants

Emerging contaminants are the active compounds present in everyday products, such as medicines, personal care products and nanomaterials. Wastewater is one of the sources of these pollutants in the environment. Although the toxic effects caused by emerging pollutants are still poorly understood, the precautionary principle requires strategies for monitoring them and remove them from wastewater. After China, Mexico is the country with the highest rate of reuse of raw wastewater for agricultural irrigation (Jiménez and Asano, 2008), as a result of which continually high loads of emerging pollutants enter agricultural soils and can migrate to water reservoirs adjacent to irrigation zones (see **Table 3**). Previous monitoring studies have systematically found the presence of emerging contaminants in the wastewater of Mexico City, at levels of µg/L to ng/L (Gibson *et al*., 2007, Siemens *et al*., 2008, Durán *et al*., 2009, Chávez *et al*., 2011). Unfortunately, no published reports have been found that show their presence in the wastewater of other megacities, border areas or populations along the Mexican coast. More recently, a study by Félix-Cañedo *et al*. (2013) found the presence of drugs, plasticizers and surfactants in the aquifer and surface supply sources in Mexico City. The origin of such contamination was attributed to leaks in the obsolete drainage network of the city. Previously, Metcalfe *et al*. (2011) reported the presence of drugs and illicit drugs in the waters of the cenotes (limestone sinkholes) of the Yucatán Peninsula, which was also related to wastewater infiltration. Due to their physical and chemical properties, most emerging pollutants are poorly removed in conventional wastewater treatment systems (Miege *et al*., 2009), so, even if the current treatment rate in Mexico were

Table 3. Emerging contaminants in Tula Valley

Wastewater from Mexico City is reused without previous treatment, for irrigating forage crops in Tula Valley, 90 km north of the city. The irrigation method involves flooding plots, which causes the water to infiltrate the subsoil. The emerging contaminants present in the wastewater are mostly adsorbed by the soil. However, some of them manage to reach the aquifer, which is why traces (ng/L) of the most water-soluble contaminants have been found in the groundwater and springs of the Tula region. A macro treatment plant for wastewater in Mexico City has recently begun operating. The lower content of organic matter in irrigation wastewater can cause a decrease of the latter in the soil and therefore mobilize the emerging contaminants held there. It should be noted that one of the main uses of the Tula aquifer is for human consumption.

Figure 6. Presence of emerging pollutants in groundwater (wells) and surface (dams) sources in Mexico City and storage tanks where water is kept before being pumped to the network



The marks indicate the frequency with which pharmaceutically active substances were found in the water samples taken (n = 10).

increased, a significant reduction in the pollutant loads in the treated water would not be expected. Currently, tertiary treatment systems based on bioreactors with membranes are being developed (Estrada-Arriaga and Mijaylova, 2001) together with advanced oxidation processes (Durán *et al.*, 2016), which show high removals of emerging pollutants in wastewater, but are extremely expensive. Given this situation, one way to reduce the problem is through the use of cleaner production methods in the industry that avoid the use of this type of compounds in the products society uses.

3.3 Deforestation and water quality

Deforestation impacts on the provision of environmental services by the soil and results in biodiversity loss, the disruption of hydrological and geochemical cycles, and an increase in greenhouse gas emissions (Masera *et al.*, 1997; Maass *et al.*, 2005; Galicia and Zarco, 2014). In Mexico, deforestation has been more intense in the tropical region of the country (Palacio *et al.*, 2000, Velázquez *et al.*, 2002), where over 95% of the original tropical forest cover has been lost (Durán and Lazos, 2004). Official data indicate that the states of Campeche, Chiapas, Jalisco, Quintana Roo and Yucatán report the highest rates of deforestation in the country (IRE, 2016). The problem is also observed in Aguascalientes, Veracruz and Oaxaca (Chapa *et al*., 2008; Vaca *et al*., 2012; Chevalier and Buckles, 1995; Dirzo and García, 1992; Palacio *et al*., 2000; Velasco-Murguía *et al*., 2014; Corona *et al*., 2016).

Forests contribute to the maintenance of water quality in watersheds by preventing soil erosion. When deforestation occurs, there is an increase in runoff, which transports the eroded soil to the bodies of surface water, carrying with it a series of pollutants including carbon, nitrogen and phosphorus, which are the main causes of eutrophication. In Mexico, deforestation due to the conversion of forest to agricultural and urban land, or even due to climatic effects, has caused serious water quality problems in various regions. Some examples of this are found in the Yucatán peninsula (Evans, 2012, Trujillo-Jiménez *et al*., 2011), in the upper basin of the Lerma River (García-Aragón *et al*., 2007), and in the accumulation of arsenic and chrome in Miramar Lake in Chiapas (Hansen, 2012a). One of the areas whose surface water sources have been most impacted by deforestation is the mountains in the state of Veracruz (Martínez *et al*., 2009).

4. Economic and social costs

4.1 Health

Chapter 4 of the Mexican Constitution stipulates that "everyone has the right to access, dispose of and sanitize water for personal and domestic consumption in a sufficient, healthy, acceptable and affordable manner" (DOF, 2017). Healthy water refers to two aspects: on the one hand, having enough to live on and perform daily activities and, on the other, ensuring that the available water is safe or innocuous in terms of not causing illness or harm to the consumer.

The most frequent source of pollution, whose effects can trigger acute damage to the health of the population, is wastewater due to its fecal matter and pathogen content (Maier *et al*., 2009). At the same time, wastewater may contain toxic chemicals, many as waste from industrial processes that can cause long-term illnesses.

Food production is the activity that consumes the most water and it is important that this water be used safely for health. In Mexico, wastewater is used for irrigation in various areas without the assessment or monitoring of potentially associated health risks. Due to water resource management in Mexico, nowadays it is not only necessary to consider water for human use and consumption, but also to expand the possible route of exposure through vegetables, especially those that are consumed raw.

4.1.3 Water-related diseases

These are diseases that can be acquired through ingestion or contact with contaminated water. In Mexico, the Secretariat of Health, through the Federal Commission for Protection from Sanitary Risks (COFEPRIS) and the General Directorate of Epidemiology (DGEPI), is the entity authorized to undertake epidemiological surveillance, which makes it possible to monitor cases of illness at a national level, including those that can be caused by the consumption of water and contaminated food. Official health data published by the Secretariat of Health (SS, 2016 and 2017) show that infectious intestinal diseases caused by microorganisms include bacteria: *Salmonella typhi, S. paratyphi, Shigella dysenteriae, Sh. flexnieri, Sh. bioydii, Sh. sonnei,* enteropathogenic, enterotoxigenic, enteroinvasive, enterohemorrhagic *Escherichia coli*, as well as protozoan parasites such as *Entamoeba hystolitica, Giardia lamblia and Cryptosporidium* spp., and intestinal infections due to viruses such as enterovirus, rotavirus, acute hepatitis A (Knepper and Ternes, 2010), as well as other viral hepatitis, which can be associated with transmission through the consumption of water and vegetables irrigated with water contaminated by faeces. It should be noted that, particularly for bacteria, one of the most worrying aspects –in addition to their presence in water- is the resistance to antibiotics caused by the large dispersion of drugs discharged into bodies of water through wastewater that has not been previously treated (Dalkmann *et al*., 2012).

4.2 Poverty

At present, 6.5% of the Mexican population speaks an indigenous language, although a much higher percentage self-identify as indigenous: 21.5% (INEGI, 2015). The 78 ethnic groups (Zolla *et al*.,

2004) identified live in 25 regions in the south, center and north of the country and 23% of the biocultural indigenous territory is located in the headwaters of the basin (Boege, 2008). In indigenous municipalities, the population lives in conditions of poverty ranging from 80% to 89%, with 41% to 50% living in extreme poverty. The highest concentrations of indigenous poverty are found in: Oaxaca (32.2%), Yucatán (28.9%), Chiapas (27.9%), Quintana Roo (16.6%) and Guerrero (15.3%) (Coneval, 2014). Associated with poverty and marginalization, the coverage of potable water services in housing in the indigenous municipalities is only 40.2% while that of drainage services is only 25.5% (INEGI, 2015).

Indigenous people not only obtain water for domestic use from these conventional systems, but also from springs, rivers, wells, waterholes and streams. The contamination of bodies of water therefore affects them directly. In states where poverty is more acute there are water quality problems only identified in this paper as areas of high contamination (CONAGUA, 2013).

4.3 Education

According to CONAGUA, an effective program of sustainable water management requires participation from individual citizens to community organizations or non-government social organizations. To this end, during the past decade, government programs have been launched to promote the culture of water use and conservation among the population of Mexico.

In accordance with the evaluations that have been undertaken of the effectiveness of these programs, assessment has focused on compliance with the implementation of the programs and the use of economic resources for dissemination and population training activities, but does not quantify the effect of programs on people (González and Arzaluz, 2011). In other words, there is no reliable information to prove that the population is acquiring knowledge and developing conservation practices and sustainable use of water.

4.3.1 Education and curriculum programs

In 2013, Mexico began undertaking a sweeping education reform that ultimately led to the development of a new proposal for an education model, particularly an adaptation of curricular contents. This new model is designed for compulsory education (from 3 to 17 years old), which includes the levels of basic education (pre-school, primary, and secondary) and upper secondary education. An analysis of the new education model shows that the subject of water quality is approached from a basic descriptive perspective and more for consumption purposes regulated by the characteristics of water scarcity.

The document on the new education model, for the level of basic education (from 3 to 14 years old), establishes the field of Exploration and Understanding of the Natural and Social World. It includes the subjects of knowledge of the environment, natural sciences and technology, and geography where specific curricular contents on the subject of water are limited to promoting the prevention of water and soil contamination, and general concepts on sustainable consumption in climate change mitigation. At the level of upper secondary education (from 15 to 17 years) there is no explicit reference to the issue of water.

A critical review on the subject shows that the topic of natural resources is approached as a series of curricular contents that are covered in class hours, yet the topics concerning environmental sustainability and use of common resources are not seen as a cross-cutting issue encompassing several disciplines on the curriculum. In particular, the issue of water is seen as a limited resource that requires administrative regulations for its exploitation. This is a limited vision that does not form a global awareness of the citizen responsibility children and young people will have in the future to guarantee the sustainability of the common resources of the planet.

4.4 Gender

Women and men have a different relationship with water, since they have different interests and perceptions about it. This is due to the role society assigns to each one; For example, due to gender roles, women are more -although not exclusively- aware of water problems in the domestic sphere (low availability, shifts, poor quality, increased rates, etc.), while men know more about the status of water in production (RGEMA, IMTA, UNDP, 2006).

When there are water-related problems, women are responsible for finding solutions to provide water in their homes, which adds to the domestic work for which they are usually responsible. These activities may add 30 hours a week to the time used by both rural and urban women (MMA, 2012).

4.5 Rural areas

Providing water and solving sanitation issues in rural communities in Mexico is a major challenge due to the poverty conditions and characteristics of rural communities in the country. In 2010, one out of four Mexicans lived in any of the 188,593 localities with fewer than 2,500 inhabitants; 139,156 of which have fewer than 100 inhabitants (INEGI, 2010). According to CONAPO calculations, three out of every four rural localities have a high or very high degree of marginalization and are home to 61% of the rural population. Marginalization in rural settlements tends to increase as they move away from larger human settlements and communication routes. The states with the greatest number of people living in rural areas are: Veracruz, Chiapas, Oaxaca, State of Mexico, Puebla and Guanajuato.

According to the results of the Intercensal Survey of 2015 conducted by INEGI, 31.0% of the homes in rural communities with fewer than 2,500 inhabitants do not have any drainage, so their inhabitants defecate in the open air, while the inhabitants of 40.0% of the homes have to fetch water from relatively nearby sources, although sometimes they sometimes have to carry it for long distances.

The problem of the geographical dispersion of these communities is compounded by the low public investment in the water supply and the improvement of drainage and sewerage services for these communities. In recent years, although the amount of investment for infrastructure has increased, it has not been enough since major differences persist.

4.6 Urban areas

At present, 78% of the Mexican population lives in cities, in other words, in localities with more than 2,500 inhabitants. The National Urban System comprises 384 cities, 11 of which have over one million inhabitants, and is home to 41.3 million people, accounting for 51% of the total national population (CONAPO, 2012). Mexican cities have 95.4% potable water service coverage and 96.3% sewerage coverage. Nationwide, approximately 10 million inhabitants lack piped water and 11.5 do not have access to sewerage (CONAGUA, 2015).

The aforementioned coverage indicator is insufficient, since it does not make it possible to identify the inequalities that occur within each city, in terms of the quality of the water received and the frequency with which it is received (PUEC-UNAM, 2011). However, an approximation of the quality of the water received in urban dwellings can be seen in the results of a survey conducted in Mexico City, which found that 77% of the population obtains drinking water by purchasing water in a carboy or bottled water; 11% boil tap water; 4% install filters in their taps and only 5% drink it directly from the tap (INEGI, 2008).

Distrust in the quality of piped water has increased in recent decades. One indicator of the population's distrust of tap water is the enormous growth of the bottled water market. According to a study by the Inter-American Development Bank, the per capita volume of bottled water consumed in Mexico is the highest in the world. In 2010, Mexico consumed 46% of the total bottled water in Latin America (IDB, 2010).

On the other hand, since the constitutional recognition of the human right to water in 2012, the poor quality of water accessed by a given population can be denounced as a violation of that right (CEUM, 2012). Thus, in addition to being a poorly measured phenomenon, poor water quality has potentially become an element of mobilization of civil society to demand a human right.

4.7 Conflicts related to industry, mining and agriculture

Social conflicts over water quality are triggered when local communities perceive that water contamination creates a risk of contracting certain diseases or because it directly affects their economic activities, mainly fishing or farming (Ávila, 2003). To a lesser extent, citizen interest may demand the need to protect aquatic ecosystems, or modify the health paradigm of urban development that has used rivers and lakes as part of the drainage system (González *et al.*, 2010).

Pollution caused by industry and mining in water bodies can be classified in two ways: as systemic or due to an environmental emergency. In the first case there are basins which, for several decades, have significantly deteriorated due to the absence of an effective state apparatus which inspects, monitors and sanctions companies that discharge their waters without prior treatment or without complying with the maximum permissible limits established in the National Waters Law. Examples include the basins of the rivers Atoyac, Lerma, Santiago, Blanco and Sabinas, characterized by their high level of contamination since the last third of the 20th century. These basins have seen growing mobilization of citizen organizations, which pressure the authorities to clean up the riverbed.

Conversely, environmental emergency pollution is caused by the spillage of toxic substances into a water body as a result of an accidental leak. In this area, there is a high recurrence of pollution due to hydrocarbons caused by accidents by vehicles that transport them or the illegal removal of gasoline in pipelines that cross rural areas, as well as spills of substances such as cyanide or sulfuric acid, related to mining activity. In 2016, PROFEPA reported 1,882 spills of oil and other chemical substances, the vast majority of which ended up in a body of water. Agricultural pollution elicits the fewest public protests. Research on the subject has revealed that neither farmers nor government authorities are aware of the scope of the problem, so that they reproduce unsustainable practices, including with financing and subsidies of public policies that favor the intensive use of agrochemicals (Pérez Espejo and Aguilar, 2012).

4.8 Economic impacts of water quality

The quality of drinking water has a direct economic effect due to losses of economic productivity and the healthcare costs of diseases attributable to water pollution. Although there are various methodological proposals to assess this impact, there is no estimated national figure (Nigenda *et al*., 2002).

In the regulatory impact manifesto submitted for the Mexican official standard project NOM-250-SSA1-2014 –designed to tighten restrictions on permissible levels of contaminants and simplify sampling- costs for the implementation of reverse osmosis for the removal of arsenic and fluorine close of approximately 4,000 million pesos were calculated, (COFEPRIS, 2013), which is well above the available budget.

At the same time, in the System of Economic and Ecological Accounts of Mexico, the INEGI calculated a cost equivalent to 0.3% of GDP for water pollution and 0.2% for the depletion of aquifers for 2015 (INEGI, 2017). This suggests that it would make economic sense for Mexico to use the resources and financial instruments required to preserve water quality and ensure the potability of public supplies.

5. Infrastructure for improving water quality

5.1 Potabilization

Mexico has 922 drinking water treatment plants with an installed design expense of 142 m^3/s (CONAGUA, 2016). Of these, 48 plants -with a total expenditure of 2 m^3/s- are out of service (CONAGUA, 2016). The INEGI data (2015) report that 94% of the total population has access to water from a public system, which implies that approximately 6.5 million inhabitants lack this service. With respect to the quality of the water supplied, information systems are not very accessible to the public. In this respect, the law requires drinking water to meet the quality parameters defined by the NOM-127-SSA1-1994 standard for water for human use and consumption, and NOM-179-SSA1-1998 standard for water distributed by public supply systems (INEGI, 2016). Given the uncertainty of its quality, society has sought alternatives for obtaining drinking water, which involve the installation of purification systems in homes or the purchase of purified water. Mexico is the country that consumes most bottled water in the world, amounting to 28,453 million liters per year (PWC, 2015).

5.2 Purification

According to CONAGUA (2016a), in 2015, 450 m3/s of municipal wastewater (which includes the contribution of industries connected to the sewerage system) and non-municipal wastewater were generated in Mexico.[3] It is estimated that these discharges annually represent a contaminating load of 12.1 million tons of organic matter (measured as

3. CONAGUA (2016a) defines municipal wastewater discharges as those generated in population centers and collected in urban and rural sewerage systems, while non-municipal wastewater is generated by other users, such as the self-supplied industry, and discharged into bodies of water without being collected in the sewer system.

Biochemical Oxygen Demand, BOD5), 84% of which corresponds to non-municipal discharges. To reduce the impact of these discharges, there are 5,309 treatment plants that purify 191.4 m3/s, of which 47% are municipal discharges and the remainder industrial. In 2015, the treated flow amounted to 120.9 m3/s, which implies that 57% of the discharge collected in the sewerage was treated. In the case of municipal plants, approximately 79% of the treated flow undergoes activated sludge, stabilization pond or dual system (combination of biological or biological and physicochemical processes) processes, which in most cases produces effluents of acceptable quality for reuse in various sectors. Even though the number of existing plants is considerable, the average flow treated in each of them is 36 l/s, which indicates a large number of small plants, which usually have higher unit operating costs and less automation than larger plants. In fact, in 2015 there were only 22 municipal plants operating at a rate of over 1,000 liters per second.

In terms of efficiency, municipal and industrial treatment plants remove only 19% of the pollutant load, meaning that 9.8 million tons of BOD5 are still discharged into water bodies throughout the country (89% of them from non-municipal discharges). As a result, 32% of the 2,766 sites where chemical oxygen demand is monitored have levels ranging

Table 4. Water quality in Mexico and goals related to Development Goal 6

Goals:

6.1 Percentage of the population with access to safe drinking water: Although there are data on access and type of service by place of residence, information on water and service quality is incomplete or with limited access.

6.2 Percentage of the population with safely managed sewerage services and a hand-washing facility with soap and water: There is information on access, type of service and proportion of the population that uses basic sewerage services and has fecal waste management. There are no data on access to hand washing facilities.

Indicators:

6.3.1 Proportion of safely treated wastewater: Information is available on the proportion of wastewater received and treated, as well as the treatment level. There is no clear, sufficient information on the quality of the treated water, or infrastructure operation and maintenance

6.3.2 Percentages of bodies of water with good quality water: In Mexico, the five quality parameters proposed by the UN for aquifers are not analyzed.

Goal 6.4.1 Change in the efficiency of water use over time: There are estimates based on national productivity data, but not for all the economic activities proposed by the UN.

Target 6.5 Degree of application of integrated water resource management IWRM (0-100): Medium level, the elements of IWRM are institutionalized and their implementation is underway. High marks for cross-border data exchange and aquifer management tools and average marks for watershed management due to lack of cooperation and inter-institutional coordination.

Target 6.6 Percentage of change over time in water-related ecosystems measured according to: a) the area of ecosystems (wetlands, forests and drylands); b) the amount of water in ecosystems (rivers, lakes and groundwater); and c) the resulting health of ecosystems: Information available on stored volume and extension for main water bodies, verification and on-land data interpretation (including classification of type of wetland), but not for health data on ecosystems in all the water bodies.

Target 6.a Percentage of official development assistance included in a spending plan coordinated by the Government, either: (1) in treasury or (2) within the budget: Of the 32 states comprising the country, information is only available on water and sewerage expenditure in three of them and it is difficult to apply the UN-GLASS methodology.

from polluted to heavily polluted (COD greater than 40 mg/L) and, for the most part, are close to the population centers generating the discharges in the central-western area of the country.

It should be mentioned that in 2015, investment in sewerage amounted to 16% of the $2,233 million USD invested in the water sector -equivalent to 0.20% of the Gross Domestic Product (GDP), whereas almost 60% of the investment was allocated to the potable water and sewage system (CONAGUA, 2016b).

5.3 Investment in water quality programs

Mexico has various instruments to finance the development of its infrastructure and hydraulic services. Capital investment funds are mostly obtained from fiscal resources through the transfer of subsidies from the federal government to states and municipalities. Investments to preserve the quality of the water supplied and treat wastewater form part of the PROAGUA program, divided into the following "sections"

- APAUR - urban (water and sewerage infrastructure)
- PRODI - Project for the Integral Development of Water and Sewerage Operating Organizations (technical and commercial efficiency)
- APARural -Rural (coverage and sustainability)
- AAL - clean water (disinfection of drinking water)
- AMPIOS - support for municipalities with fewer than 25,000 inhabitants (strengthening)
- WWTP - wastewater treatment plants (investment)
- INCENTIVES - for wastewater treatment (operating subsidies)

CONAGUA directly implements nearly half of the total budget in this area and participates in 80% of the investments (World Bank, 2016); the remaining investment comes from other areas of government and the private sector. Between 2010 and 2015, the available resources exceeded the amount required to reduced coverage gaps (Campanaro and Rodríguez, 2014), estimated at $32,200 million pesos annually (ANEAS, 2016). Due to the country's economic situation, between 2015 and 2017, funds were drastically reduced; and last year the reduction was greater than 70% (Montoya, 2017).

Investment in infrastructure suffers from deficiencies in terms of equity, efficiency, stability and sufficiency. Funds do not always end up being allocated where they are most needed; they may vary from one year to the next without their long-term evolution being guaranteed and are insufficient

Table 5. Successful experiences

Successful experiences in Mexico are scattered and range from local to national, through community, regional and citizen. They were selected because they identify opportunities to strengthen water quality management based on a vision of long-term ecological conservation that will maintain ecosystem and ecological sanitation services as an alternative to conventional sewerage and collective action for identifying problems and solutions.

Water Management and Sustainable Use (WMSU) Models in the Copalita-Zimatán-Huatulco (CZH) basins, Oaxaca, Mexico

This basin, located on the coast of Oaxaca, encompasses an area of 282,300 ha. It has a population of 86,392 inhabitants, most of whom live in 851 scattered localities with fewer than 2,500 inhabitants. The CZH system has been recognized, nationally and internationally, as being of great importance for its biodiversity (González-Mora et al., 2009). Since 2005, the Alliance formed by the World Wide Fund for Nature (WWF) and the Gonzalo Río Arronte Foundation (FGRA) has been working in CZH to develop new water management models in Mexico. The objective has been to consolidate a process of participatory and integrated management of watersheds, particularly of water resources, with the participation of rural communities and indigenous groups with different environmental and socioeconomic scenarios.

To date, there are 42 types of WMSU in 29 communities in eight municipalities, which benefit 19,146 people. A total of 921 works have been constructed and there is an installed capacity to store rainwater and runoff of 2,263 m^3/year; of treatment for 12,496 m^3/year of gray water, and reuse of 8,865 m^3/year. As a result, 113 m^3 of water is purified and the discharge of 152,505 m^3 of wastewater is prevented by using compost toilets.

Intervention model for the provision of water and sewerage in scattered rural communities (CRD)
The aim of this project is to develop and validate an Intervention Model in scattered rural communities in Mexico that integrate social and technical elements to improve access to basic sustainable water and sewerage services. The actors in the project are: Sarar Transformación, which provides the methodological and technical approach; World Vision Mexico (WVM), as an operating agency; 400 families from four states in Mexico; and the Inter-American Development Bank, which is the main source of financing.

The project was implemented from 2014 to 2017, involving and benefiting families in nine pilot communities in the State of Mexico, Michoacán, San Luis Potosí and Veracruz. The socio-technical strategy for the implementation of the systems included (1) training local promoters of WSH – Water, Sewerage and Hygiene, also known as WASH, - in the coordination and facilitation of participatory diagnostics, design aspects, accompanying the community in the construction, operation, maintenance and monitoring of domestic systems; and (2) the technical design of water and sewerage systems, and preparing construction and use-operation-maintenance manuals.

Environmental recovery of the Pátzcuaro lake basin, Michoacán
This program began in 2003 to establish the bases for the sustainable development of the basin by: (a) halt and reverse the deterioration of the water quality of Pátzcuaro lake; (b) participate in the solution of social conflicts and improve the environmental culture; (c) reduce deforestation, erosion and soil contamination; (d) contribute to promoting sustainability in resource management and make good use of surface and underground water. The program consisted of four stages to address seven key problems: 1) social conflicts and environmental culture; 2) deterioration of lake water quality; 3) deterioration of health, public welfare and extreme poverty; 4) deforestation, erosion and soil contamination; 5) fish reduction and loss of aquaculture biodiversity; 6) lack of economic resources, and 7) decrease in the amount of water in the lake and the volume of groundwater.

More than a hundred projects, actions and studies have been carried out, yielding a series of tangible and measurable benefits. The most notable ones are having managed to mobilize wills and achieve consensus at the intergovernmental and inter-institutional level on needs, actions and investments in favor of the basin, through five artificial wetlands that reduce pollution and health and environmental risks at low cost, as well as the operation of wastewater treatment plants in the municipalities of Pátzcuaro and Quiroga.

Water Reserves Decree in the San Pedro Mezquital River Basin: a new framework for water quality management in Mexico
The San Pedro Mezquital river is located on the Pacific slope, in the states of Durango, Zacatecas and Nayarit. It is currently the only river that crosses the Sierra Madre Occidental free of infrastructure and flows into the sea. It is therefore an allochthonous basin that transports water, sediment, genetic material and energy from the Durango plain to the coastal lagoons of Nayarit. These unique conditions in Mexico have been conserved by two bans on surface waters established in 1948 and 1955, lifted by presidential decree on September 15, 2014.

Lifting the ban provided an opportunity to order water withdrawals through the establishment of a water reserve for the environment and complementary reserves for public supply and power generation. The water reserve for the environment was determined through ecological flow estimates based on the NMX-AA-159-SCFI-2012, which establishes the procedure for the determination of the ecological flow in hydrological basins (NMX). This standard represents a milestone in water management in Mexico, achieved more than twenty years after the publication of the National Water Law through the active participation of civil society, academia and various federal government agencies.

to make up the growing lag in rehabilitation and expansion.

SDG 6 for the sustainable provision of water and sewerage contains several indicators relating to water quality. Mexico's classification according to its possibility of monitoring for SDG 6 is shown in **Table 4**.

6. Conclusions

Interest in water quality has been reflected in the generation of a significant amount of information. However, although a great deal of progress has been made in the country, there is still a need to make full use of this data to define solutions and establish long-term public policies that will effectively protect and preserve water quality and the ecosystems associated with it, in order to complete the regulations regarding wastewater discharges.

It should be clarified that it is not only the lack of regulations regarding water quality that causes its contamination, but, to a much greater extent, their non-compliance and, in fact, its lack of enforcement. The lack of monitoring of wastewater standards pollutes the environment and creates risks for the health of the population. Failure to monitor drinking water standards causes health problems for the population, creating distrust about the quality of drinking water and forcing people to buy bottled water.

The problem of pollution affects the population in general, since consumption of bottled water due to the lack of water quality is a common issue in Mexico, particularly because of its impact on the most disadvantaged population such as women, children, indigenous and poor people. The decision to address the problem of water quality is a matter for all levels of government, but it is also the responsibility of society to demand it.

The costs of poor quality water bodies in the country are covered in many ways, but also cause side effects; for example, the consumption of bottled water means that millions of plastic bottles are discarded every year. It is the obligation of both government and society's to make understanding the fact that water quality can be good business for everyone a priority.

Bibliographical references

Armienta M.A., Segovia N. (2008). Arsenic and fluoride in the groundwater of Mexico. *Environmental Geochemistry and Health,* 30, 345-353.

Armienta M.A., Villaseñor G., Rodriguez, L.K. Ongley, H. Mango (2001). The role of arsenic-bearing rocks in groundwater pollution at Zimapán Valley, México. *Environmental Geology,* 40, 571-581.

Asociación Nacional de Empresas de Agua y Saneamiento de México A.C. (ANEAS) (2016). Página de la LXIII Legislatura. Recuperado de Cámara de Diputados: http://www5.diputados.gob.mx/

Ávila, Patricia (2003). De la hidropolítica a la gestión sustentable del agua. En: *Agua, medio ambiente y desarrollo en el siglo XXI.* Patricia Ávila (Ed.). Zamora, Michoacán: El Colegio de Michoacán, Secretaría de Urbanismo y Medio Ambiente, Instituto Mexicano de Tecnología del Agua, pp. 41- 53.

Boege, Eckart (2008). *El patrimonio biocultural de los pueblos indígenas de México.* México: INAH-CDI.

Campanaro, A., & Rodriguez, D. (2014). *Strengthening the financial system for water in Mexico. From a conceptual framework to the formulation of pilot initiatives.* Washington, D.C.: World Bank.

Cardona A., Carrillo-Rivera J.J., Huízar-Álvarez R., & Graniel-Castro E. (2004). Salinization in coastal aquifers of arid zones: an example from Santo Domingo, Baja California Sur, Mexico. *Environ Geol,* 45: 350–366 DOI 10.1007/s00254-003-0874-2.

Carrillo-Rivera J.J., Cardona A., Edmunds W.M. (2002). Use of abstraction regime and knowledge of hydrogeological conditions to control high-fluoride concentration in abstracted groundwater: San Luis Potosí basin, Mexico. *Journal of Hydrology,* 261, 24-47.

Carrillo–Rivera, JJ, Cardona, A; Huizar-Álvarez R; Graniel, E. (2008). Response of the interaction between groundwater and other components of the environment in Mexico. *Environmental Geology,* 2(303-319).

Cebrián, M. E., Albores A., García-Vargas G., Del Razo L.M. (1994). Chronic arsenic poisoning in humans: The case of México. In: J. O. Nriagu (Ed.), *Arsenic in the environment Part II* (pp. 93–107). New York: Wiley.

Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente (CEPIS). (2001). *Metodologías Simplificadas para la Evaluación de Eutrofización en Lagos Cálidos Tropicales.* Programa Regional CEPIS/HPE/OPS, 1981-1990. 60pp.

Comisión Federal para la Protección contra Riesgos Sanitarios (COFEPRIS) (2013). Análisis de impactos y evaluación beneficio costo. Anteproyecto de Norma Oficial Mexicana NOM-250-SSA1-2014. México: COFEPRIS.

Comisión Nacional del Agua (CONAGUA) (2013). *Base de datos de calidad del agua 2013.* México.

Comisión Nacional del Agua (CONAGUA) (2015). *Estadísticas del Agua en México.* Edición 2015. México: CONAGUA, Diciembre de 2015.

Comisión Nacional del Agua (CONAGUA) (2016). Estadísticas del Agua en México. México: Secretaría de Medio Ambiente y Recursos Naturales-CONAGUA. Recuperado de http://201.116.60.25/publicaciones/EAM_2016.pdf

Comisión Nacional del Agua (CONAGUA) (2016a). *Estadísticas del Agua en México.* Edición 2016. México City: CONAGUA, Diciembre de 2016.

Comisión Nacional del Agua (CONAGUA) (2016b). *Situación del Subsector Agua Potable, Drenaje y Saneamiento.* Edición 2016.

CONAGUA-SEMARNAT (2014). Inventario Nacional de Plantas Municipales de Potabilización y de Tratamiento de Aguas Residuales en Operación. Diciembre de 2014. Recuperado de http://www.CONAGUA.gob.mx/CONAGUA07/Publicaciones/Publicaciones/Inventario_Nacional_Plantas1.pdf [Último acceso 31 de marzo de 2017].

Consejo Nacional de Evaluación de la Política de Desarrollo Social (CONEVAL) (2014). La pobreza en la población indígena de México, 2012. México, D.F.

Consejo Nacional de Población (CONAPO) (2012). *Sistema Urbano Nacional. Catálogo.* México: CONAPO.

Constitución Política de los Estados Unidos Mexicanos (CPEUM) (1917). *Diario Oficial de la Federación* del 5 de febrero de 1917. Última reforma publicada DOF 24-02-2017. Recuperado de: http://www.diputados.gob.mx/LeyesBiblio/pdf/1_240217.pdf [10 de marzo de 2017]

Corona, R., Galicia, L., J. L. Palacio-Prieto, M. Bürgi, & A. Hersperger (2016). Local deforestation patterns and their driving forces of tropical dry forest in two municipalities in Southern Oaxaca, Mexico (1985-2006). *Investigaciones Geográficas,* núm. 91, Instituto de Geografía, UNAM, México, pp. 86-104.

Chapa Bezanilla D., Sosa Ramírez, J., de Alba Ávila, A. (2008). Multitemporal study on forest fragmentation in Sierra Fría, Aguascalientes, México. *Madera y Bosques* 14(1):37-51.

Chávez A., Maya C., Durán J., Becerril A., Gibson R., & Jiménez B. (2011). The Removal of Microorganisms and Organic Micropollutants in a Large Scale Unplanned Soil Aquifer Treatment. *Environ Pollut*, 159: 1354–1362. DOI:10.1016/j.envpol.2011.01.008

Chevalier, J.M. & Buckles, D., (1995). *A Land without Gods: Process Theory, Maldevelopment and the Mexican Nahuas.* London and New Jersey: Zed Books. 194 pp.

Dalkman, P., Broszat, M., Siebe, Ch., Willascheck, E., Sakinc, T., Huebner, J., Amelug, W., Grohmann, E., Siemens, J. (2012). Accumulation of Pharmaceuticals, Enteroccoccus, and Resistance Genes in Soils and Soils Irrigated with Wastewater for Zero to 1000 Years in Central Mexico. *PlosOne* 7(9): e45397.

Diario Oficial de la Federación (DOF) (1989). Criterios Ecológicos de Calidad del Agua. México: Secretaría de Desarrollo Urbano y Ecología, 13 de diciembre de 1989. pp. 7-23.

Diario Oficial de la Federación (2017). Constitución Política de los Estados Unidos Mexicanos. Párrafo adicionado, 8 de febrero de 2012. México: 5 de febrero de 2017.

Dirzo, R. & García, M.C. (1992). Rates of Deforestation in Los Tuxtlas, a Neotropical Area in Southeast México. *Conservation Biology* 6: 84–90.

Downs T.J., Cifuentes-Garcia E., & Suffet I.M. (1999). Risk Screening for Exposure to Groundwater Pollution in a Wastewater Irrigation District of the Mexico City Region. *Environ Health Persp,* 107(7): 553–561. DOI: 10.2307/3434397

Durán-Álvarez, J. C., Becerril-Bravo, E., Castro, V. S., Jiménez, B., & Gibson, R. (2009). The analysis of a group of acidic pharmaceuticals, carbamazepine, and potential endocrine disrupting compounds in wastewater irrigated soils by gas chromatography–mass spectrometry. *Talanta*, 78(3), 1159-1166.

Durán-Álvarez, J. C., Avella, E., Ramírez-Zamora, R. M., & Zanella, R. (2016). Photocatalytic degradation of ciprofloxacin using mono-(Au, Ag and Cu) and bi-(Au–Ag and Au–Cu) metallic nanoparticles supported on TiO2 under UV-C and simulated sunlight. *Catalysis Today,* 266, 175-187.

Durand, L., & Lazos, E. (2004). "Colonization and tropical deforestation in the Sierra Santa Marta, Southern Mexico". *Environmental Conservation* 31 (1): 11–21

Esteller, Vicenta y Díaz-Delgado, C. (2001). Calidad y contaminación del acuífero profundo del Valle de Toluca, Edo de México. México. 1st Joint World Congress on Groundwater, Fortaleza, Brazil, 2001.

Estrada-Arriaga, E.B., & Mijaylova, P.N. (2011). Influence of operational parameters (sludge retention time and hydraulic residence time) on the removal of estrogens by membrane bioreactor. *Environmental Science and Pollution Research,* 18(7), 1121-1128.

Evans, S. (2012). King henequen: Order, progress, and ecological change in Yucatán, 1850-1950. In *A Land Between Waters: Environmental Histories of Modern Mexico*, Edited by Christopher R. Boyer, 328 pp.

Félix-Cañedo, T. H., Durán-Álvarez, J., Jiménez- Cisneros, B. (2013). The Ocurrence and distribution of a group of organic micropolutants in Mexico City's water sources". *Science of The Total Environment,* pp. 109-118.

Flores-Márquez E.L., Jiménez-Suárez G., Martínez-Serrano R.G., Chávez R.E, & Silva-Pérez D. (2006). Study of geothermal water intrusion due to groundwater exploitation in the Puebla Valley aquifer system, Mexico. *Hydrogeol J,* 14: 1216–1230. DOI: 10.1007/s10040-006-0029-0.

Galicia, L. y A. E. Zarco Arista (2014). Multiple ecosystem services, possible trade-offs and synergies in a temperate forest ecosystem in Mexico: a review. *International Journal of Biodiversity Science, Ecosystems Services & Management,* vol. 10, no. 4, pp. 275-288.

Gallegos E., Warren A., Robles E., Campoy E., Calderón A., Sainz G., Bonilla P., & Escolero O. (1999). The Effects of Wastewater Irrigation on Groundwater Quality in Mexico. *Wat Sci Tech,* 40(2): 45–52.

García de Llasera M.P. & Bernal-González M. (2001). Presence of Carbamate Pesticides in Environmental Waters from the Northwest of Mexico: Determination by Liquid Chromatography. *Wat Res,* 35(8): 1933–1940. http://dx.doi.org/10.1016/S0043-1354 (00)00478-4.

García-Gutiérrez C. y Rodríguez-Meza G.D. (2012). Problemática y riesgo ambiental por el uso de plaguicidas en Sinaloa. *Ra Ximhai: Revista de Sociedad, Cultura y Desarrollo Sustentable,* 8(3): 1–10. ISSN: 1665-0441.

Gibson, R., Becerril-Bravo, E., Silva-Castro, V., & Jiménez, B. (2007). Determination of acidic pharmaceuticals and potential endocrine disrupting compounds in wastewaters and spring waters by selective elution and analysis by gas chromatography–mass spectrometry. *Journal of Chromatography* A, 1169(1), 31-39.

González, M.E. y M. Arzaluz (2011). El Programa de Cultura del Agua en el noreste de México. ¿Concepto utilitario, herramienta sustentable o requisito administrativo? *Región y Sociedad,* Vol XXIII, No. 51.

González Reynoso, Arsenio; Hernández M., Lorena; Perló, Manuel; Zamora S., Itzkuauhtli (2010). *Rescate de ríos urbanos. Propuestas conceptuales y metodológicas para la restauración y rehabilitación de ríos urbanos.* Ciudad de México: Programa Universitario de Estudios sobre la Ciudad, UNAM. 109 pp. Recuperado de https://goo.gl/6MqXzy [Última consulta, 21 de abril de 2017].

Hansen, A.M (2012a). "Lake sediment cores as indicators of historical metal(loid) accumulation – A case study in Mexico". *Applied Geochemistry* 27, 1745–1752

Hansen, A.M. (2012b). Nota técnica: Programa de monitoreo y evaluación de STPB en cuencas hidrológicas y acuíferos. *Tecnología y Ciencias del Agua,* 3(4): 167–195.

Hansen, A.M., F. Mahé & C. Corzo-Juárez (2013). Metodología para determinar la liberación de metales del sedimento al agua en lagos y embalses. *Rev Int Contam Ambie* 29 (3) 179-190.

Hurtado R., Gardea-Torresdey J. (2004). Environmental evaluation of fluoride in drinking water at "Los Altos de Jalisco", in the central México region. *J Toxicol Environ Health* A, 67(20-22): 1741, 1753.

Iniciativa de Reducción de Emisiones (IRE) (2016). Forest Carbon Partnership Facility (FCPF). Carbon Fund, Emission Reduction Program. México: 17 de noviembre de 2016.

Instituto Nacional de Estadística y Geografía (INEGI) (2008). Encuesta Nacional de Ingresos y Gastos de los Hogares 2008. Aguascalientes: Instituto Nacional de Estadística, Geografía e Informática.

Instituto Nacional de Estadística y Geografía (INEGI) (2010). Censo de Población y Vivienda 2010. Recuperado de http://www.beta.inegi.org.mx/proyectos/ccpv/2010/

Instituto Nacional de Estadística y Geografía (INEGI) (2015). Conteo de población. México.

Instituto Nacional de Estadística y Geografía (INEGI) (marzo de 2017). PIB y cuentas nacionales. Obtenido de http://www.inegi.org.mx/est/contenidos/proyectos/cn/ee/

Instituto Nacional de Estadística y Geografía (INEGI) (2017). Agua. "Cuéntame de México". Recuperado de http://cuentame.inegi.org.mx/territorio/agua/dispon.aspx?tema=T

Jiménez B. (1995). *Bases para el Manejo Integral de la Cantidad y Calidad del Agua en México.* México: Instituto de Ingeniería-UNAM. 90 pp.

Jiménez B. (1996). *Elaboración del Proyecto de Norma y Fundamentación de la NOM-001-ECOL-1996 para el Control de Descargas a Cuerpos Receptores Nacionales.* México: Instituto Nacional de Ecología y Comisión Nacional del Agua.

Jiménez B. (2001). *La Contaminación Ambiental en México: Causas, efectos y tecnología apropiada.* México: Limusa, 926 pp. ISBN: 968-18-6042-X (Distribución en Latinoamérica).

Jiménez, B., & Asano, T. (2008). Water reclamation and reuse around the world. Water reuse: an international survey of current practice, issues and needs. London: IWA, 3-26.

Jiménez, B., González, A., Gutiérrez, R. y Marañón, B. (2011). *Evaluación de la Política de acceso al agua potable en el Distrito Federal.* México: UNAM, Academia Mexicana de Ciencias y Evalúa-DF.

Knepper, T.P., & Ternes, T.A. (2010). Water Quality as a component of a Sustainable Water Supply. En: *Linkages of Sustianability. Graedel,* T.F. y van der Voet, E. Cambridge, Mass: MIT Press. pp. 233-241.

Lamparelli, C. M (2004). "Grau de trofia em corpos de água do Estado de São Paulo: Avaliação dois métodos de monitoramento". Tese (Doutorado) -Instituto de Biociências da Universidade de São Paulo, Departamento de Ecologia, São Paulo, Brasil. 235 pp.

Ley de Aguas Nacionales (1992). Ley publicada en el *Diario Oficial de la Federación* el 1 de diciembre de 1992. Última reforma publicada DOF 24-03-2016. Recuperado de: http://www.diputados.gob.mx/LeyesBiblio/pdf/16_240316.pdf [11 de marzo de 2017]

Ley General del Equilibrio Ecológico y Protección al Ambiente (LGEEPA). 1988. Nueva Ley publicada en el Diario Oficial de la Federación el 28 de enero de 1988. Última reforma publicada DOF 24-01-2017. Recuperada el 11 de marzo de 2017 de http://www.diputados.gob.mx/LeyesBiblio/index.htm

Maass, J. M., P. Balvanera, A. Castillo, G. C. Daily, H. A. Mooney, P. Ehrlich, M. Quesada, A. Miranda, V. J. Jaramillo, F. García Oliva, A. Martínez Yrízar, H. Cotler, J. López Blanco, A. Pérez Jiménez, A. Búrquez, C. Tinoco, G. Ceballos, L. Barraza, R. Ayala y J. Sa¬rukhán (2005). Ecosystem services of tropical dry forests: insights from long-term ecological and social research on the Pacific Coast of Mexico, *Ecology and Society,* vol. 10, no. 1, p. 17.

Maier R. M., Pepper I. L., C. P. Gerba (2009). *Environmental Microbiology.* Cambridge, Mass: Elsevier (Academic Press). Recuperado de https://booksite.elsevier.com/samplechapters/9780123705198/Sample_Chapters/01~-Front_Matter.pdf

Martínez, M.L. Pérez-Maqueo, O., Vázquez, G., Castillo-Campos, G., García-Franco, J., Mehltreter, K., Equihua, M., Landgrave, R. (2009). Effects of land use change on biodiversity and ecosystem services in tropical montage cloud forests of Mexico. *Forest Ecology and Management* 258, 1856–1863. Recuperado de https://www.sciencedirect.com/science/article/pii/S0378112709001364

Masera O. R., Ordonez J.M., & Dirzo, R. (1997). Carbon emissions from Mexican forests: current situation and long term scenarios. *Climatic Change* 35: 265-295.

Metcalfe, C. D., Beddows, P. A., Bouchot, G.G., Metcalfe, T.L., Li, H., & Van Lavieren, H. (2011). Contaminants in the coastal karst aquifer system along the Caribbean coast of the Yucatan Peninsula, Mexico. *Environmental Pollution,* 159(4), 991-997.

Miege, C., Choubert, J.M., Ribeiro, L., Eusèbe, M., & Coquery, M. (2009). Fate of pharmaceuticals and personal care products in wastewater treatment plants–conception of a database and first results. *Environmental Pollution,* 157(5), 1721-1726.

Molina, M.A. (2004). *Estudio hidrogeoquímico en la Comarca Lagunera, México.* M.en C. Tesis, Posgrado en Ciencias de la Tierra, UNAM, México D.F.

Montoya, M.A. (20 de septiembre de 2017). V. La CONAGUA en el Proyecto de Presupuesto de Egresos 2017. *Ágora-Boletín del Grupo Parlamentario del Partido de la Revolución Democrática,* 15-17.

Morales I., Villanueva-Estrada R.E., Rodriguez R., Armienta M.A. (2015). Geological, hydrogeological and geothermal factors associated to the origin of arsenic, fluoride and groundwater temperature in a volcanic environment "El Bajío Guanajuatense". *Environmental Earth Sciences,* 74, 5403-5415.

Mujer y Medio Ambiente, AC (MMA) (2012). *Agenda de Género y Agua en Iztapalapa: Acciones para el disfrute del derecho al agua.* México.

Nigenda, G., Cifuentes, E., y Duperval, P. A. (2002). *Estimación del Valor Económico de Reducciones en el Riesgo de Morbilidad y Mortalidad por Exposiciones Ambientales.* México: Instituto Nacional de Ecología. Recuperado de http://www.inecc.gob.mx/descargas/dgipea/valor_eco_riesgos_mort.pdf

Ortega-Guerrero, M.A. (2004). Origin of high concentrations of arsenic in groundwater at the "La Laguna Region", northern Mexico, and implications on aquifer management. In Workshops: Program with Abstracts, 32nd IGC Florence. 1486 pp.

Palacio, José Luis *et al*. (2000). "La condición actual de los recursos forestales en México: resultados del Inventario Forestal Nacional 2000". *Invest. Geog* [online]. n.43 [citado2018-01-21], pp.183-203. Recuperado de http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0188-46112000000300012&lng=es&nrm=iso ISSN 2448-7279

Pérez Espejo, Rosario y Aguilar, Alonso (Coord.) (2012). *Agricultura y contaminación del agua.* Ciudad de México: Instituto de Investigaciones Económicas, UNAM. 288 pp.

Price Water house Cooper (PWC). Beverage Industry in México (2015). Recuperado de https://www.pwc.com/mx/es/knowledge-center/archivo/20150917-kc-beverage.pdf

Procuraduría Federal de Protección al Ambiente (2017). *Informe de actividades 2016.* Ciudad de México: PROFEPA. 148 pp. Recuperado de https://goo.gl/1LDBSm [Última consulta, 21 de abril de 2017]

Razo, I., Carrizales L., Castro J., Díaz-Barriga F., Monroy M. (2004). Arsenic and heavy metal pollution of soil, water and sediments in a semi-arid climate mining area in Mexico. *Water, Air, and Soil Pollution,* 152, 129–152.

Red de Género y Medio Ambiente (RGEMA) - Instituto Mexicano de Tecnología del Agua (IMTA) - Programa de las Naciones Unidas para el Desarrollo (PNUD) (2006). Agenda Azul de las Mujeres. México.

Reyes-Gómez V.M., Alarcón-Herrera M.T., Gutiérrez M., Núñez López D. (2013). Fluoride and arsenic in an alluvial aquifer system in Chihuahua, Mexico: contaminant levels, potential sources, and co-occurrence. Water, Air, and Soil Pollution 224: 1433, doi:10.1007/s11270-013-1433-4

Sánchez-Guerra M., Pérez-Herrera N. & Quintanilla-Vega B. (2011) Organophosphorous pesticides research in Mexico: epidemiological and experimental approaches. *Toxicology Mechanisms and Methods,* vol. 21, no. 9, 681-691, DOI: 10.3109/15376516.2011.602130

Sandoval Madrigal M.T. (2015). Contaminación por plaguicidas en acuíferos del Valle de Autlán, Jalisco. *Revista Iberoamericana para la Investigación y el Desarrollo Educativo,* 5(10). ISSN 2007 – 7467.

Secretaría de Salud (2016). *Boletín Epidemiológico.* Sistema Nacional de Vigilancia Epidemiológica. Sistema Único de Información. Dirección General de Epidemiología. Boletín No. 1, Vol. 33. 9 de enero, 2016. México. Datos hasta semana 52 del 2015. Recuperado de http://www.gob.mx/salud/acciones-y-programas/direccion-general-de-epidemiologia-boletin-epidemiologico

Secretaría de Salud (2017). *Boletín Epidemiológico.* Sistema Nacional de Vigilancia Epidemiológica. Sistema Único de Información. Dirección General de Epidemiología. Boletín No. 1, Vol. 34. 7 de enero, 2017. México. Datos hasta la semana 52 del 2016. Recuperado de http://www.gob.mx/salud/acciones-y-programas/direccion-general-de-epidemiologia-boletin-epidemiologico

Siemens, J., Huschek, G., Siebe, C., & Kaupenjohann, M. (2008). Concentrations and mobility of human pharmaceuticals in the world's largest wastewater irrigation system, Mexico City–Mezquital Valley. *Water Research,* 42(8), 2124-2134.

Sistema de Información de Calidad del Agua (2016). Comisión Nacional del Agua. Subdirección General Técnica. Gerencia de Calidad del Agua. Subgerencia de Estudios de Calidad del Agua e Impacto Ambiental. Red Nacional del Monitoreo. Ciudad de México. Recuperado de http://files.CONAGUA.gob.mx/transparencia/CalidaddelAgua.pdf.

Trujillo-Jiménez, P., Sedeño-Díaz, J.E., Camargo, J.A., López-López, Eugenia (2011). Assessing environmental conditions of the Río Champotón (México) using diverse indices and biomarkers in the fish Astyanax aeneus (Günther, 1860). *Ecological Indicators* 11, 1636–1646

Vaca RA, Golicher DJ, Cayuela L, Hewson J, Steininger M (2012). Evidence of Incipient Forest Transition in Southern Mexico. *PLoS ONE* 7(8): e42309

Valenzuela-Vásquez L., Ramírez-Hernández J., Reyes-López J., Sol-Uribe A., Lázaro-Mancilla O. (2006). The origin of fluoride in groundwater supply to Hermosillo City, Sonora, México. *Environmental Geology* 51, 17-27.

Vega-Granillo, E. L., Cirett-Galán, S., De la Parra-Velasco, M. L., & Zavala-Juárez, R. (2011). Hidrogeología de Sonora, en *Panorama de la geología de Sonora, México,* pp. 57-88. México: UNAM-Instituto de Geología.

Vega-Granillo, Ricardo; Vidal-Solano, Jesús Roberto; Herrera-Urbina, Saúl Island (2011). Arc tholeiites of Early Silurian, Late Jurassic and Late Cretaceous ages in the El Fuerte region, northwestern Mexico. *Revista Mexicana de Ciencias Geológicas,* vol. 29, núm. 2, pp. 492-513. Querétaro, México: UNAM.

Velasco Murguía, A., E. Durán Medina, R. Rivera y D. Barton Bray (2014). Cambios en la cobertura arbolada de comunidades indígenas con y sin iniciativas de conservación, en Oaxaca, México. *Investigaciones Geográficas,* 83: 56-74.

Velázquez, A., J.-F. Mas, J.L. Palacio-Prieto & G. Bocco (2002). Land cover mapping to obtain a current profile of deforestation in México. *Unasylva* 210, Vol. 53.

World Bank (2016). México - Revisión del gasto público. Washington D.C.: World Bank Group. Recuperado en marzo de 2017 de http://documents.worldbank.org/curated/en/284151472615491033/Mexico-Public-expenditure-review

Zolla, Carlos; Emiliano Zolla Márquez (2004). *Los pueblos indígenas de México, cien preguntas.* México: UNAM.

Gender and Water

An important often overlooked component of **water quality** is its relationship to gender because **women** are most often charged with the responsibilities of water gathering, production and usage in the home and in agricultural production. Two thirds of the world's poor populations lack access to safe and reliable water. One of the key recommendations that emerges from this and other studies is that more women must be included in the managerial and decision making institutions especially in developing countries.

Kichwa woman in the rain forest of Yasuni National Park, Ecuador © iStock

Gender, Women and the Quality of Water

Frances Henry, Milena Cabrera Maldonado, Neela Badrie, Mónica Moraes R., María Eugenia García, Christina Villamar, Banu Örmeci y Dayra Álvarez

Introduction

This chapter discusses an important, but often overlooked, component of water quality and that is its relationship to gender and specifically women who are most often charged with the responsibilities of water usage in the home as well as in agricultural production. Women in many areas of the developing world are the primary users of water but due to economic and environmental circumstances are often forced to use water that is below the acceptable quality for human consumption and usage.

Most of the world's 1.2 billion poor people lack access to safe and reliable water, two thirds of them women. Diversion of water for industry, agriculture, and power generation reduces availability of water for domestic use, making it even more difficult for the poor and especially women to access water. Worldwide, over 2.6 billion people still lack access to flush toilets or other forms of improved sanitation and difficulties with access to and usage of water often leads to health problems primarily affecting women. Lack of water or unsafe water generates a very large range of water-borne, water-based, water-related, water-washed and water-dispersed diseases. In most cultures, women and men have different roles and responsibilities in the use and management of water. Women use water for production, consumption and domestic purposes, including cooking, cleaning, health and hygiene, and, if they have access to land, also for growing food. In rural areas, women and girls walk long distances to fetch water, often spending 4 to 5 hours per day carrying heavy containers and waiting in lines. The burden of fetching water (and firewood) inhibits their access to education, income generation, cultural and political involvement, and rest and recreation. (UNCTAD, 2011; BOTH ENDS, 2006).

The work of eight scientists who have knowledge and expertise in how water quality affects humans but especially women is presented. It is divided into five sections: 1) the role of water in creating illness and disease with a special focus on the Dominican Republic; 2) a case study overview of the Caribbean region; 3) a case study of an underdeveloped area of Bolivia; 4) a case study overview of Ecuador; 5) waste water management and the quality

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of water; 6) an appendix citing water parasites. A concluding section will present recommendations for improving the water quality and therefore the experiences and lives of women.

1. Water and Women's Health

Milena Cabrera M.

Water and the health of the human being cannot be separated. The availability of quality water is essential for life, and more than anything else, the quality of water conditions the quality of life. Water is a fundamental human life right: a) it is a human intake right and therefore the basis for other human rights; b) As a resource, it is the economic good of the public domain and the axis of the nation's economic development, closely linked to food production, energy production, industrial and mining, transport, tourism support, c) Good social cohesion and fellowship between people.

Most cities in Latin American countries have access to direct drinking water in homes. However, it must be stressed that the sanitation of water in some cases is very poor. The importance of the pollution of water and the great impact it has on health and family dynamics cannot be over emphasized.

The problems related to sanitation, water supply and storage are very closely linked. Sanitation should not merely be understood as a means for the disposal of waste to prevent a polluted environment. It should be considered part of the general policies for the protection of the environment, to avoid diseases and protect the quality of life. Supply plays an important role because today there are communities where drinking water is not available for daily consumption. Home storage of water therefore, where women play an important role, should be based on health policies to prevent vector and other vermin diseases.

Water is vital for the functions of the organism, so having access to it is essential. Since centuries ago the role of women in water collection has been indispensable to perform the functions of the home, but sometimes these waters are not of good quality, therefore affecting the family the health of the family.

Daily hydration is essential for proper functioning of the body. For a healthy adult, dehydration of 2.8% of body weight due to exposure to heat or after a strong exercise, leads to a decrease in concentration, physical performance, short-term memory, increased tiredness, headaches, and a reduction in response time.

Infectious waterborne diseases are the cause of up to 3,2 million lives each year, equivalent to 6 percent of the total deaths in the world. The burden of disease attributed to the lack of water, sanitation and hygiene is equivalent to 1.8 million deaths and the loss of more than 75 million years of healthy life.

A major problem that affects water supply and quality is wastage. The National Institute of Hydraulic Resources (Indri) in the Dominican Republic warns that to continue wasting water in the current proportions, would lead to serious problems of supply in its main urban centers by 2025. The city of Santo Domingo produces 420 million of liters of drinking water per day. A rationalization plan for the use of drinking water has already been announced because there are many broken pipes throughout the streets and puddles of thrown water. As well, as many laundries do not exercise water control. 58% of the water supply in the Dominican Republic is wasted.

There are risks associated with the use of water. During the entire cycle that water undergoes to reach human consumption, isolated or generalized pollution, whether industrial, agricultural or urban, can reduce water quality and make it unsuitable for its use. Water supply systems, recreational places and water settlements also represent a risk to human health. The result of water contamination by chemical or microbiological elements can lead to diseases that can occur in hours or even sometimes years. Water that is contaminated by industries whose chemical waste can be predisposing factors for cancer. Eating foods that have been washed with contaminated water or ingesting contaminated water can generate symptoms in the consumer ranging from mild to very serious depending on the susceptibility of the user. Infants, due to their nutrition based mainly on foods supplemented with water, are particularly at risk of this type of contamination, except when they are breast-fed, which is strongly promoted by the World Health Organization.

Waterborne diseases are caused by the consumption of water contaminated with fecal remains of humans or animals and containing pathogenic microorganisms. Information is available for certain water related diseases including salmonellosis, cholera, shigellosis, but others such as malaria, schistosomiasis or other more recent infections such as legionellosis or SARS Coronavirus need analysis and investigation.

It is estimated that diarrheal diseases cause around 3.6% of all pathologies in the first years of life adjusted for disability due to diseases and cause 1.5 million deaths each year (WHO, 2012).

Among the diseases that are attributed to water contaminated either by microorganism, transmitted by vectors or fecal-oral, the most frequent in the Dominican Republic is dengue fever. From January 1 to December 23 of 2017 1,344 were reported, including 24 deaths with suspicion of this disease. In the same year, Leptospira caused 777 suspected cases and 76 deaths, one hundred and eighteen (118) cases of cholera were suspected and confirmed resulting in four deaths. This figure presents a significant reduction in morbidity and mortality from the disease compared to the period of 2016, when there were 1,154 cases and 27 deaths. For the last weeks of 2017, 9,058 episodes of acute diarrheal disease and 389 cases of foodborne diseases were reported.

Waters influence on women’s health is particularly critical in pregnancy where it plays a major role in favoring proper development of mother and foetus. As well, it is important in preserving the quantity and quality of breast milk.

Access to water and sanitation is one of the main requirements for the enjoyment of good health and affects men and women very differently. The lack of safe water and basic sanitation services is a serious problem for women and girls living in poor and overcrowded neighborhoods in cities and rural areas in some countries.

The traditional role of women in the home explains why men devote more time to paid activities and women take care of household chores, an essential work for the functioning of our society but with very little recognition and no monetary remuneration. Therefore, when there is no water service (or this is limited) women in the world, the main users, providers and administrators of the services, spend more than six hours a day searching for water, boiling it to drink, cooking, bathing children, cleaning the house and washing clothes instead of going to college, work or rest. Another serious problem is that women and girls who do not have access to bathing facilities often walk long distances, alone at night to avoid being seen and/or harassed. Forced to defecate in open spaces attacks their dignity and personal safety.

Another example of gender-specific disadvantage is the impact on women's health of water work. As girls and women carry water on their heads, this can have effects that are harmful to health, as it can lead to problems in the cervical spine. It is common to hear people in rural areas say that men do a stronger job than women, claiming that women do relatively light work. However, a bucket of water worn on the head can weigh up to 40 kg and it has been shown that the transport of water has detrimental effects on the development and health of the spine, resulting in deformities, arthritic diseases and injuries.

The consumption of energy involved in the collection of water can lead to a deficient nutritional intake. Water and sanitation lead women to be very concerned about the health problems that this can cause in family members. In countries such as the Dominican Republic, where sanitation is not widely available for the poor, open defecation on the banks of rivers, streams and roads or on vacant land seems to provide fewer problems for men than for women. Women tend to have a greater appreciation for domestic toilets than men and specifying more benefits of improved sanitation ranging from comfort and privacy to a clean home environment.

Water collection has a great impact on the protection and safety of families, particularly on women and girls. Women are subject to long walks, and although they consider water to be vital for all household activities, the implications of not having close access to their home causes stress and frustration.

Water is vital for the functions of the organism, as well as necessary to perform the daily functions of the home. Access to drinking water, of good quality is a right of every human being. Women, who support the home in the collection and use of water and its maintenance are the most affected by illnesses. Gender inequity therefore creates social, cultural and political problems for which solutions are needed for the good of women's health. Women are the nucleus of the family.

2. Gender Perspectives- Water Quality in Latin American and Caribbean Homes

Neela Badrie

Access to Good Quality Water

Imagine going through a day without access to clean, safe water in your Caribbean home for drinking, cooking, washing, or bathing whenever you need it, and consider the needs and priorities of women and young girls. According to the WHO/UNICEF Joint Monitoring Programme 2017 report, in 2015, 29% of the global population (2.1 billion people) lacked safely managed drinking water services – meaning water at home (WHO/UNICEF Joint Monitoring Programme, 2017). **Table 1** shows the drinking water supplies provided to the population of Caribbean countries in 2015, in which most countries provided between 93-98% national basic service of drinking water except for Haiti. For Haiti, the national basic supply of drinking water was 64% with differences between rural basic service (40%) and urban basic service (81%). An estimated four million out of the nine million inhabitants of Port-au-Prince, Haiti have no access to safe water (Khasdurian 2013), with a very high index waterborne disease vulnerability (Pacific Disaster Center, 2016).

Many rural areas throughout the Caribbean are forced to live without a pipe borne supply of water. Some individuals must walk miles to get a potable supply of water. Their only source of water is from rivers, standpipes or paying for the delivery of water by water trucks. Rainwater harvesting can be a means of self-reliance for these communities, especially in the southern islands in the Caribbean where there are high rainfall levels (Global Water Partnership, Caribbean, 2017).

In Trinidad and Tobago, rain water storage tanks can be seen in both urban and rural areas since rain water collection is traditional and the taste is highly preferred by many. However, individuals in rural areas are more dependent on this water as it is at times their only water supply (Meera and Ahammed 2006). Also, the quality of harvested water from roof - top catchments often does not meet the drinking-water guideline values. The heavy rainfall during the rainy season provides an ideal vehicle for the spread of pathogenic water related diseases. These pathogens may be washed into rivers, lakes, streams and even crop irrigation canals from the land surface along with water from failing septic tanks, seeping or flooded latrines or from recreational activities (Roslev and Bukh, 2011).

A survey of residents living in six communities in Grenada revealed residents experienced several

Table 1 Drinking water services (%) provided to population for Caribbean countries in 2015

Caribbean countries	National Basic service	National Limited service	National Unimproved service	National No service	Rural Basic Service	Urban Basic service
Antigua & Barbuda	97	-	3	0	(-)	(-)
Barbados	98	0	2	0	(-)	(-)
Dominica	97	-	4	0	(-)	(-)
Grenada	96	1	0	3	(-)	(-)
Guyana	95	1	1	2	(93)	(100)
Haiti	64	7	29	0	(40)	(81)
Jamaica	93	3	2	2	(88)	(97)
St. Lucia	98	2	0	0	(98)	(98)
St. Vincent & the Grenadines	95	-	4	1	(-)	(-)
Suriname	95	1	1	1	(88)	(98)
Trinidad and Tobago	97	1	2	0	(-)	(-)

Source: Extracted from WHO/UNICEF JMP 2017. (-) no available data water related problems such as water service interruptions, episodes of 'dirty water,' and other resident-perceived service problems. (Neff 2013). The severity of 'dirty water' ranged from slight discolouration to being described by residents as being 'like mud'. Crude storage systems capture, and store rainwater using buckets and rain barrels and are not plumbed into the home.

Gender Perspectives

In Trinidad and Tobago society, men are expected to be providers, protectors of women, children and the community and view themselves as strong authority figures (Ryan, 2013). Women, on the other hand, are socialised and are expected to be carers and nurturers both in the home and outside of the home. Hence, the provision of physically accessible clean water is essential for enabling women and girls to devote more time to the pursuit of education, income generation and even the construction and economic activities that will improve their families' quality of life and their own health and wellbeing. (UNDP water, 2006). The home-based care approach implies that there should be water of enough quality and quantity to avoid secondary infections as well as to reduce the burdens of care-givers, who, in most cases, are women and girls (UNDP 2006). Also, women have specific hygiene needs during menstruation, pregnancy and child rearing (UN Water and Gender, 2018) and since they supply most water for the household, unsafe water affects them the most. (Cap-Net/GWA 2006).

Table 2. Some reported water-related diseases in the Caribbean

Disease	Agent
Gastroenteritis	Virus
Hepatitis A	Virus
Hepatitis E	Virus
Dengue	Virus
Giardiasis	Protozoan
Bacillary dysentery/Shigellosis	Bacterium
Cholera	Bacterium
Diarrhoea	Bacterium
Legionnaires' disease	Bacterium
Helicobacter pylori / Gastric mucosa	Bacterium
Typhoid fever	Bacterium

Health and Water-borne Diseases

At the 2018 World Water Forum held in the Caribbean, the Inter-American Development Bank (IDB), agenda for sustainable development established goals for the safe guarding of water supply and the prevention of waterborne diseases in the Caribbean by 2030 (Fletcher, 2018). Women's health as well as dignity and sense of personal worth can be affected by their experiences while collecting water and, particularly sanitation-related diseases and illnesses, by the within-household allocation of water itself (Sorenson et al. 2011). For immuno-compromised people living with HIV/AIDS, their status makes it imperative to have a safe and adequate supply of water for drinking and for personal care (UNICEF 2005). Also, for pregnant women and infants, extra precautions are recommended to reduce the risk of infection from contaminated water.

The Protocol on Water and Health defines water-related disease as, "any significant adverse effects on human health, such as death, disability, illness or disorders, caused directly or indirectly by the condition, or changes in the quantity or quality, of any waters". The hazards or agents that are the direct cause of damage include bacteria, viruses, protozoa, helminthes, chemicals and personal physical factors (Bartram et al. 2015). Water-borne diseases are linked to significant disease burden worldwide. They are responsible for 2 million deaths each year, with the majority occurring in children under 5 years (WHO, 2018). Proper household water and sanitation practices can increase resilience to waterborne disease risks.

One of the 2030 goals, established by the Caribbean Water and Waste Water Association Sustainable Development Goals (SDG) is to combat hepatitis and other water-borne diseases within the islands sighting the importance of a clean, safe and reliable water supply system (Fletcher, 2018). The World Health Organisation has enlisted several water-borne diseases (Bartram and Hunter 2015). **Table 2** informs about some reported water-related disease in the Caribbean.

An UNDP study of youth in Trinidad and Tobago identified poor environmental conditions, espe-

Table 3. UNICEF Estimates of child cause of death, Diarrhoea 2016

Country	Under 5 deaths due to diarrhoea	% under five deaths due to diarrhoea
Global	477,293	8
Antigua and Barbuda	-	0
Barbados	-	0
Dominica	-	1
Grenada	-	0
Guyana	22	4
Haiti	1,720	10
Jamaica	3	0
St. Kitts and Nevis	0	0
St. Lucia	-	0
Suriname	3	2
Trinidad and Tobago	2	0
St. Vincent and the Grenadines	1	4

Source: WHO and Maternal and Child Epidemiology Estimation Group (MCEE) estimates 2018.
http://apps.who.int/gho/data/node.main.ChildMort?lang=en

cially water supply problems, as a significant cause of gastrointestinal diseases resulting in morbidity as well as skin infections (UNDP, 2001). In a recent study conducted of rural and urban perception of potable water quality in rural and urban areas in Trinidad, a survey showed that less than half of the participants (47.8%) were not knowledgeable about water-related diseases (Mc Clean 2018).

In a study conducted in the island of St. Lucia, Moutoute and Cashman (2015) pointed out that women were more knowledgeable about water quality because of their roles and responsibilities of being home makers. However, a study which assessed the knowledge of mothers on water-borne diseases and prevention reported that although most mothers were knowledgeable about cholera, only those who had basic secondary school education knew about other water-borne diseases such as typhoid and gastroenteritis (Sharmila et al. 2017).

Diarrhoea is a leading killer of children, accounting for approximately 8 per cent of all deaths among children under age 5 worldwide in 2016 (UNICEF, 2018). This translates to over 1,300 young children dying each day, or about 480,000 children a year. **Table 3** shows that most Caribbean countries have reported between 0-4% under 5 years old death due to diarrhoea except Haiti (10%). The most common causes of severe diarrhoeal disease include Rotavirus, pathogenic *Escherichia coli*, *Campylobacter jejuni*, and protozoan parasites. Rotavirus is a common cause of gastroenteritis and is the leading cause of severe childhood diarrhoea and is responsible for an estimated 40 per cent of all hospital admissions due to diarrhoea among children under age 5 worldwide (UNICEF 2012). Infection with pathogenic protozoa, such as *Entamoeba histolytica, Giardia lamblia* and *Cryptosporidium* spp., is common, though bacterial pathogens account for most cases of diarrhoeal disease (UNICEF, 2012). Epidemic diarrhoeal diseases are caused by *Shigella* and *Vibrio cholera*. Overall, improvements in drinking water and sanitation have been associated with decreased risks of diarrhoea in low- and middle-income settings (Wolfe et al. 2014).

In a study of the burden and impact of acute gastroenteritis (AGE) and foodborne pathogens in Trinidad and Tobago, the monthly prevalence of AGE was the highest among children aged <5 years (1.3 episodes/year) and the mean duration of diarrhoea was 2.3 days (range 2-10 days) (Lakhan et al. 2013). Overall, 56 (10%) AGE specimens tested positive for foodborne pathogens. It was estimated that 135,820 AGE cases occurred in 2009 (84%). Overall, improvements in drinking water and sanitation have been associated with decreased risks of diarrhoea (Wolf et al.2014).

Cases of Legionnaires' disease have been reported in relation to the presence of *Legionella pneumophila* in drinking water supplies in the Caribbean (Valster et al. 2011).

School-age children are especially prone to worm infections because their high level of activity brings them into regular contact with contaminated water and soil. One study on Jamaican children aged 9–12 years, highlighted the debilitating nature of trichuriasis (whipworm) UNICEF, 2005). Treatment of infected children was followed by immediate improvements in short-term and long-term memory. School attendance was significantly higher for uninfected children; in some cases, infected children attended for only half the time of their uninfected friends.

Food Safety Practices

Foodborne illnesses are one of the most common public health issues in the Caribbean region and have increased by 26% since 2010 (St. Lucia News Online, 2015), after exposure to contaminated food or drinks. Persons affected usually experience severe diarrhoea, vomiting, stomach pain, sometimes accompanied by fever, headaches and other symptoms. (Morgan 2017). The World Health Organization (WHO) has estimated that 70% of diarrhoeal episodes are caused by biologically contaminated food. Foodborne illnesses associated with microbial pathogens or other food contaminants are a serious health threat in developing and developed countries. Outbreaks of such illnesses can spread rapidly and transnationally, and disproportionately affect children and the elderly (Satcher, 2000).

In a study by Franklyn and Badrie (2015) which investigated vendor hygienic practices and consumer perception of food safety during the Carnival festival on the island of Tobago, West Indies revealed that most vendors were females (70.0%) and the majority (68%) had failed to clean utensils. Of those (32.0%) who exercised the cleaning of utensils, 24.0% used clean water (unused water without detergent), 12.0% used dirty water (previously used water stored in containers), 6.0% used cold soapy water and none used warm soapy water. Almost half of the vendors (48.0%) were unable to access any water and 82.0% had access to nearby toilet facilities.

Figure 1. Fisherman of the Uru people who faced the Poopó lake drought in 2015

Using an observational approach of the hygienic practices by vendors of the street food “doubles” at vending sites in Trinidad, West Indies revealed containers with faucets supplied water (85.7%) and toilets were not close (97.5%) (Benny-Ollivierra and Badrie, 2007). Some (30.6%) respondents indicated that they felt ill from eating doubles, but only 2.7% reported the condition to a medical doctor/health authority.

Conclusion

Gender equality has long been recognised both as a core development goal and a human right (UNESCO 2014). It implies that the interests, needs and priorities of both women and men are to be taken into consideration, recognising the diversity of different groups of women and men. There has been considerable progress in Caribbean efforts to promote women as empowered actors in development while at the same time encouraging men and boys to be active partners in the process of social transformation and in efforts to reduce gender gaps in opportunities and rights.

Embedding gender equity into policy at all levels will be crucial to achieving water and sanitation for all. Lack of water supply, sanitation and hygiene (WASH) takes a huge toll on health and well-being and comes at a large financial cost, including a sizable loss of economic activity. In order to achieve universal access, there is a need for accelerated progress in disadvantaged groups and to ensure non-discrimination in WASH service provision. (WHO and UNICEF Joint Monitoring Programme, 2013). Caribbean Governments will have to concentrate efforts to achieve universal good water quality service coverage, with emphasis on household connections, improvement in service quality and sustainability in water management.

3. Bolivia: Water Quality in the Andean High Plateau

Maria Eugenia Garcia, Monica Moraes

Bolivia, a country located in the centre of South America, has a surface of 1,098,581 km2 with headwaters of three hydrographic basins (Amazonas, Paraná-Paraguay and Andean endorheic basin) and a population of 10.89 million (INE 2016). It is one of the poorest countries in the region; although extreme poverty declined from 37.7% in 2007 to 17.3% in 2014, it remained at 36.1% in rural areas (WHO 2017) It also has a long mining tradition dating from pre-Columbian cultures which has operated without environmental control since the colonial period. At present, the production of acid drainages and the accumulation and transport of toxic metals and mineral remains is taking place, causing health risks to human communities, flora and fauna and water resources degradation. In 2015, 90% of the Bolivian population had access to improved water sources and 84% of dwellings had running water: 97% in urban areas and 76% in rural ones; approximately 50% of the population had access to improved sanitation: close to 63% in urban areas and 43% in rural ones (WHO 2017).

The Bolivian Altiplano or Andean high plateau, an extensive and desert plain with 3,750 m elevation in the west of the country is located between two mountain ranges with summits that exceed 6,200 m (Argollo et al. 2001). The region is characterized by gradually reducing glaciers (Soruco 2008), water scarcity and it has therefore consequences for health and other socioeconomic consequences such as on agriculture. Because of the intense mining activities and the natural pollution, conflicts in the use of water and pollution of surface water, resources are increasingly endangered creating an important problem.

TDPS system and quality of water

The endorheic basin of the Altiplano, also known as the TDPS system (Titicaca, Desaguadero, Poopó and Salares) (**Figure 1**), is located between 14°38 ' to 22°58'LS and 66°14' to 69°40'LW, covers 145,176 km2 (Argollo et al. 2001). The Poopó province in the Oruro department of W Bolivia has 16,806 inhabitants with 8,539 (men) and 8,267 (women). The area of influence of Poopó lake is characterized by an extreme and marginal poverty of the population (76%, an index that surpasses the departmental and national average), the lack of permanent employment opportunities, the low access to basic services and the low institutional capacity of intervention in the productive and environmental lines (**Figure 1**). The living conditions of the population settled in the basin show worrying levels: life expectancy is 58 years, lower than the national average (63.3) and the average infant mortality is 89%, higher than the average of the department (82%) and the country (66%).

The Poopó lake receives heavy metals and acid water from natural deposits and mines along rivers north and northeast, affecting major quality conditions. Different chemical parameters have been analyzed and monitored along several years (García et al. 2005, Ormachea 2015), such as pH, conductivity, suspended solids, temperature, redox potential, alkalinity, sodium, potassium, calcium, magnesium, chlorides and sulphates; in addition to heavy metals, nitrates, phosphates, carbonates and bicarbonates; and finally, also making comparisons between rainy and dry seasonal periods

The north and northeast of the Poopó basin, where the rivers discharge their waters into the Poopó and Uru lakes also have a strong influence from the mining activities of the region and receive around 28% of thermal, carbonated and bicarbonate waters. These rivers have concentrations of heavy metals that exceed hundreds and even thousands of times the maximum limit according the Bolivian and the international regulations. 90 percent of wells studies on water consumption (45) exceed the maximum recommended by WHO.

It also has only a small outlet with an average flow of 2.5 m^3/s, a value that corresponds to the rainy season, and during the dry season, the water of this lake does not have any discharge and it becomes a sink for dissolved solids and sediments. The concentration ranges of the different elements compared with national and international regulations indicates that the quality of its waters is totally deteriorated, useless and inadequate for human consumption. This evaluation allows us to know the critical situation of the water resources used for consumption, irrigation, consumption of animals and to conserve the few water bodies and especially the groundwater that these communities have.

Key roles of women

Access to water is supplied from rivers or wells, which make up the 50% of the Bolivian rural area that lacks water treatment or sanitation services. About 50% of the population that uses the water resource in the Poopó province are women with 2,226 (27% of women) between 20-39 years of age, who participate in productive and household tasks. They take care of both agricultural & animal breeding and domestic tasks, such as food preparation, bread making, raising, cleaning and health of children, laundry, subsistence agriculture, livestock activities (as collaborative to men), among others.

Although there are so many tasks to fulfill in the community and in the family, where dedicated women make often less visible but persistent efforts, such as the following:

- Women carry water at great distances from the house or community several times a day beginning very early each morning, or every other morning Drinking water must be boiled and cooled before it can be consumed with the needed quality. In the short periods of rain, water is accumulated in ceramic bowls searching and gathering of water supplies for their homes, women also risk their health by making direct contact with contaminated sources or toxic waters. These strenuous efforts are then translated into health consequences such as weight and back problems.

Table 4. Chemical parameters of Poopó lake (Bolivia) that affect quality of water comparing between low quality and better conditions of water

	Low quality of water	Better conditions of water quality
pH	2.2 ≤ pH ≤ 4.0	7.0 ≤ pH ≤ 8.9
8.3 ≤ pH ≤ 9.6	-	0
Heavy metals	Cd: 3.0 mg/l, Pb: 0.53 mg/l, Como: 2.07 mg/l, Fe: 4.8 mg/l, Zn: 7.5 mg/l	Cd: 0.6 mg/l, Pb: 0.24-0.27 mg/l, Como: 0.02-0.22 mg/l, Fe: 0.1-0.2 mg/l, Zn: 0.1 mg/l
Sulphates, chlorides	SO42-: 2900-6000 mg/l, Cl-: 11800-12900 mg/l	

Source: García *et al.*, 2005.

- As in several societies, women are responsible for food security of the family. They also participate in the construction of ditches and mud dams for irrigation of crops. They are also involved in the sowing and harvesting of agricultural products, together with their partners and children.
- When drought conditions prevail, women help in alleviating economic scarcity by making handicrafts such as hats, handles and clothing which is then sold at local fairs. This knowledge comes from their ancestral and cultural history as people who have subsisted in adverse and markedly seasonal ecological conditions. Preserving this knowledge becomes a necessity.
- The water resource issue has become a political reality especially since the alert during the dry season of 2015 in the Poopo lake region. Political movements arose during the dry season and especially the alert of 2015. Women were part of local water associations or committees and collaborated in the convening of meetings and actions. However, the governmental schemes are mostly run by men who often silence women's voices. Women leaders are mostly in larger towns in rural areas or in urban centers.
- The quality and strength of greatest value and contribution for their families and the community itself is that women are the ones that take care jealously of their wells and drinking water, and the small bodies of water supplying their community. Their knowledge allows the classification of types of water and water sources intended for different applications: from direct consumption to that intended for agricultural work and food preparation.

Therefore, it is necessary to recognize the important role of women in water quality management, not only historically as recognized by the spaces dedicated to domestic activities, but to the entire range of family life strategies. It is also critical to involve these communities in training of gender roles and responsibilities and to provide guidance on governance systems that make decisions about the conservation and preservation of water.

4. Women and Water: Case Study Ecuador

Christina Villamar Ayala

Introduction

About 70% of actual population worldwide (approx. 7,000 million inhabitants) live in developing countries (Lutz et al., 2001). However, only 5 million km3 water is available and it is not where the population is concentrated. Thus, about 40% of the worldwide population suffers from water shortage (AQUAstat, 2015). Water shortage is also increased by at least 20% due to climate change. (Arnell, 1999). Water is determined not only by its distribution and availability, but also by its access, and quality.

Ecuador has water (27,000 m3/inhabit-year), which favors water access (AQUAstat, 2015). Thus, Ecuador reports a national, rural, and urban coverage of drinking water of 82, 94, and 57%, respectively. However, the installed capacity of basic water infrastructure and quality are also important factors for a country´s health. At the level of basic sanitation (sanitary installations + sewerage) the national coverage reaches 75%. Reported treatment coverage at municipal level is close to 62%. Water, sanitation and hygiene indicators measure the potential risk of water quality (INEC, 2015). These indicators were pre-evaluated on a population sample (4,000 households), that found only 79 percent of the national population has water free from *Escherichia coli* and 31% of rural population reported some level of contamination in drinking water (Pozo et al., 2016). Therefore, as the coverage of drinking water and sanitation increases, the water access with drinking quality should be possible, ensuring public health and increased life quality.

Water quality: guidelines and risks in Ecuador

The drinking water needs to be of good quality and quantity to be a vital resource for life. The Health Worldwide Organization (HWO 2011) Organization has defined the drinking water standard associated with the application and monitoring of physical, chemical and microbiological parameters. Microbiological quality is the key parameter because it affects the population's health instantly. Meanwhile, physicochemical quality will gradually influence human health conditions, mainly through micro-contaminants (emerging contaminants,), which are not regulated. (Ebele et al., 2017)

The water quality in Ecuador is based on use criteria, being defined as water with quality for human consumption or domestic activities, such as: food cooking, personal hygiene, and washing kitchen utensils (TULMAS, 2005). To protect quality in Ecuador there are two standards annexed 1-TULMAS (2005) and NTE INEN 1108 (2014). The first standard regulates the maximum permissible limits to define the water quality from the water extraction source. Meanwhile, the other standard defines quality criteria of water extracted or treated, which will be used for drinking. In practice, only fecal coliforms (microbiological parameter) are monitored because of the high cost of monitoring.) (Kayser et al., 2015).

The main microbiological contaminant in drinking water resources are municipal and livestock wastewaters, which have higher microbiological loads (10^3-10^8 CFU/100 mL) (Villamar et al., 2018). In Ecuador, some coast rivers report temporal (seasonal and hourly) microbiological contamination with *Escherichia coli* (10^2 - 10^4 CFU/100 mL) (Levy et al., 2009). Condition that could get worse thanks to the hydrodynamic conditions of their rivers (Rao et al., 2015). Safe drinking water in Ecuador depends not only on the resources available but also on how its quality is monitored and how it could influence sanitation.

The most commonly used microbiological indicator for drinking water quality is the pathogen bacteria *Escherichia coli.* However, the biological variety potentially present in water encompasses several levels (viruses, bacteria, protozoa and nematodes (Cabral, 2017). This variety microbiological is described by WHO guidelines, which mention more than 20 pathogen microorganisms potentially present in drinking water (WHO, 2016). Several of these microorganisms are responsible for gastrointestinal diseases (Rosado-García et al., 2017). However, other microorganisms (e.g. influenza) detected in drinking water come into water through inhalation. (WHO, 2016). The conventional purification treatment removes some pathogens microorganisms (*E. coli*), but several other parasites (viruses, protozoa and nematodes) persist after purification treatment (Betancourt and Rose, 2017). In Ecuador preliminary studies have detected the transference of parasites from water to human, and the population of all regions (Coast, Andean, and Amazon) has reported parasites in feces (Peplow, 1982). Therefore, the exposure level at microbiological contamination from drinking water within Ecuadorian population is higher.

Water purification treatment requires several phases. Some natural (solar radiation) and artificial (ultraviolet radiation, oxidant agents, and electrochemical) methods have been used within disinfection (Gibbons and Laha, 1999). However, chemical disinfection with chlorine products under some purity level (NaClO, and Ca $(ClO)_2$) is the most used in Ecuador (Cirelli and Mortier, 2005). This method has demonstrated be the most cost-effective technique to remove *E. coli* (> 99.9%), but it is not efficient in the removal of other parasites. (Betancourt and Rose, 2004; WHO, 2006). Therefore, new technologies (e.g. microfiltration) have appeared to improve the removal of parasites, but still very expensive. Thus, the quality of drinking water also depends on the accessibility of adequate treatment.

Water: quality and women

Although water is publicly controlled in Ecuador some privatization of water is permitted under current legislation. (Boelens et al., 2015). This dual model could influence the way in which water is handled and who has the right to use it. The right to access resources in Ecuador is described by the Ecuadorian Constitution of 2008, which highlights that "The human right to water is fundamental and inalienable. Water constitutes a strategic national patrimony for public use, inalienable, imprescriptibly, un-attachable and essential for life "(Article 12-AC, 2008). In addition, it mentions the "equality of rights and opportunities of women and men in access to property" (Article 324-AC, 2008). In practice, these rights are still not effective despite women being the main pillars of the family and responsible for local food security (Radcliffe, 2014). One of the main reasons for not exercising certain rights is related to the education gap between men and women, because illiteracy levels in Ecuador are around 9.5 and 13.5%, respectively (INEC, 2015). This factor also influences the economic independence of women, where 94% of the economically active Ecuadorian female population are employed, but only 33% have adequate employment. In rural areas and in all Ecuadorian Indigenous groups, the gap is even wider because Indigenous women earn about 17% less than men (Radcliffe, 2014; INEC, 2015). The wage differences not only denote gaps in education with respect to men, but also the availability of time that women must combine work and family administration. All these factors not only reflect gender differences, but also the impossibility for women to take important roles in the management and administration of water resources.

The ancestral role that Indigenous women have had in the access to water resources is based on agriculture, since more than 75% of rural women are engaged in this activity, which is compatible with domestic tasks (INEC, 2015). In general, the agriculture practiced by women is based on subsistence crops, rotating, with agro-diversity, medicinal plants and combined with animal care, which favors critical thinking and activist women (Radcliffe, 2014). Therefore, water quality for agriculture and drinking water are very important features that worry Ecuadorian rural women. This fact has been reflected in the anti-Water Law protests carried out by Ecuadorian Indigenous communities, where women have been the main protagonists. They have also been active in environmental protests due to water contamination by industrial activities of national interest (e.g. mining) (Kayser et al., 2015). Despite this, in the rural world women do not have easy access to water use rights since rights have always been granted at a non-individual family level (Radcliffe, 2014). These facts are difficult to understand especially when one considers that the relationship of women with food and reproductive security at the family level is essential.

Thus, water quality is an issue that has a special interest in women's thinking, especially the microbiological contamination of water. Indeed, water´s microbiological quality directly affects the health of the woman and her family nucleus. Some studies report the incidence of parasites (*Ascaris lumbricoides*) in women is higher than men, often as resulted of lower incomes by women and therefore less access to good drinking water (González et al., 2001). There is a direct relationship between poverty (women 2% more poverty than men) and access to basic services (drinking water and sanitation) in Ecuador (SEMPLADES, 2014). This condition could also affect reproductive health and family planning. Studies on Indigenous women in Bolivia have reported a relationship between the parasites presence (*A. lumbricoides*) and their higher reproductive rate (9 children per woman). The lowering of the immune system would also explain the low rate of abortions on this Indigenous group (Blackwell et al., 2015). Parasitic infections in pregnant women could generate sensitivity or resistance in the fetus, influence birth rate and infant mortality. Pregnant women's mortality and diseases in children of Indigenous or poor women (Afro descendants or mixed race) are concentrated in Ecuadorian rural areas. Indeed, 70% of maternal deaths has been reported in Ecuadorian rural zones (INEC, 2015). Moreover, studies indicate that one of the main causes of death in Indigenous Ecuadorian women (pregnant and non-pregnant) is diarrheal diseases due to parasites (Hughes, 2004). The entire Ecuadorian female population also reports parasites (2.5%) as one of the causes of maternal death, and the youngest group of 15-year olds are the most vulnerable. Infections are one of the main causes of death causes in newborns in Ecuadorian rural areas (Finerman, 1987; INEC, 2015). On the other hand, higher birth rate (4 – 6 children per woman) and infant mortality (Indigenous: 60%, Afro descendants: 40%) in Ecuadorian rural areas where these groups are concentrated could be related to the vulnerability of this population group (INEC, 2015).

The relationship that women have with water and its quality is direct, due to its fundamental role in food security and the health of her and her family nucleus. As the education gaps between men and women are reduced, there is the possibility of incorporating more women into water management decisions. This condition undoubtedly opens the possibility of incorporating the water management ideas that these women have based on family health harmonized with respect to the environment.

5. Gender and waste management

Banu Örmeci

Clean water and a clean environment are essential for protecting public health. Past efforts in both developed and developing countries have largely focused on providing clean drinking water while proper treatment and management of waste have been given much less importance, and in some countries have been completely ignored due to lack of finances. If waste is not collected and managed properly, water supplies are directly contaminated negating the efforts and finances spent towards providing clean drinking water to communities. In developing countries and water scarce regions, inadequate sewage and solid waste management affect women and young girls because of many cultural and social factors and adversely impact their health, education, safety, security, empowerment, and overall well-being.

Men and women both participate in solid waste management, but there are deep segregations in terms of the quality of jobs and large inequalities in terms of pay. In developing countries, women and children constitute the main workforce for collecting, sorting, recycling and selling valuable materials recovered from garbage and other solid waste. For example, women make up approximately 80 percent of waste pickers in India and 56 percent in Brazil (Dias and Fernandez, 2013). The strenuous work conditions, domestic responsibilities, hierarchical gender relations, and marginalization of waste workers are some of the main challenges that they face daily. Women waste workers with intersecting identities, such as race, class, sexuality, and age, are further marginalized in their communities (Purdie-Vaughn and Eibach, 2008). Investments made to the solid waste management programs result in better jobs that are also safer for solid waste handlers, but these jobs are typically filled by men leaving women at a disadvantage with less income and work opportunities.

Gender differences and inequalities can be seen at various levels of solid waste management starting with the household responsibilities, priorities and values placed on waste disposal, decision-making process at work and in the community, and employment opportunities. A well-established gender division of labour was seen in the waste management system of Ho Chi Minh City, Vietnam where the door-to-door collectors were entirely women, and it was men that purchased the collected goods, recycled, and marketed them (Mehra et al., 1996). In Port-au-Prince, Haiti women working in the solid waste industry were reported to receive lower salaries and have higher work-related injuries and turnover rates compared to their male counterparts (Noel, 2010).

A bottom-up approach is vital in developing waste collection and management policies which protects the rights of low-income women (Bisht, 2005). A gendered perspective is also necessary for examining the waste management issues involving women and developing tools to tackle these issues (Dias and Fernandez, 2013). Economic and entrepreneurial programs that employ microfinancing and other creative approaches for waste collection and management can help to improve the employment conditions and opportunities for women in developing countries (Madsen, 2006) with more established sectors. In less developed sectors, however, women are more subject to harassment, violence, and health and safety hazards, and basic protection of physical safety and human dignity would have a more transformative effect in these communities compared to economic and entrepreneurial programs (Oganda et al., 2017).

Addressing gender inequality in solid waste handling is necessary and this can be achieved through the training and education of women workers to provide them with tools so that they can stand up for equality at home and work, increase their leadership roles in their relevant organizations, and contribute to their economic empowerment (WIEGO et al., 2015a). With the participation of women waste pickers from Latin America, The Gender & Waste project initiated the discussion and addressed these important needs by providing a practical toolkit for women to enhance their political and economic power at their work place and in their communities. The toolkit consists of three parts and is available online for waste workers, practitioners, researchers, and policymakers (WIEGO et al., 2015a, b, c, d).

Understanding the issues around gender inequalities in the waste sector is the first step toward removing gender barriers and providing an equitable work environment for both men and women. This would help to improve the work conditions and safety for all workers and increase the efficiency of the waste collection, separation, and management programs resulting in savings as well as protection of public health and the environment.

Conclusions

These case studies demonstrate that water quality is of extreme importance to the lives of women especially in developing countries. The quality of water affects women far more than men especially if they must fetch and carry water under sometimes dangerous conditions. Carrying heavy loads also has health implications. Although both sexes are prone to water borne diseases and infections from contaminated water and parasites, women suffer more because of pregnancy, child birth and breast feeding. They are also the primary caregivers of persons already ill and infected and thus come into contact with disease more frequently. Problems associated with water quality take a huge toll on women and young children. There are also economic implications for the family as unhealthy women are poor providers and producers. The attempts to find potable water, and the extra time to secure its quality by boiling it and trying to make it usable as well as all the other responsibilities that women have in the family impacts the time that women and young girls have to spend on education. The under-education of women, in turn, sustains gender inequity.

Target 6.2 of the Sustainable Development Goals: "Achieve access to sanitation and hygiene and end open defecation" emphasizes the need for special attention to necessities of women and children for good water quality and waste treatment.

Another important issue related to water quality and gender but given far less importance is the management and control of waste water and its contents. In some areas and less developed countries, proper waste management has been largely ignored. In these countries young girls and women work as waste pickers and collectors, are paid substantially less than men and do primarily the menial work while men are the main administrators and policy makers. A gendered viewpoint and policies which protect and strengthen the rights of women workers are vitally needed in many countries.

One of the key recommendations that emerges from these and other studies is that more women must be included in the managerial and decision-making institutions especially in developing countries. Governments must take more responsibility in providing the resources to maintain good quality water for the population and more women need to be in administrative and supervisory positions to make sure that happens. In regard to water and water quality and even waste management, it is indeed ironic that women who are the main users and often producers of this important element critical for life and health have little or no governmental or legislative control over this resource, its use and management.

Appendix A: Common Parasites

Dayra Alvarez MT, MSc[1]

Diarrheal disease is one of the major causes of mortality and morbidity in children; killing 2,195 children everyday around the world, making diarrhea the second leading cause of death in children under the age of 5 ("Diarrhea: Common Illness, Global Killer" 2018). Diarrhea diseases can be caused by viruses (rotavirus, enterovirus, etc), bacteria (*Escherichia coli*, *Shigella* species etc) and waterborne parasites include the four most prevalent protozoa *Blastocystis* sp, *Giardia lamblia, Entamoeba histolytica, Cryptosporidium* species (Wawrzyniak et al. 2018) (Azam, Peerzada, and Ahmad 2015). These parasites can be transmitted through the ingestion of contaminated water or food with the infectious stage that can be the cysts of *Blastocystis*, *G. lamblia* and *E. histolytica,* and oocysts of *Cryptosporidium* spp. The infection comes from poor quality of the water for consumption or because of poor hygiene and sanitation conditions. *Blastocystis* is an intestinal parasite with a wide genetic diversity, with a prevalence that often exceeds 5% in the general population of industrialized countries and can reach 30-60% in developing countries. The quality of drinking water, sanitation and poor personal hygiene habits are the major risks for contamination in children(Wawrzyniak et al. 2018) *Giardia lamblia* has a prevalence in humans ranges from 2%– 3% in industrialized countries, up to 30% in developing countries. Giardiasis is directly associated with poverty and poor quality of drinking water(Cernikova, Fasoid, and Hehlid 2018). Some biological aspects

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of the pathogens, *G. lamblia* and *Cryptosporidium* spp are the extremely resistant to chemical disinfectants and other adverse environmental effects (Marshall et al. 1997). *Entamoeba histolytica* has a high prevalent in the first 2 years of life in children living in the developing world, where diarrhea remains the third leading cause of death(Shirley et al. 2018). It is common in communities where much of the water supply for drinking is untreated and the reuse of human wastewater very important for the parasite transmission. *Cryptosporidium* spp. is considered as one of the most common causes of diarrhea in both the immunocompetent and immunocompromised individuals. *C. hominis* and *C. parvum* are the primary causative agents of human cryptosporidiosis, but their prevalence varies in different regions of the world. *Cryptosporidium* oocysts have been reported in both surface and ground water and in treated drinking water (Cernikova, Fasoid, and Hehlid 2018). Waterborne transmission is one of the most common sources of infection for cryptosporidiosis. One of the most important outbreak of this parasite was in 1993, commonly involving the immunocompromised patients resulting in 4,03,000 affected cases, 5000 confirmed cases, and 100 fatalities(Fayer R 2007).

Women are mothers and care takers of the home. They are care takers of illness and diarrheal diseases of their families. They play an important role in the collection, storage and water management for the consumption of their families. They need to learn how to prevent these parasitic diseases. Some authors, mentioned three hygiene-related behaviors that protect infants against diarrhea: washing hands before preparing foods and after using the toilet, safely disposing infant feces and safely storing water in the house(Clasen and Cairncross 2004). Women also can learn that boiling water with temperatures exceeding 70° C will kill the parasites(WHO/FWC/WSSH/15.02, n.d.).

Photo 1. Poor sanitary conditions at Guna Yala region, Panama Republic

No access to safe water, the sewage from latrines go directly to the water surrounded by the community. Children are the most susceptible population to develop intestinal diseases. ©Dayra Alvarez, Panamá.

Appendix B. References to Sections

Section 1

20minutos.es - Últimas Noticias (2018). *El agua es salud: conoce su importancia, sus tipos y sus beneficios.* [online] Available at: https://www.20minutos.es/noticia/1817766/0/agua/mineral/tipos-beneficios/#xtor=AD-15&xts=467263

Who.int. (2018). OMS | *Servicios de aguas para la salud.* [online] Available at: http://www.who.int/globalchange/ecosystems/water/es/ [Accessed 10 Sep. 2018].

www.diariolibre.com (2018). *Situación del agua en RD ya alcanza la categoría de crítica.* [online] Available at: www.diariolibre.com/noticias/situacin-del-agua-en-rd-ya-alcanza-la-categora-de-crtica-IJDL239001 [Accessed 11 Sep. 2018].

Metro República Dominicana (2018). *El agua en el país corre riesgo por contaminación.* [online] Available at: https://www.metrord.do/do/destacado/2017/03/21/agua-pais-corre-riesgo-contaminacion.html [Accessed 11 Sep. 2018].

Hoy Digital (2018). *El problema del agua.* [online] Available at: http://hoy.com.do/el-problema-del-agua/ [Accessed 11 Sep. 2018].

Bvsde.paho.org. (2018). [online] Available at: http://www.bvsde.paho.org/acrobat/aguasa.pdf [Accessed 10 Sep. 2018].

Lenntech.es (2018). *Enfermedades transmitidas por el agua, lenntech.* [online] Available at: https://www.lenntech.es/biblioteca/enfermedades/enfermedades-transmitidas-por-el-agua.htm#ixzz5RH2yj4mr [Accessed 08 Sep. 2018].

Organización Mundial de la Salud (2018). *Enfermedades y riesgos asociados a las deficiencias en los servicios de agua y saneamiento.* [online] Available at: http://www.who.int/water_sanitation_health/diseases-risks/es/ [Accessed 09 Sep. 2018].

www.diariolibre.com (2018). *Salud reporta baja incidencia de muertes por dengue, malaria y cólera en 2017.* [online] Available at: https://www.diariolibre.com/noticias/salud/salud-reporta-baja-incidencia-de-muertes-por-dengue-malaria-y-colera-en-2017-JH8922964 [Accessed 11 Sep. 2018].

20minutos.es - Últimas Noticias (2018). *El agua es salud: conoce su importancia, sus tipos y sus beneficios.* [online] Available at: https://www.20minutos.es/noticia/1817766/0/agua/mineral/tipos-beneficios/#xtor=AD-15&xts=467263 [Accessed 09 Sep. 2018].

Prosalus.es (2018). *Agua, género y determinantes de la salud* | Prosalus. [online] Available at: https://prosalus.es/es/noticias/agua-genero-y-determinantes-de-la-salud [Accessed 10 Sep. 2018].

G., S. (2018). Opinión | El agua: ¿cosa de mujeres? [online] *EL PAÍS*. Available at: https://elpais.com/elpais/2016/03/07/planeta_futuro/1457349350_436641.html [Accessed 11 Sep. 2018].

Fondo Centroamericano de Mujeres (2018). *Las mujeres y su lucha por el agua.* [online] Available at: https://www.fcmujeres.org/las-mujeres-y-su-lucha-por-el-agua/ [Accessed 16 Sep. 2018].

Section 2

Bartram, J. and Hunter, P (2015). In Bradely classification of disease transmission routes for water-related hazards. Chapter 3 *Routledge Handbook of Water and Health*, London, UK 20-37. Eds Jamie Bartram, Rachel Baum, Peter A. Coclanis, David M. Gute, David Kay,Stéphanie McFadyen, Katherine Pond, William Robertson, Michael J. Rouse (Accessed 11/09/2018).

Cap-Net/GWA (2006). *Why Gender Matters: a tutorial for water managers.* Multimedia CD and booklet. CAP-NET International network for Capacity Building in Integrated Water Resources Management, Delft. Cap-Net and Gender and Water Alliance (Cap-Net/GWA).

Benny-Ollivierra, C. and Badrie, N. (2007). Hygienic practices by vendors of the street food "doubles" and public perception of vending practices in Trinidad, West Indies. *Journal of Food Safety,* 27 (2007) 66–81.

Fletcher, J. 2018. *Regional Process of the Americas World Water Forum 2018.* Technical, Inter-American Development Bank. Accessed May 12, 2018. World Water Forum – March 18 to 23, 2018.

Franklyn, S. and Badrie, N. (2015). Vendor hygienic practices and consumer perception of food safety during the Carnival festival on the island of Tobago, West Indies. *International Journal of Consumer Studies*. 39 (2015) 145–154

Global Water Partnership, Caribbean (2017).*Toolbox – Rainwater harvesting in the Caribbean.* Caribbean Environmental Health Institute for the Global Water Partnership – Caribbean (GWP-C). Accessed 12/09/2018. http://carpha.org/saint-lucia/Rain/Rainwater%20Harvesting%20Toolbox/index2.htm#

Khasdurian. L. (2013). Making water safe in Haiti filters and dispensers for the Haitian People.55-58. *ReVista. Harvard Review of Latin America.* 730 Cambridge Street Cambridge, MA 02138. Winter 2013 Volume Xii no. 2 http://revista.drclas.harvard.edu/files/revista/files/water_0.pdf?m=1442956331

Kulinkina, A.V., Shinee, E., Herrador,B.R.G. Karin Nygård, K. and Oliver Schmoll, O. (2016). *The Situation of Water-Related Infectious Diseases in The PAN-European Region.* WHO. Accessed 11/09/2018/ http://www.euro.who.int/en/publications/abstracts/situation-of-water-related-infectious-diseases-in-the-pan-european-region-the-2016

Lakhan, C., Badrie, N., Ramsubhag, A., Sundararaneedi, K. and Indar, L. (2013). Burden and impact of acute gastroenteritis and foodborne pathogens in Trinidad and Tobago. *Journal of Health Population and Research.* Dec; 31(4 Suppl 1): S30–S42.

Ryan, S. (2013). *No time to quit. Engaging youth at risk. Executive report of the committee on young males and crime in Trinidad and Tobago.* School of Education, Faculty of Humanities and Education, The University of the West Indies. St. Augustine, Trinidad & Tobago, W.I.

Satcher, D. (2000). *Food Safety: A Growing Global Health Problem.* JAMA.283(14):1817. Doi:10.1001/jama.283.14.1817. https://jamanetwork.com/journals/jama/article-abstract/192587 (Acceso 11/09/2018).

Mc Clean, E. (2018). *Rural and urban's resident's knowledge and perceptions of potable water in Trinidad.* Department of Food Production, M.Sc project Agri-Food Safety and Quality Assurance. Faculty of Food and Agriculture St Augustine Campus, Trinidad and Tobago.

Meera, V, and Ahammed, M. (2006). Water quality of roof top rainwater harvesting systems: a review. *Journal of Water Supply Research and Technology* – AQUA 55 (4): 257-268.

Montoute, M. C., and Cashman., A. (2015). *A knowledge, attitudes and practices study on water, sanitation and hygiene in Anse La Raye Village, Saint Lucia.* Technical, Faculty of Science and Technology, The University of the West Indies, Cave Hill Campus, Barbados, Anse La Raye: Centre for Resource Management and Environmental Studies (CERMES). Accessed 11/09/2018 https://www.cavehill.uwi.edu/cermes/getdoc/2ed8b81c-d485-4624-8efa-7a857d1ec535/montoute_cashman_2015_kap_water_sanitation_hygeine.aspx.

Morgan, K. (2017). Incidences of food-borne ailments in the Caribbean Region. *On the rise CARICOM Today,* 24th March, 2017. Accessed 12/09/2018 https://today.caricom.org/2017/03/25/incidences-of-foodborne-ailments-on-the-rise-in-the-caribbean-region/

Neff, B. P. (2013). *Traps and transformations of Grenadian water management,* Ph.D. Thesis, Department of Geography and Environmental Management, University of Waterloo, Waterloo, Ontario, http://hdl.handle.net/10012/8018.

Pacific Disaster Center (2016). *Waterborne Disease Vulnerability Assessment, Caribbean Region.* 2015/2016. PDC – HLTH-WBDV001. Accessed 15/09/2018. https://reliefweb.int/map/haiti/waterborne-disease-vulnerability-assessment-caribbean-region-1052016

Roslev, P. and Bukh, A.S. (2011). State of the art molecular markers for fecal pollution source tracking in water. *Applied Microbiology and Biotechnology.* (89 (5): 1341-1355.

Sharmila, M.S., Barua, P. and Joseph, MSM (2017). A correlational study to assess the knowledge and practice regarding water- borne Diseases and Its prevention among mothers with a view to conduct a health education programme at selected PHC of Gurgaon. *International Journal of Healthcare Science.* 5 (1): 498-503.

Sorenson, S. B., Morssink, C., and Abril Campos, P. (2011). *Safe access to safe water in low income countries: Water fetching in current times.* Accessed 11/09/2018/ from http://repository.upenn.edu/spp_papers/166. https://repository.upenn.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1192&context=spp_papers

St. Lucia News Online (2015). Foodborne illnesses on the increase in the Caribbean. May, 15, 2015. Accessed 15/09/2018. www.stlucianewsonline.com/food-safety-more-than-just-a-health-threat/

UNDP, (2001). Trinidad and Tobago National Human Development Report, 2000: Youth at Risk in Trinidad and Tobago. Media and Editorial Projects Ltd., Port of Spain

UNDP (2006). Resource guide. Mainstreaming gender in water management. Version 2.1 November 2006. Accessed 15/09/2018. www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/water-governance/resource-guide-mainstreaming-gender-in-water-management/IWRMGenderResourceGuide-English-200610.pdf

UNICEF (2005). *Water for Life project. Making it happen.* World Health Organization and UNICEF. World Health Organization can be obtained from WHO Press, World Health Organization,20 Avenue Appia,1211 Geneva 27, Switzerland. http://www.who.int/water_sanitation_health/monitoring/jmp2005/en/ (Accessed 11/09/2018).

UNICEF (2006). *Progress for Children: A Report Card on Water and Sanitation.* Number 5, September 2006. United Nations Children's Fund. (UNICEF). New York.

UNICEF (2012). *Pneumonia and diarrhoea; Tackling the deadliest diseases for the world' poorest children.* Statistics and Monitoring Section – Division of Policy and Strategy UNICEF, June 2012. Three United Nations Plaza, New York. Accessed 15/09/2018/ www.unicef.org/eapro/Pneumonia_and_Diarrhoea_Report_2012.pdf.

UNICEF (2018). *Diarrhoeal disease.* Accessed 15/09/2018. https://data.unicef.org/topic/child-health/diarrhoeal-disease/

UNESCO (2014). *UNESCO Priority Gender Equality Action Plan 2014-2021.* 37C/4-C/5-Compl.1. United Nations Scientific and Cultural Organisation, Paris. Accessed 15/09/2018. http://unesdoc.unesco.org/images/0022/002272/227222e.pdf

UN Water and Gender (2018) United Nations. http://www.unwater.org/water-facts/gender. Acceso 12/09/2018

Valster, R.M., Wullings, B.A., van den Berg, R., van der der Kooij, D. (2011). Water Supplies in the Caribbean. *Applied and Environmental Microbiology.* 77 (20): 7321-7328.

WHO (2018). *Waterborne disease related to unsafe water and sanitation.* World Health Organisation. Accessed 11/09/2018. http://www.who.int/sustainable-development/housing/health-risks/waterborne-disease/en/

WHO /UNICEF (2008). *Progress on Drinking Water and Sanitation: Special Focus on Sanitation.* United Nations Children's Fund and World Health Organization Joint Monitoring Programme for Water Supply and Sanitation, 58 pp. UNICEF, New York and WHO, Geneva, 2008. Accessed 15/09/2018. http://www.who.int/water_sanitation_health/monitoring/jmp2008/en/.

WHO/UNICEF Joint Monitoring (2013). *Progress on drinking water and sanitation: 2013 Update.* New York, WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation. (World Health Organization/United Nations Children's Fund). Accessed 15/09/2018. https://goo.gl/yVnVz4

WHO/UNICEF Joint Monitoring Program (2017). *WHO/UNICEF Joint Monitoring Program for Water Supply, Sanitation and Hygiene (JMP) – 2017* Update and SDG Baselines, Accessed 15/09/2018. https://goo.gl/Adk5QN

Wolf, J., Pruss-Ustun, A., Cumming, O., Bartram, J., Bonjour, S., Cairncross, S., T Clasen, T., Colford Jr. J.M., Curtis, V., De France, J.,Fewtrell, L., Freeman, M.C., Gordon, B. , Hunter, P.R., Jeandron, A., Johnston, R.B., Mausezahl, D., Colin Mathers, C., Neira, M. and Higgins, J.P.T. (2014). Systematic Review-Assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression. *Tropical Medicine and International Health* doi:10.1111/tmi.12331. 19 (8): 928-942. https://goo.gl/3CT4Hg

Section 3

Argollo, J. & Philipppe M. (2001). Lake Quaternary climate history of the Bolivian Altiplano. *Quaternary International* 72: 37-51.

García, M.E., Bundschuh J., Persson K., Bengtsson L., Berndtsson R., Ramos O. & Quintanilla J. (2005). Heavy metals in aquatic plants and their relationship to concentrations in surface water, groundwater and sediments – A case study of Poopó. *Revista Boliviana de Química* 22(1): 11-18.

Ormachea Muñoz, R. (2015). *Hydrogeochemistry of naturally occurring arsenic and other trace elements in the Central Bolivian Altiplano. Sources,* *mobility and drinking water Quality.* PhD Thesis, TRITA LWR PHD: 03, KTH Royal Institute of Technology, Stockholm. 39 pp.

INE (Instituto Nacional de Estadística) (2013). *Resultados censo de población y vivienda 2012 Bolivia.* La Paz. https://goo.gl/pqUXor

INE (Instituto Nacional de Estadística) (2016). *Atlas estadístico de municipios.* La Paz.

Soruco, A. (2008). *Étude du retrait des glaciers depuis cinquante ans dans les bassins hydrologiques alimentant en eau la ville de La Paz – Bolivie (16°S).* Tesis doctoral, Université Joseph Fourier, Grenoble. 235 pp.

WHO (2017). *Country report: Bolivia.* www.paho.org/salud-en-las-americas-2017/?page_id=95

Section 4

Arnell, N.W. (1999). Climate change and global water resources. *Global Environmental Change*, 9, S31-S49.

Asamblea Constituyente (AC) (2008). *Constitución de la República del Ecuador.* 218 pp.

Betancourt, W.Q., Rose, J.B. (2004). Drinking water treatment processes for removal of Cryptosporidium and Giardia. *Veterinary parasitology,* 126(1-2), 219-234.

Blackwell, A.D., Tamayo, M.A., Beheim, B., Trumble, B.C., Stieglitz, J., Hooper, P.L., Gurven, M. (2015). Helminth infection, fecundity, and age of first pregnancy in women. *Science*, 350(6263), 970-972.

Boelens, R., Hoogesteger, J., Baud, M. (2015). Water reform governmentality in Ecuador: Neoliberalism, centralization, and the restraining of polycentric authority and community rule-making. *Geoforum*, 64, 281-291.

Cabral, J.P. (2010). Water microbiology. Bacterial pathogens and water. *International Journal of Environmental Research and Public Health,* 7(10), 3657-3703.

Cirelli, A.Y.P., du Mortier, C. (2005). Evaluación de la condición del agua para consumo humano en Latinoamérica. Tecnologías solares para la desinfección y descontaminación del agua. *Solar Safe Water*, 11-26.

Ebele, A.J., Abdallah, M.A.E., Harrad, S. (2017). Pharmaceuticals and personal care products (PPCPs) in the freshwater aquatic environment. *Emerging Contaminants,* 3(1), 1-16.

FAO's Information System on Water and Agriculture (AQUASTAT) (2015). *Water Agricultural and Other Water Uses Database.* Available at: http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=es (Accessed Sept. 2018).

Finerman, R. (1987). Inside out: women's world view and family health in an Ecuadorian Indian Community. *Social Science & Medicine*, 25(10), 1157-1162.

Gibbons, J., Laha, S. (1999). Water purification systems: a comparative analysis based on the occurrence of disinfection by-products. *Environmental Pollution,* 106(3), 425-428.

González, A. H., Regalado, V. C., Van den Ende, J. (2001). Non-invasive management of Ascaris lumbricoides biliary tract migration: a prospective study in 69 patients from Ecuador. *Tropical Medicine & International Health,* 6(2), 146-150.

Gopal, K., Tripathy, S.S., Bersillon, J.L., Dubey, S.P. (2007). Chlorination byproducts, their toxicodynamics and removal from drinking water. *Journal of hazardous materials,* 140(1-2), 1-6.

Helmi, K., Skraber, S., Gantzer, C., Willame, R., Hoffmann, L., Cauchie, H.M. (2008). Interactions of *Cryptosporidium parvum, Giardia lamblia,* vaccinal poliovirus type 1, and bacteriophages ΦX174 and MS2 with a drinking water biofilm and a wastewater biofilm. *Applied and Environmental Microbiology,* 74(7), 2079-2088.

Hughes, J. (2004). Gender, equity, and indigenous women's health in the Americas. *In Gender, equity, and indigenous women's health in the Americas.*

Instituto de Normalización Ecuatoriano (INEN) (2002). *Norma Técnica Ecuatoriana NTE INEN 1108: 2014 Agua Potable: Requisitos.* INEN, 10pp.

Instituto Nacional de Estadísticas y Censo (INEC) (2015). *Base de datos nacional de acceso a agua y saneamiento.* Available at: http://www.ecuadorencifras.gob.ec/estadisticas/ (Accessed Sept., 2018).

Kayser, G. L., Amjad, U., Dalcanale, F., Bartram, J., Bentley, M. E. (2015). Drinking water quality governance: a comparative case study of Brazil, Ecuador, and Malawi. *Environmental Science & Policy,* 48, 186-195.

Levy, K., Hubbard, A. E., Nelson, K. L., Eisenberg, J. N. (2009). Drivers of water quality variability in northern coastal Ecuador. *Environmental science & technology,* 43(6), 1788-1797.

Loke, Y.W. (1982). Transmission of parasites across the placenta. *In Advances in parasitology* (Vol. 21, pp. 155-228). Academic Press.

Lutz, W.; Sanderson, W.; Scherbov, S. (2001). The end of world population growth. *Nature* 2001, 412, 543–545.

World Heatlth Organization (WHO) (2011). *Guidelines for drinking-water quality.* WHO, 564pp.

Pozo, M., Serrano, J. C., Castillo, R., Guerrero, P., Oviedo, A. M., Loughnan, L., Farfán, G. (2016). JMP (WHO/UNICEF) *Nota metodológica de los indicadores ODS de Agua, saneamiento e Higiene.* INEC, 68pp.

Rao, G., Eisenberg, J. N., Kleinbaum, D. G., Cevallos, W., Trueba, G., Levy, K. (2015). Spatial variability of Escherichia coli in rivers of northern coastal Ecuador. *Water*, 7 (2), 818-832.

Rosado-García, F. M., Guerrero-Flórez, M., Karanis, G., Hinojosa, M. D. C., Karanis, P. (2017). Water-borne protozoa parasites: the Latin American perspective. *International Journal of Hygiene and Environmental Health,* 220(5), 783-798.

Secretaría Nacional de Planificación y Desarrollo (SEMPLADES) (2014). *Agua potable y alcantarillado para erradicar la pobreza en el Ecuador.* 120 pp.

Texto Unificado de Legislación Medio Ambiental (TULMAS) (2005). Libro VI Anexo 1. Norma de calidad ambiental y de descarga de efluentes: recurso agua. Presidencia de la República del Ecuador. 54 pp.

Villamar, C. A., Vera-Puerto, I., Rivera, D., De la Hoz, F. (2018). Reuse and recycling of livestock and municipal wastewater in Chilean agriculture: a preliminary assessment. *Water*, 10(6), 817-833.

Section 5

Bisht, M. (2005). *Sanitation and Waste Management: A Perspective of Gender and Diplomacy.* Institute of Social Studies Trust, online document, New Delhi. http://www.gdrc.info/docs/waste/001.pdf

Dias, S. & Fernandez, L. (2013). Waste Pickers – A Gendered Perspective. In: Cela, B, I. Dankelman, J. Stern. (eds) *Powerful Synergies: Gender Equality, Economic Development and Environmental Sustainability.* UNDP: 153-157. http://wiego.org/publications/wastepi ckers-gendered-perspective

Mehra, R., Du, T.T.N., Nghia, N.X., Lam, N. N., Chuyen, T. T. K., Tuan, B. A., Tran, P. G., and Nham, N. T. (1996). Women in Waste Collection and Recycling in Hochiminh City. *Population and Environment,* 18 (2), 187-199.

Madsen, C. A. (2006). Feminizing Waste: Waste-Picking as an Empowerment Opportunity for Women and Children in Impoverished Communities. *Colorado Journal of International Environmental Law and Policy.* 17 (1).

Noel, C. (2010). Solid Waste Workers and Livelihood Strategies in Greater Port-au-Prince, Haiti. *Waste Management.* 30 (6), 1138-1148.

Ogando, A. C., Roever, S., Rogan, M. (2017). Gender and informal livelihoods: Coping strategies and perceptions of waste pickers in Sub-Saharan Africa and Latin America. *International Journal of Sociology and Social Policy,* 37, (7/8), 435-451.

Purdie-Vaughn, V. and Eibach, R. P. (2008). Intersectional invisibility: The distinctive advantages and disadvantages of multiple subordinate-group identities. *Sex Roles,* 59, 377-391.

WIEGO, NEPEM-UFMG, MNCR, INSEA (2005a). *From theory to action: Gender and Waste Recycling.* Book 1: Theoretical Considerations on Gender and Waste Recycling, by Dias, S. and Ogando, A.C. https://goo.gl/BYpAzs

WIEGO, NEPEM-UFMG, MNCR, INSEA (2005b). *From theory to action: Gender and Waste Recycling.* Book 2: Project Design, Tools, and Recommendations, by Dias, S. and Ogando, A. C. http://www.wiego.org/sites/default/files/resources/files/Dias-Ogando-gender-and-waste-toolkit-book-two.pdf

WIEGO, NEPEM-UFMG, MNCR, INSEA (2005c). *From theory to action: Gender and Waste Recycling.* Book 3: Resource Book, by Dias, S. and Ogando, A. C. http://www.wiego.org/sites/default/files/resources/files/Dias-Ogando-gender-and-waste-toolkit-book-three.pdf

WIEGO, NEPEM-UFMG, MNCR, INSEA (2005d). *Women Waste Pickers: Discussing women's empowerment and changes in their relationships with men.* http://www.wiego.org/sites/default/files/resources/files/Gender-Toolkit-EN-LR.pdf

Appendix A

Azam, Amir, Mudasir N Peerzada, and Kamal Ahmad (2015). Parasitic Diarrheal Disease: Drug Development and Targets. *Frontiers in Microbiology* 6. Frontiers Media SA: 1183. doi:10.3389/fmicb.2015.01183.

Cernikova, Lenka, Carmen Fasoid, and Adrian B Hehlid (2018). *Five Facts about Giardia Lamblia.* doi:10.1371/journal.ppat.1007250.

Clasen, Thomas F, and Sandy Cairncross (2004). Editorial: Household Water Management: Refining the Dominant Paradigm. *Tropical Medicine & International Health* 9 (2). Wiley Online Library: 187–91. doi:10.1046/j.1365-3156.2003.01191.x.

Diarrhea: Common Illness, Global Killer (2018). (Accessed Oct. 1) https://goo.gl/4KDax8

Fayer R, Xiao L. (2007). *Cryptosporidium and Criptosporidiosis. Cryptosporidium and Criptosporidiosis.* 2nd ed. Boca Raton (FL).

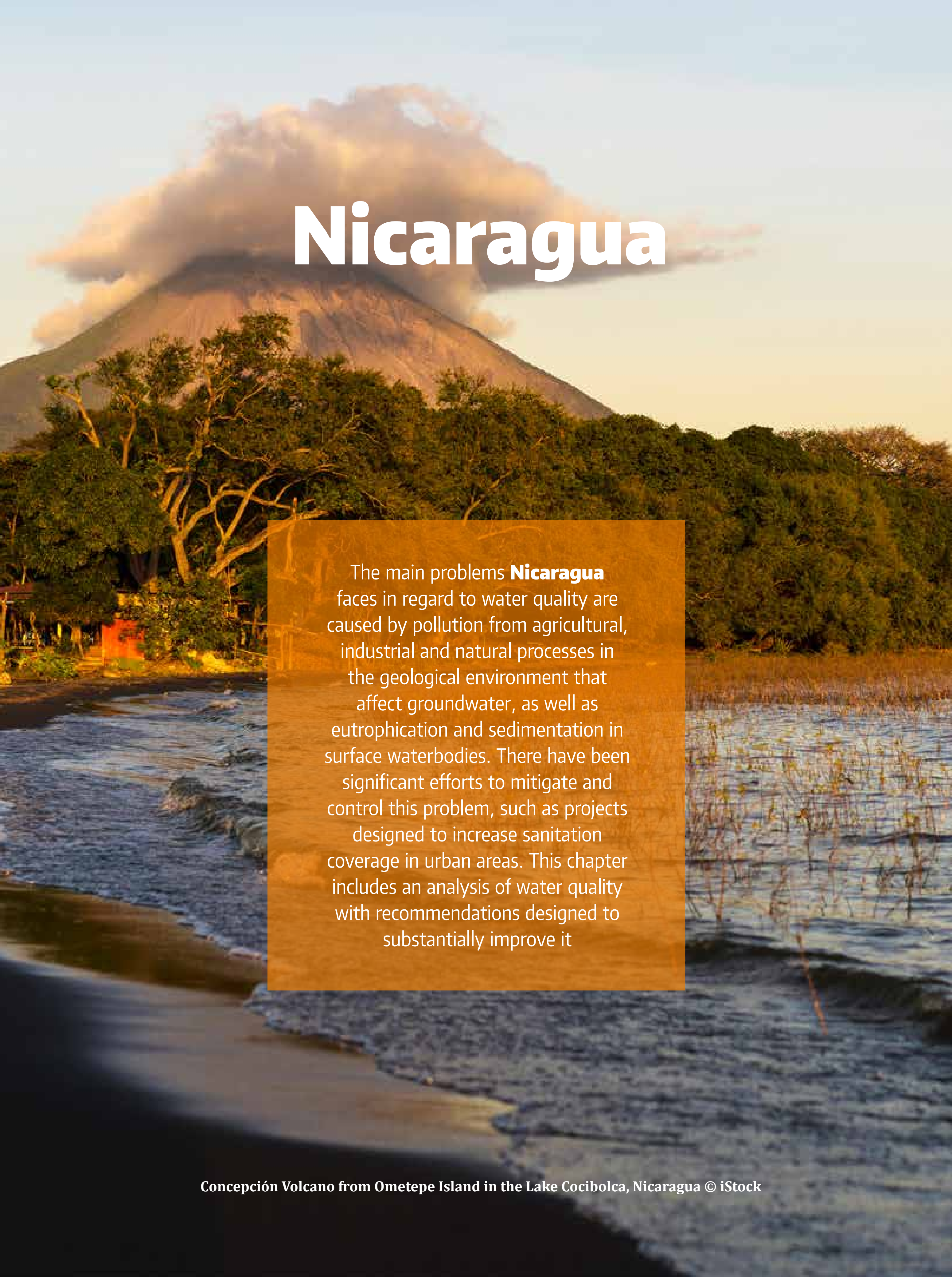
Marshall, Marilyn M, Donna Naumovitz, Ynes Ortega, and Charles R Sterling (1997). *Waterborne Protozoan Pathogens*. Vol. 10. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC172915/pdf/100067.pdf

Shirley, Debbie-Ann T, Laura Farr, Koji Watanabe, and Shannon Moonah (2018). Open Forum Infectious Diseases ® A Review of the Global Burden, New Diagnostics, and Current Therapeutics for Amebiasis (Accessed Oct. 3). doi:10.1093/ofid/ofy161.

Wawrzyniak, Ivan, Philippe Poirier, Eric Viscogliosi, Meloni Dionigia, Catherine Texier, Frédéric Delbac, and Hicham El Alaoui (2018). *Blastocystis, an Unrecognized Parasite: An Overview of Pathogenesis and Diagnosis.* Accessed Oct. 1. doi:10.1177/2049936113504754.

WHO/FWC/WSSH/15.02. n.d. "BIOL WATER." http://www.who.int/water_sanitation_health/

Nicaragua



The main problems **Nicaragua** faces in regard to water quality are caused by pollution from agricultural, industrial and natural processes in the geological environment that affect groundwater, as well as eutrophication and sedimentation in surface waterbodies. There have been significant efforts to mitigate and control this problem, such as projects designed to increase sanitation coverage in urban areas. This chapter includes an analysis of water quality with recommendations designed to substantially improve it

Concepción Volcano from Ometepe Island in the Lake Cocibolca, Nicaragua © iStock

The Challenges of Protecting Water Quality in Nicaragua

Katherine Vammen, Elizabeth Peña, Indiana García, Erick Sandoval, Mario Jiménez, Ivania Andrea Cornejo, Thelma Salvatierra, María José Zamorio, Claudio Wheelock, Analy Baltodano and Romer Altamirano

1. Introduction

Nicaragua has an abundant water potential (renewable water resources) of 27,059 m^3 per inhabitant per year (FAO-AQUASTAT, 2013), which is above the average for Central America. However, in the past two decades, it has suffered a progressive reduction of 10,830 m^3 per inhabitant per year (Montenegro, 2016), a serious amount for the future of a country which needs to ensure access to water for the population and its development. This reduction has a number of causes, the main one being the *loss of water quality in Nicaragua.*

The Sustainable Development Goals, particularly Goal 6, seek to improve water quality through measures that control pollution from "the discharge of hazardous chemicals, promote an increase in wastewater treatment and improve its reuse through quality control" (United Nations, 2018). Achieving these objectives entails introducing measures that pose enormous challenges for water management in Nicaragua.

The main problems affecting Nicaragua's water quality are the factors of change in water, caused by pollution from agricultural, industrial and natural processes in the geological environment in groundwater, as well as eutrophication and increased sedimentation in surface water bodies. The causes involved vary from the change in land use (deforestation) almost throughout the entire country, which leads to increases in erosion processes, the lack of adequate sanitation coverage in urban and rural areas of the country, leaching processes into groundwater and surface water that contain pollutants from poorly-managed solid waste dumps, and the location of waterbodies in areas of Holocene volcanism with active thermalism and seismic activity.

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The Environmental Performance Index System (EPO, 2018) evaluated Nicaragua in the Water Resource category with a score of 0.00 rating it 143rd out of 180 countries and in terms of Water and Sanitation with 41.96 meaning in the position 111. In the category of Vitality of Ecosystems, the score resulted in 50.27 to reach a position of 105.

This chapter on Nicaragua seeks to describe the current status of water resources, focusing on their quality, existing efforts to improve it and recommendations to move forward, with the aim of limiting the loss of availability and improving the quality of water, which has been acknowledged as the resource that can most restrict the population's quality of life. At the same time, good management of this resource can establish an essential guideline for the development and future of the country.

General Characteristics of Water Resources in Nicaragua

Nicaragua has an area of 130,373.47 km^2, of which 10,034 km^2 are lakes, crater lakes and rivers (INIDE, 2000). The hydrological system of Nicaragua is divided into six major level 4 watersheds: the Autonomous Region of the South Caribbean Coast Basin (RACCS) (9519), the Autonomous Region of the North Caribbean Coast Basin (RAAN) (9517), the San Juan River Basin (952), the Río Coco Basin (9516), the Rio Grande de Matagalpa Basin (9518) and the Pacific Basin (9533), according to the Otto Pfafstetter System (**Figure 1**). The Autonomous Region of the South Caribbean Coast is the largest, with 25 672.62 km^2. All the surface waters in the six basins drain into the Caribbean with the exception of the Pacific basin (9533). Of the 80 main rivers, 51 have their

Figure 1. Hydrographic Basins in Nicaragua according to the Pfaffstetter System

Source: ANA, INETER, GIZ and UNI, 2014.

watersheds that flow into the Caribbean Sea, and 12 to the Pacific Ocean. Four of these are tributaries to Lake Xolotlán and 12 to Lake Cocibolca, which then enter the Caribbean Sea via the San Juan River.

Groundwater-Geological Formations and Aquifers

Geology of Nicaragua

According to the Nicaraguan Institute of Territorial Studies (INETER and COSUDE, 2004), Nicaragua is divided into six geo-structural provinces: the Mesozoic Platform, the Paleozoic Nucleus Province, the Atlantic Coast Basin, the Ignimbritic Province, the Central Mountainous Transition Zone, the Southern Volcanic Province and the SE Part of the Nicaraguan graben.

Volcanic eruptions have led to the sedimentation of fertile soils especially in the Pacific region of Nicaragua and part of the Central region, the areas with the greatest economic activity as a result of agriculture.

Groundwater

The geological classification of Nicaragua is one of the determining factors for defining the aquifers located in the country. Quaternaries, alluvial deposits, pyroclastic, ancient alluvia and rocks in the Las Sierras group are the main ground- water reservoirs in the country (Losilla *et al*., 2001) and therefore of great hydrogeological importance. According to INETER (2016), Nicaragua has 12 main aquifers located in the Pacific area, approximately 70% of which are shallow and prone to contamination due to the characteristics of the environment. Small intramontane valleys are located in the Central and Caribbean regions.

In its hydrogeological bulletin (2010), INETER mentions that 80% of the Nicaraguan population is supplied by groundwater used for irrigation, industry and drinking water, specifically in the Pacific region of Nicaragua. The following map (**Figure 2**) shows the location of the main aquifers in the country in yellow.

Surface water

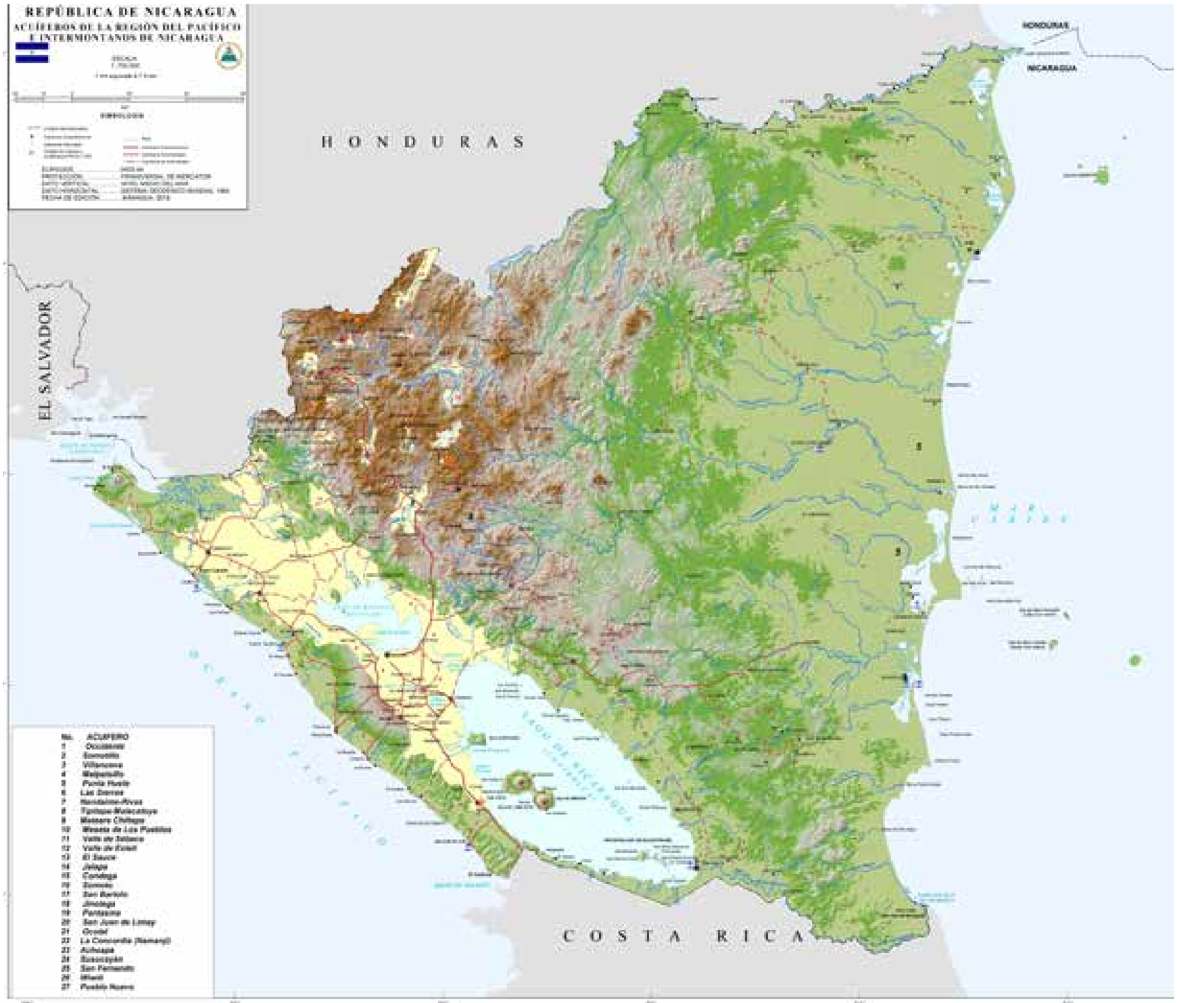
The great lakes of Nicaragua, Xolotlán (Managua) and Cocibolca (Nicaragua), (**Figure 2**) are the largest lakes in Central America. Lake Cocibolca is the largest tropical lake in area in the Americas. They are an integral part of the San Juan River Basin (Basin 952), with an area of 19 533.46 km^2. They are both shallow tropical lakes which are polymictic or exposed to the action of wind, meaning that their waters constantly mix from top to bottom. Lake Xolotlán (1016 km^2) was the receiving body of sewage, industrial and domestic wastewater and rainwater from the capital city of Managua from 1927 to 2009, when the Managua treatment plant was installed. Lake Cocibolca, its indigenous name, or Lake Nicaragua is the twentieth largest lake in area worldwide (8144 km^2) (Schwoerbel, 1987). This tropical lake is characterized by its shallowness: 60% of the lake has a depth of less than 9 m, 37% between 9 and 15 m while certain areas have a maximum depth of 40 m (Instituto Geográfico Nacional, 1972; Bathymetric Map of Lake Nicaragua). Tropical shallow lakes are fragile ecosystems with a different dynamic of recycling nutrients (Jorgensen, Tundisi, Matsumura-Tundisi, 2012) and a special biodiversity that has not yet been fully studied. The two lakes, resulting from tectonic processes in the Miocene Era, are located at the bottom of the tectonic graben.

The surface waters of Nicaragua are also characterized by a total of 16 volcanic lakes, Maar geological formations, known locally as Crater Lakes, as they will henceforth be called in this document (**Figure 3**), distributed along a chain of volcanoes from the north to the south of the Nicaraguan Pacific. Most of them are situated in a tectonically active area called the graben or the Nicaragua depression, located inside of the volcanic craters. These waterbodies of volcanic origin have different hydrogeochemical properties, depending on the geological characteristics of their location and the active tectonic processes in their basin.

2. Impacts on water quality

In 2010, the United Nations General Assembly adopted the binding resolution that declared access to safe, clean drinking water and sanitation a human right that has been recognized by member states. This right extends to aquatic ecosystems, since water is a renewable natural resource that does not begin in a tap or end in a toilet. However, our water sources have been converted into receiving bodies

Figure 2. Main aquifers and Great Lakes of Nicaragua



Source: Compiled by Elizabeth Peña, based on data from INETER, 2016.

for our wastewater and solid waste (UNEP, 2017). Recognizing and diagnosing the impacts on water quality makes it possible to produce the information required to plan efforts to ensure and protect water sources with adequate quality for their intended use.

Nowadays, the quality of water in water resources has a social and economic value as a source of water supply, associated with the various uses by the population such as drinking water, irrigation water, the means for preserving the biodiversity of aquatic ecosystems and, of course, it has potential for the development and future of a country. When there are processes that interfere with the various uses of water- bodies for human beings or degrade ecological value in the preservation of ecosystems, attempts are made to analyze the state of the water body and find solutions that ultimately involve improving water management in hydrographic basins, which can contribute to or limit the impacts that affect *water quality*.

The quality of Nicaragua's water resources has been subjected to various hazards such as the following:

- Eutrophication of surface waters.
- The natural physical-chemical influence due to geological activities associated with hydrothermal alteration in specific areas, resulting from tertiary volcanism.
- Pollution in crater lakes due to urbanization and the two great lakes of Nicaragua and groundwater.

- Contamination from agrochemicals and fertilizers due to agricultural activities.
- Surface water pollution resulting from mining (artisanal and industrial).
- Increase in sedimentation towards surface waters due to massive deforestation and changes in land uses observed in recent decades.
- Salinization of groundwater in coastal areas and crater lakes.
- Contamination from wastewater due to inadequate treatment, which affects the microbiological and chemical quality of the receiving waterbodies.
- Leaching into groundwater and surface waterbodies due to poor solid waste management.

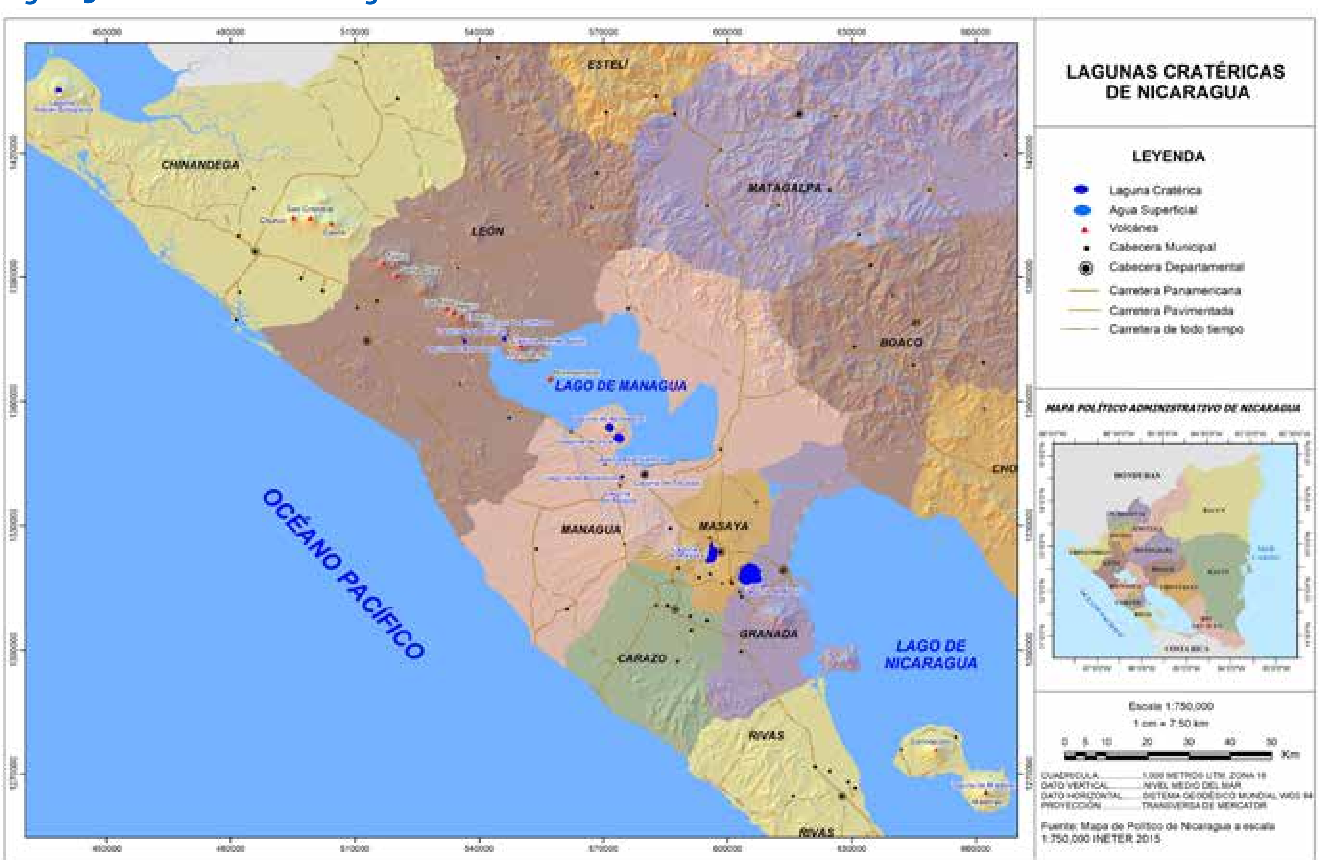
Eutrophication and Microbiological Pollution of Surface Waters

The accelerated process of enrichment of waterbodies with nutrients leads to the deterioration of water quality with symptomatic changes such as: increased phytoplankton production, reduced light penetration and loss of biodiversity at all trophic levels detected by the simplification of the community structure. Eutrophication interferes with the uses of the waterbody for humans, making its treatment more difficult and therefore more expensive.

Microbiological contamination has been detected by water quality monitoring programs, where the presence of pathogens has been found through fecal contamination indicators, fecal coliforms and *Escherichia coli* in almost a third of the rivers in Africa, Asia and Latin America, entailing a health risk for millions of people (UNEP, 2016).

The great lakes of Nicaragua, **Xolotlán** and **Cocibolca** have undergone rapid eutrophication processes in recent decades caused by point pollution from urban development and non-point diffuse source contamination in their basins. This is due, in the latter case, to changes in land use in their

Figure 3. Crater Lakes of Nicaragua located in the Pacific Zone Chain of Volcanoes



Source: Prepared by E. Peña, 2018, based on data from INETER, 2015.

basins that have led to an increase in erosion and, therefore, an increase in sedimentation in the lakes. In the case of *Xolotlán*, it was mainly due to the urbanization on its banks, especially in the capital city of Managua. Point pollution from the surrounding municipalities and cities that lack proper wastewater treatment have contributed to the increase in nutrients entering the two lakes.

Lake Xolotlán was the water body that received waste from the capital city of Managua from 1927 until the installation of the Managua treatment plant in 2009. In a study conducted by the Center for Research in Aquatic Resources (CIRA/UNAN, 2008), a year before the installation of the treatment plant, extremely high concentrations of nutrients were found, including total phosphorus (0.87 mg. l^{-1} - 1.17 mg.l^{-1}) at an average of 16 sampling points on four monitoring dates in 2007 and 2008. Calculation of the trophic level (Carlson, 1977; Toledo *et al*., 1984), which takes into account total phosphorus, orthophosphate (case of Toledo *et al*., 1984), transparency and chlorophyll-a, detected the highest trophic states of eutrophic and hypertrophic predominant in all the points distributed in the lake. It was concluded that "the loss of water quality in the ecosystem was due to the influx of untreated wastewater and the misuse of the soils in its drainage basin". (CIRA/UNAN, 2008).

Five years after the installation of the Managua Treatment Plant in 2014 and 2015 (CIRA/UNAN-CSRSR, 2014-2016), lake water was monitored, with total phosphorus being found a similar range of 0.542 mg. l^{-1} - 1.038 mg. l^{-1}. After analyzing the trophic state (result of trophic status analysis by Carlson, *Eutrophic*, result by Toledo, *Hypertrophic*) (calculated by A. Baltodano and K. Vammen, with data provided by CSRSR-Taiwan, 2018), very little change was observed in the trophic state between eutrophic and hypertrophic. This lake has lost its potential for use as a source of drinking water and irrigation, precisely because of changes in land use in its immediate basin and because of the influx of liquid wastes, rain and solid waste, which has impacted the quality of its waters due to the influx of nutrients and excessively high concentrations of dissolved solids (an average of 1121.21 mg.l^{-1}) from both sources (CIRA/UNAN, 2008).

Moreover, toxic metalloid arsenic has been found in other studies in concentrations exceeding the guideline value of 10µg.l^{-1} issued by the Pan American Health Organization (PAHO) for drinking water, and the Canadian water quality guide for the protection of aquatic life in freshwater systems (5 µg.l^{-1}) (CCME, 2007), observed in CIRA/UNAN monitoring results in 2008 with concentrations ranging from 19.59 µg.l^{-1} to 56.18 µg.l^{-1} and in 2011 with a range of concentrations from 18.8 to 25.0 µg.l^{-1} (CIRA/UNAN, 2008; CIRA/UNAN, 2011). Parello *et al*. (2008) also reported concentrations of between 24.7 µg.l^{-1} and 31.8 µg.l^{-1} in the lake. Boron is another element that exceeds permitted concentrations in water and limits the use of lake water for irrigation, since concentrations of 1 to 2mg.l^{-1} may prevent normal growth in certain crops (FAO, 1994). Boron levels have been found by Parello *et al*. (2008) of between 1.13 mg.l^{-1} and 2.05 mg.l^{-1} and CIRA/UNAN (2008) with an average of 2.42 mg.l^{-1}. The effects on water quality related to the high concentrations of arsenic, boron and dissolved solids could at least partly be influenced by volcanism in the immediate basin and hydrothermal activities on the banks and inside of Lake Xololtán located in the Miocene depression of Nicaragua (Parello, 2008).

As a result of changes in land use in the **Lake Cocibolca** basin, most of its sub-basins have been transformed into land for the use as pastures, as a result of progressive deforestation over time (Vammen, 2006). Land use in the lake basin is shown (**Figure 4**) through a map of its sub-basins and the satellite image: 75% is dedicated to the use of different types of pastures, 8.8% to agriculture and 15% to forests.

This change in land use illustrated in interaction with volcanic geological features and soils causes an increase in erosion in the basin, which in turn leads to more sedimentation in the lake tributaries and boosts the acceleration of eutrophication in the lake (Vammen, 2006).

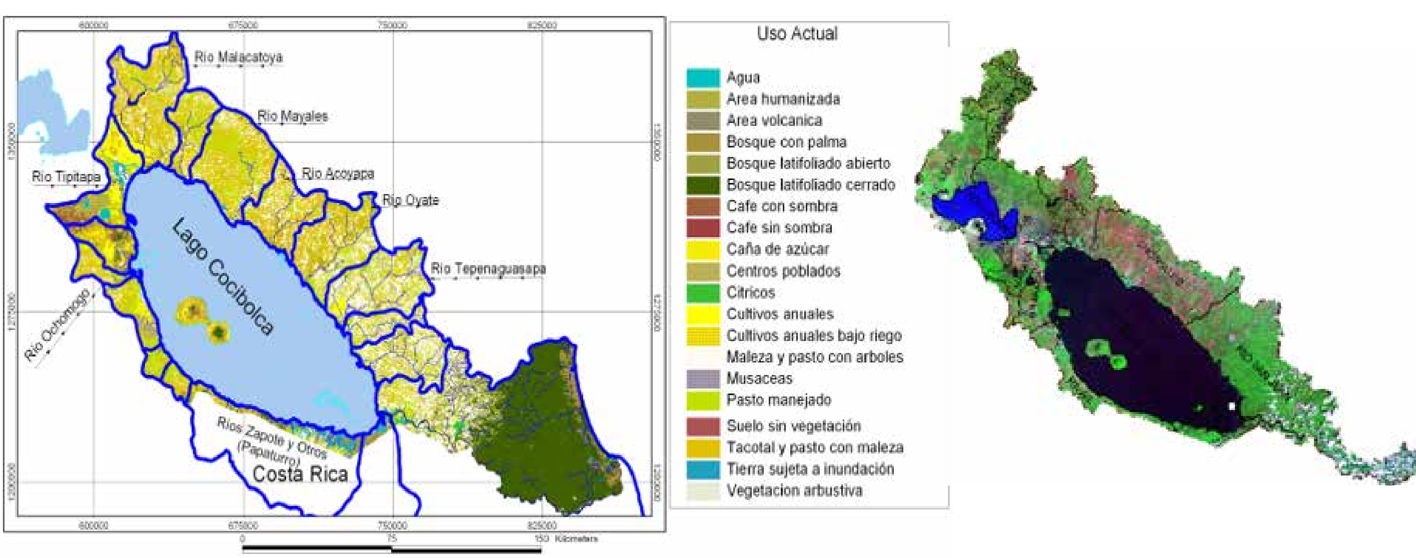
The most recent monitoring of water quality in **Lake Cocibolca** was carried out from 2014 to 2016 (Chang *et al*., 2017) in a project undertaken by CIRA/UNAN and CSRSR-Taiwan: Project-Monitoring of the two Great Lakes of Nicaragua -Lake Xolotlán and Lake Cocibolca, in order to set up a Satellite Remote Sensing System for Future Water Quality Assessments. The results of the analysis of the trophic level have identified the mesotrophic to eutrophic state of the water with zones of high eutrophication located at the entrance to the Tipitapa River that connects with Lake Xolotlán and around cities that do not yet have an adequate sanitation system or where there is an influx of rainwater (trophic level calculated by A. Baltodano, and K. Vammen, with data provided by CSRSR-Taiwan, 2018). According to calculations by Carlson (1977), a third of the points on the various sampling dates indicated the mesotrophic level. Using the Toledo calculation (1984), 13% of the points were found to be at the mesotrophic level. The remaining points were classified as eutrophic.

There are already three cities that use water from the lake connected to a treatment-purification system as drinking water: Juigalpa (60 535 inhabitants) (INIDE, 2018), San Carlos (51 313 inhabitants) and San Juan del Sur (15 811 inhabitants), and there are projects either underway or planned for Cárdenas (7 539) and Rivas (53 208) with the aim of obtaining drinking water from the lake. "As a result of the increase in the use of water from the Lake for human supply, actions are expected to be strengthened to improve the management of the Lake Basin" (personal interview with director of AECID Water and Sanitation Projects, Miguel Torres), which involves improving land use and preventing soil erosion processes and therefore controlling non-point diffuse contamination of the lake. This implies measures such as regulating the use of fertilizers, improving the means of managing livestock, reforestation, re-establishing riparian zones, re-establishing the upper part of the lake sub-basins as a forest reserve and more. There are currently several efforts to install and complete sewerage systems in the cities around the lake and Ometepe Island such as Cárdenas, Granada and San Carlos which, over time, will aid in controlling the influx of nutrients from point sources into the lake. It is important to note that it is not only recommended to control domestic wastewater but also urban stormwater. In the case of Granada, it has been observed that, although the sewage system is partly operational, there are still critical points in the lake precisely where urban streams carrying rain waters, which also carry solid waste, flow into it Miguel Torres).

Water quality in crater lagoons

The crater lakes of Nicaragua have different chemical characteristics depending on their origin, location, tectonic activities or volcanism, whether currently underway or in the past. Many of them have saline waters caused by the thermalism present around them or in the lake beds themselves (Parello, 2008). The great majority of these lakes suffer impacts from the changing seismic and volcanic processes and/or as a result of the human activities that have degraded their water quality.

Figura 4: Uso de suelo de la Cuenca del Lago Cocibolca e imagen satelital



Fuente: Datos se origen del Estudio de Uso del Suelo de la Cuenca del Lago Cocibolca (MARENA, 2011); mapas elaborados por Yelba Flores.

The special characteristics of the water in these lagoons of volcanic origin with their aquatic ecosystems, has a specific form of biodiversity depending on the properties of the water. Many of them also experience various anthropogenic impacts, mainly in urban areas in Nicaragua. Although a Technical Standard for the Environmental Control of Crater Lakes (NTON 05 002-99, MARENA, 1999) exists, it is not implemented and there is a lack of protection and management. The standard accurately describes the special characteristics: "[...] owing to their natural conditions, aquatic ecosystems of volcanic origin are regarded as fragile ecosystems due to their metamorphic characteristics and their endorheic conditions, which are highly susceptible to the impacts of pollution, eutrophication and sedimentation".

There are five lagoons located in urban areas of Nicaragua, four in Managua (with an urban population of 1 388 927) and one in Masaya (with an urban population of 218 566), and two cases have been detailed using information on the impact on quality caused by phenomena linked to urbanization.

The waters of **Tiscapa Lagoon**, located in Managua, have suffered environmental impacts due to poor management of its basin, involving the dragging and silting up of sediment as a result of the deterioration of its drainage area (23.10km^2) and its usage as a receiving body for storm water, as well as domestic and solid waste dragged from the urban channels of San Isidro de la Cruz Verde since 1958, and from Jocote Dulce and Los Duartes since 1980. The lagoon was originally recommended as a source of drinking water supply for Managua (Eckman, 1893) in a 1964 Hazen and Sawyer report and again in a UN study (1975) stating that its chemical quality was suitable for drinking water and that a plan of action in its basin could prevent microbiological contamination. In the 1980s, it was used as a recreation area, which was partly restored through the installation of recreational elements in the 1990s. A study conducted in 2008 by CIRA/UNAN showed that it had undergone severe eutrophication, while its waters indicated the highest levels of the trophic state between eutrophic and hypertrophic. The microbiological quality of its waters also deteriorated, and several studies have determined that its waters are no longer suitable for recreational use, showing contamination of fecal origin (Chacón, 1994). Its biodiversity has drastically changed, revealing the strong dominance of Cyanophyta, indicating waters rich in nutrients and organic substances from its basin, as well as the influx of storm water and domestic wastewater through the aforementioned urban channels. Attempts have been made on several occasions to treat the waters with special bacterial systems to decompose the organic pollution, albeit without success, since the influx of sewage water from the channels and the overflow from the sewage system have not been solved. A management plan was not implemented in its micro-basin to control the loss of quality of its waters. Its potential as drinking water has been lost due to the lack of implementation of measures to protect the lake from eutrophication and microbial contamination, and the fact that it is a receiving body of sediment from its basin, which has considerably reduced the volume of water due to silting and the consequent depth loss.

Lake Masaya, located in the city of Masaya, is the second largest (8.8km^2) of all the crater lakes. It is located in a discharge area for groundwater from the aquifer, which forms part of the Masaya-Tisma underground basin. Its water is also a major source for the Managua aquifer (INAA-JICA, 1993). Despite its importance as a potential source of drinking water and for other aquifers for drinking water, the lake has served as a receiving body for sewage for the past eight decades. Firstly, in 1936 it received wastewater from San Antonio Hospital and, in 1973, the first sanitation system for the city of Masaya was designed for a population of 13, 533 inhabitants. In 1985, the second pond was built, followed by the expansion to six ponds in three modules with two stabilization ponds in series, in 1988 (communication from the ENACAL authorities, Sergio Tercero Talavera and Mario Gutiérrez Soto, 2012), effluent from which always poured into Lake Masaya.

In order to diagnose the water quality status of Lake Masaya, in 2012-2013, CIRA/UNAN conducted a one-year study, the results of which showed the severe impact on water quality caused by the influx of effluents from the oxidation pond: 1) 80% of the water column was found to be in an anoxic state at most points, monitored through four samplings in the annual cycle, 2) its microbiological quality was strongly affected, with evidence being found of high concentrations of organisms indicating fecal contamination, given the composition of domestic wastewater effluent entering, 3) its trophic level varied from hypertrophic at the discharge point to mesotrophic to eutrophic depending on the changes in the volume of water in the lake and obviously related to the amount of rainfall during the year, and 4) concentrations of ammonium were found that exceeded the reference values to protect aquatic organisms and critical episodes occurred as a result of the high concentrations (1.2mg.l^{-1}) throughout the water column.

The main source of contamination was effluent from the oxidation pond, although there was also some influence at certain periods of the year from runoff entering from its immediate micro-basin. The Technical Standard for the Environmental Control of Crater Lakes (MARENA, 1999) stipulates that whether directly or indirectly, neither treated nor untreated wastewater of domestic, industrial or agricultural origin, nor storm water drainage is allowed in crater lakes, nor is the channeling of rainwater carrying solid waste, all showing that it has not been implemented in this crater lake.

A paleolimnological study (Fuentes, 2015), which involved sediment dating (corresponding to 130 years), showed a sharp increase in sedimentation in the lake since the 1960s with the last decade accounting for the highest contribution of sediment to the lake bed. A study of the biodiversity of certain groups of organisms preserved in the sediment showed that since the 1950s, there has been a tendency towards the simplification of biodiversity, in other words, the dominance of eight species has increased.

The domestic water treatment system in the city of Masaya is currently being reformed and in two years' time, it is planned to inaugurate the new Wastewater Treatment Plant in this city, a project undertaken by the Nicaraguan Empresa de Aqueducts and Sewers (ENACAL) funded by the Spanish Agency for International Cooperation for Development (AECID). This project will prevent the direct discharge that currently flows into Lake Masaya, eliminating its main source of pollution (personal communication, Miguel Torres, AECID).

Water quality in selected rivers in Nicaragua

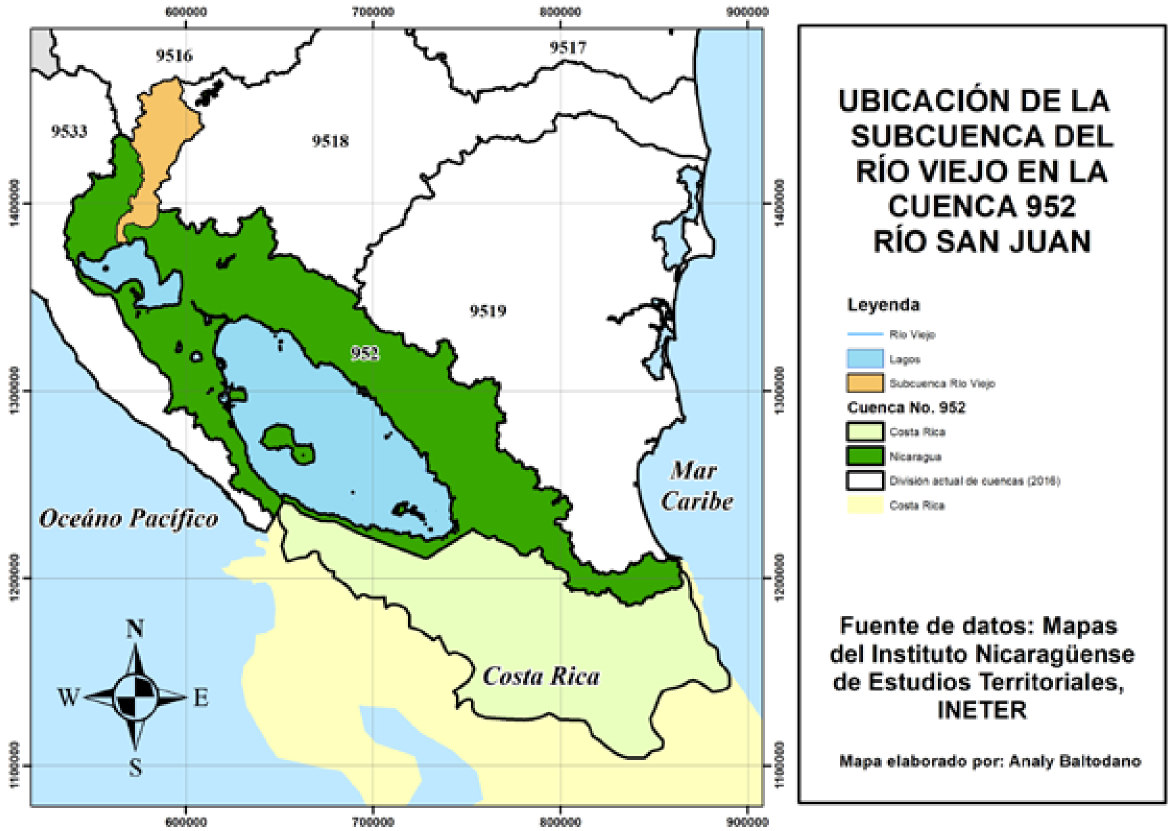
The impact on water quality in Nicaragua has been observed and documented in a number of rivers with high environmental degradation, such as an increase in sedimentation from eroded areas of their watersheds due to the change in land use, particularly deforestation, contamination by domestic waters due to the lack of sanitation systems in cities and rural areas, indiscriminate use of their waters for irrigation in agriculture, which affects the ecological flow of the river and contamination by fertilizers and pesticides used in agriculture.

Río Viejo is strategically important for Nicaragua, since it is located in the upper area of the San Juan River Basin (Basin 952), in other words, the basin of the Great Lakes that eventually drain into the Southern Caribbean Coast watershed of Nicaragua (**Figures 1 and 5**). The 1 553 km^2 basin of Río Viejo covers 12 municipalities and the 157 km-long river eventually flows into Lake Xolotlán.

A diagnosis was undertaken of the quality and availability of the waters in the Río Viejo sub-basin (**Figure 5**) in 2010 and 2011 (Vammen, 2012) to produce the multidisciplinary information that would be used to develop a strategy for the sub-basin to guarantee an environmentally balanced state for the benefit of the population. Some of the conclusions of this study include the following: 1) water production in the upper part of the sub-basin of the Río Viejo is high to medium, showing the importance of its protection and reforestation, 2) deforestation processes were found in all its micro-basins and, since the land has inclined slopes, runoff predominates over recharge and causes base flows not to be maintained in the dry season, 3) microbiological contamination due to fecalism (human and livestock) in the river and groundwater, which represents a risk factor for consumption and recreational use by the population, and 4) overexploitation of surface water in the use of water for irrigation.

On the basis of the conclusions of the diagnosis, some of the most important components of the comprehensive institutional strategy recommended to improve integrated management in the sub-basin of the Río Viejo to ensure water quality were to: 1) regulate the volume of water for irrigation and introduce water treatment systems for return-water irrigation, 2) promote good agricultural practices in pesticide use, 3) work on sanitation plans to improve the disposal of solid and liquid waste, 4) environmental education and introduction of activities by the population focusing on the

Figure 5. Location of the Río Viejo in the San Juan River Basin



Source: INETER, 2017. Prepared by Analy Baltodano.

protection of wells and river water quality, to improve integrated management in the sub-basin of Río Viejo, 5) introduce protected areas particularly in the upper part and protection of recharge zones in the entire sub-basin, 6) rearrange urban centers (introduction of sanitary sewerage in La Trinidad, with an urban population of 12 538), currently underway, 7) declare the upper part a forest reserve area and design plans for reforestation in areas with potential, 8) establish water protection zones in the riparian zone of the river, and 9) control livestock access to river and well water sources (Vammen, 2012).

Water quality in estuaries and coastal lagoons

Nicaragua has the enormous ecological benefit of having two watershed drainage directions: towards the Atlantic (Caribbean) and the Pacific. It has 910 km of coastline with 509 km on the Caribbean and 325 km on the Pacific. Its coasts also have a wealth of estuaries and coastal lagoons. Most of them have environmental problems, which affect their quality of water and ecosystems due to the influx of wastewater from agriculture, of either domestic or industrial origin.

The largest, most important estuary on the Pacific is the **Estero Real**, which flows into the Gulf of Fonseca, providing a significant amount of freshwater (approximately 1443 m^3/year) (González, 1997).

The Estero Real Natural Reserve Delta was recognized by the RAMSAR convention as a "Wetland of International Importance" in 2003, given its values as a wetland and the productivity of the mangrove ecosystem, as well as the importance of its habitat due to the passage of migratory birds through the site. The point where the Estero Real River flows into the Fonseca Gulf has economic benefits, since it has favorable conditions for shrimp farming and there are extensive areas dedicated to this activity.

El Bravo *et al*. (2016), of the Instituto de Capacitación, Investigación y Desarrollo Ambiental (CI-

DEA-UCA), in "Development of an Environmental Monitoring System to Improve the Prevention and Adaptation Capacity to Climate Change of the Fishing and Aquaculture Communities: A Case Study of the Estero Real, Nicaragua," conducted six-month physical and chemical studies in 2013 and 2014 on the water in the Estero Real to examine water quality in a five-point transect, beginning at the point where the river flows into the estuary towards the middle. The results indicate that there has been a deterioration of water quality, reflected in the reduction of dissolved oxygen concentrations as it moves away from the mouth, which also corresponds to an increase in suspended solids, pointing to sedimentation processes caused by soil erosion due to agricultural activities in the immediate basin of the estuary. Pesticide, organochlorine and organophosphate residues were also found in the sediment (DDE, a metabolite resulting from the decomposition of DDT) used in the basin during the cotton *boom* from the 1950s to the 1980s.

The results of this study were used in the Development of an Environmental Monitoring System to Improve the Prevention and Capacity for Adaptation to Climate Change of the Fishing and Aquaculture Communities, with support from FAO, the main product being an *Environmental Monitoring Manual,* which includes the monitoring steps that can be replicated in other locations under environmental and climate pressure due to fisheries and aquaculture.

The microbiological quality of the water from the Padre Ramos, Aserradores and Realejo estuaries, located in the western region, was affected by runoff that sweeps away fecal matter deposited in the pastures, stables and poorly built latrines, located in communities close to these water bodies. In a bacteriological study (Sandoval and Saborío, 2008) conducted specifically at the collection sites of black clams, the presence of *Escherichia coli* was found in both the summer months and in winter, the latter being the time when the highest concentrations were recorded of this bacterium, an indicator of fecal contamination in the three estuaries.

The prevalence of Hepatitis A virus was also studied in those estuaries, while studying the mollusk *Anadara* spp, since this organism is fed by filtration and therefore acts as a bio-accumulator. A prevalence of 0.78% of samples positive to HAV was found, showing that untreated sewage is discharged into these saline water bodies (Saborío and Sandoval, 2008).

Deforestation and sedimentation in Nicaragua and its effects on water quality

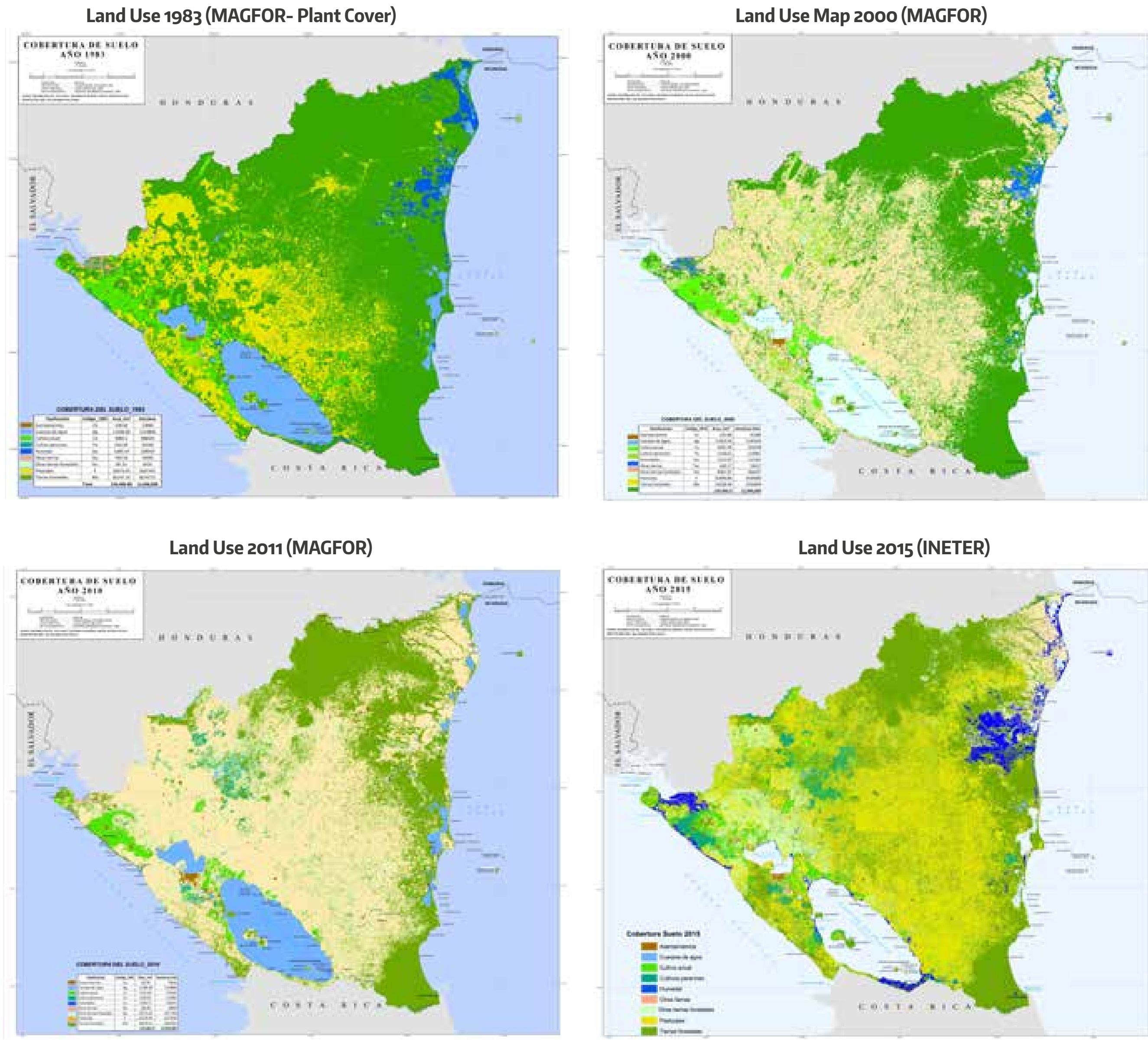
Forests and trees are important as modulators of water flow in the water cycle (Bonell and Bruijnzeel, 2005). Forests can have a direct influence on water quality in rivers and other streams, including factors such as temperature, sediment and nutrient content and biological oxygen demand (Stelzer *et al*., 2003). Forest areas can be barrier zones that act as filters for sediments, nutrients and contaminants before they reach the water, in other words, they limit erosion and therefore the entry into water of soil solids with all their constituents.

Nicaragua is a country with a forest potential estimated at 71.9% (forestry and agro/silvopastoral vocation) of the total area of the country (MAGFOR, 2002). In 2015, INETER reported forest coverage of 30% (3,938,670 ha) of the national territory. Approximately 89% of forests are found on the Caribbean Coast of Nicaragua, where one million inhabitants earn their livelihood from forests (MARENA, 2017).

The forests of Nicaragua have been subjected to a severe process of reduction (an average of 70,000 ha per year in the past 50 years), which has led to the conversion of important areas of forest land to another type of use, particularly agricultural and livestock (INAFOR, 2008). In the Socio-Environmental Crisis of Post Drought Nicaragua Study (2016), conducted by the Humboldt Center and the group of organizations in the Nicaraguan Partnership on Climate Change, a comparative analysis of forest cover was conducted on the basis of official data from the Ministry of Agriculture and Forestry (MAGFOR) on the Actual Use of Soil in 2011 and updated information from 2016 (January-April), in which six departments were prioritized. A reduction of the open and closed broadleaved forest was observed, corresponding to more than 36,000 hectares, together with a reduction of over 6,000 hectares of open and closed pine forest for the departments of Madriz, Boaco, Nueva Segovia, Estelí, Chinandega and Jinotega.

Taking the land use maps for 1983, 2000, 2010 and 2015 (**Figure 6**) drawn up by MAGFOR and IN-

Figure 6. Change in forest cover in Nicaragua 1983, 2000, 2011 and 2015



ETER as a reference, we can see major changes in terms of the increase in pastures, crops (perennial and annual) and the corresponding decrease in forest areas.

There is a significant increase in pasture area (from 26,464.45 km^2 in 1983 to 45,730 km^2 in 2015) for a total of 19,265.55 km^2. Likewise, in crops (perennial and annual), it rose from 5717 km^2 in 1983 to 7643 km^2 in 2015 with a 1926 km^2 increase in total area. Consequently, these changes have led to a significant reduction in forest areas from 82,147 km^2 in 1983 to 51,517 km^2 in 2015, meaning a total of 30,630.16 km^2 loss of forest coverage in three decades.

Deforestation leads to the destabilization of hydrological systems, affecting the water quality of rivers, lakes, wetlands and coastal lagoons.

The effects can not only be seen in the interior hydrological system but can also cause impacts on water quality in coastal areas and affect the fishing industry, leading to a reduction in marine biodiversity and therefore, widespread changes in water quality in coastal areas.

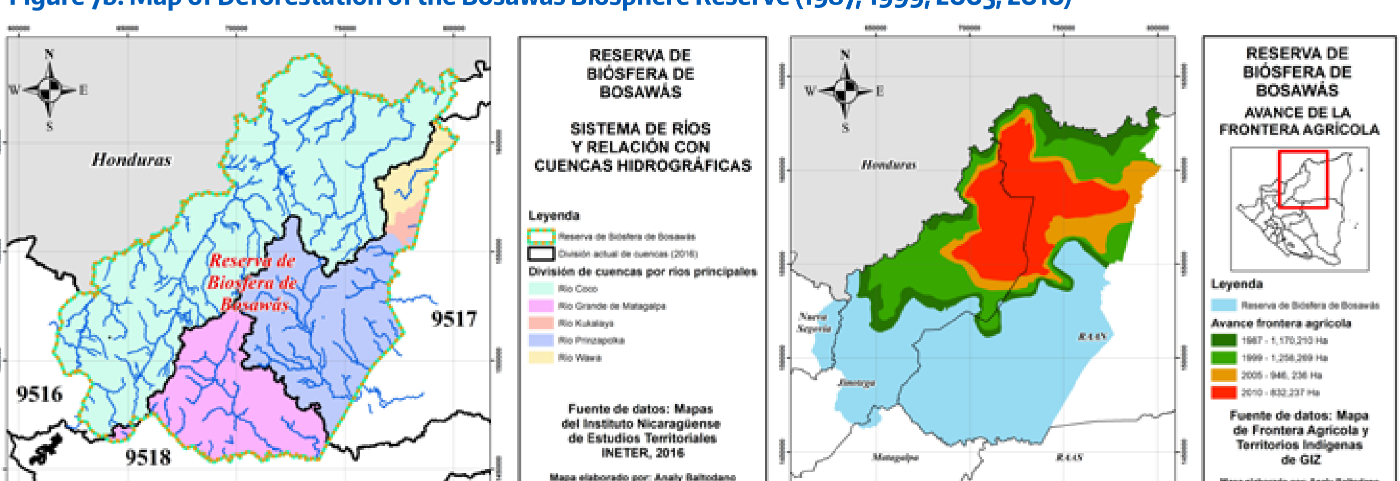
Nicaragua is committed as part of a regional Latin-American and Caribbean initiative to reforest 2.8 million hectors in national territory up to 2020 which is organized from Initiative 20x20 of the World Resources Institute. The National Forest Institute of Nicaragua (INAFOR) has organized campaigns of reforestation in the last years; these campaigns have involved nurseries with species such as cedar (Hyeronyma clusioides), teak (Tectona grandis), eucaliptos (Eucalyptus camaldulensis) among others with the objective in reforestation in zones with major problems. The policy to reforest should take into account the situation of the water resources in these zones and the involved needs for the development of an integrated management of watersheds as well as the geology and soil characteristics. It is important that it is not recommendable reforest exclusively with trees that grow rapidly as they could have adverse effects due to the need for more water for growth and therefore could affect the ecological flow regime.

Nicaragua has 2,243,245 hectors of forest area corresponding to the low and highlands of *humid forests*, which are predominantly collectively classified as Latifoliate Evergreen Forests, whether in lowlands (0-600 m), submontane or montane. These humid forest areas correspond to approximately 17% of the total area of the country (MARENA, 2010) and, despite being partly protected areas, have been exposed to the same deforestation. These tropical humid forests of course receive a high rate of precipitation, but they also have special characteristics in relation to water and its quality; they can prevent sedimentation processes in a basin if the geological substrate allows it, provide a humid environment to maintain high biodiversity and maintain intense filtration of water to recharge groundwater, which, at the same time, guarantees basic flows in the basin rivers. Consequently, the deforestation of humid tropical forests involves a loss and/or intensive impact in terms of these properties for the water resources. **Figure 7** shows the hydrological system in the Bosawas Biosphere Reserve, a tropical forest and the largest forest reserve in Central America (19,926 km^2), and its deforestation over the past three decades.

Example of sedimentation in coastal lagoons

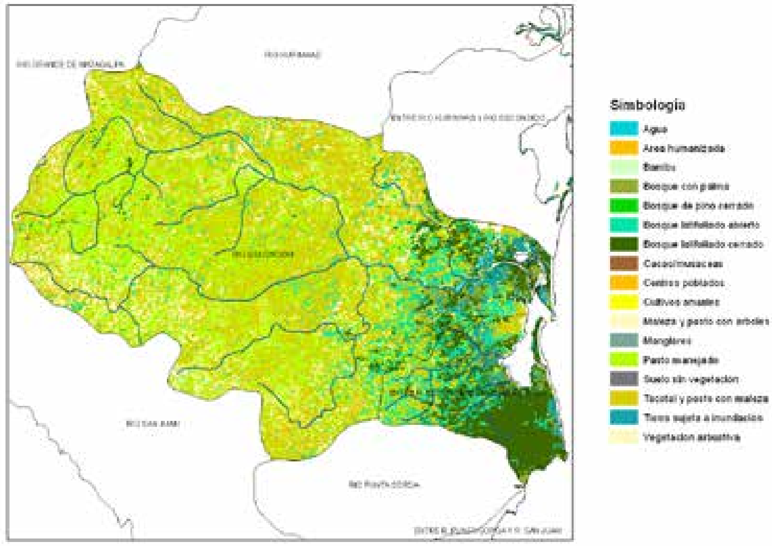
One of the most important *Coastal Lagoons* in Nicaragua is Bluefields Bay on the Caribbean Coast of Nicaragua, where the capital city of the Southern Autonomous Region of the Caribbean Coast (RACCS) is located. The Bay has an area of approximately 10 400 km^2 and currently operates as a protected port due to its shape. However, its use for transport has been under continuous threat due to the intense sedimentation caused by the rivers that flow into it, including Río Escondido, the largest river that contributes a major volume of fresh water

Figure 7a. River System in Basins
Figure 7b. Map of Deforestation of the Bosawas Biosphere Reserve (1987, 1999, 2005, 2010)



Source: prepared by A. Baltodano, 2018.

Figure 8a. Map of Vegetation and land use in 2002
Figure 8b. Río Escondido showing a high degree of turbidity of water being discharged into Bluefields Bay



Source: MARENA, 2002.

Photo: Svetlana Dumailo

and suspended sediments (11 641 million m^3 of sediment annually) (PARH, 1996) from its basin (surface area of 11,517km^2). In a study conducted in 2009, the International Atomic Energy Agency (IAEA) used radioisotopes to determine the sedimentation rate over the past 100 years in sediment profiles of Bluefields Bay using 210Lead dating methodology. The results (Martínez *et al*., 2014) indicated an increase in the accumulation of sediments since the 1960s, which has caused great changes in the water quality of the lagoon, which can be explained by anthropic activities involving land use change such as deforestation, the expansion of the agricultural frontier, forest fires and an increase in the population of Bluefields. The land use map (**Figure 8a**) of 2002 indicates that 77% is dedicated to pasture land, which affects Accumulation Rates of sediments in the Bluefields Bay. Moreover, frequent extreme climate events such as hurricanes caused greater soil vulnerability and increased their susceptibility to erosion and the sedimentation in the rivers (**Figure 8b**, Río Escondido).

Groundwater quality

Groundwater is currently the main source of drinking water in Nicaragua. A total of 68% of the water sources used to ensure the supply of water for human consumption in urban areas of Nicaragua are groundwater, accounting for 70% of the total for domestic use (IANAS, 2015). For example, of the 200 drinking water supply systems existing in 2007, 136 rely on groundwater (ENACAL, 2008).

This trend could change in the next few decades due to an increase in the use of Lake Cocibolca water and other sources of surface water to supply populations in the future. New supply systems are already under construction as part of the PISASH Project, for example, on the Caribbean Coast of Nicaragua, where water from the Kukra river will be used to improve the drinking water system in Bluefields, and a new system under construction in Bilwi in the RAAN using the waters of the Likus River as a supply source. The drinking water systems of the cities of Acoyapa and Santo Tomás have been improved, using the Mico River as a new supply source. (personal communication from Miguel Torres).

Studies on groundwater quality (Briemberg, 1994) focused on pesticide contamination have been conducted since the 1990s. The establishment of institutional capacity to determine water quality at the university level – such as the Centro para la Investigación en Recursos Acuáticos de Nicaragua (CIRA/UNAN), the Instituto de Capacitación, Investigación y Desarrollo Ambiental (CIDEA-UCA) and UNAN-León- has led to more research and monitoring of water quality, and of groundwater at the ENACAL laboratories.

The massive use of persistent agrochemicals in the organochlorinated group began in the 1950s without any management of cotton cultivation, mainly in western Nicaragua, in the department of León and Chinandega. The aquifer, the most important groundwater reservoir in the country, comprises three hydrogeological units, an unconfined alluvial aquifer followed by a volcanic aquifer with an ignimbritic bedrock. The land is devoted to agriculture and partly under irrigation, which has its origin in the shallow unconfined alluvial aquifer, no deeper than 70 meters and, therefore, exposed to pollutants used in agriculture in the medium term.

A master's thesis (Delgado, 2003) found evidence of the presence of persistent (organochlorine) agrochemicals at 12 meters due to pesticide use in cotton cultivation. One problem in the area is the abundance of excavated wells with no protection measures, which fails to limit the transport of pesticides in the soils around the wells or the contamination of well water through the action of the wind. Another study (Moncrieff *et al*., 2008) developed a conceptual model of pesticide transport, concluding that the distribution and concentration of pesticides in the aquifer could be affected by an increase in the extraction of groundwater from the area.

A study in the department of Chinandega (Montenegro *et al*., 2009), in old banana plantations, showed the presence of Nemagon (DBCP) and other organochlorines in the water of 15 supply wells. Although Nemagon was used 40 years ago, DBCP can persist up to 140 years due to its low hydrolysis rate.

A study on quality of water for consumption in rural community's northeast of Leon also detected agrochemicals specifically, Chlorpyrifos and DDT in wells. (González, *et al*., 2007).

Salinization

Saltwater intrusion into groundwater on both coasts of Nicaragua poses an extremely serious threat. Along the Pacific coast, it could occur particularly in areas with heavy extraction of groundwater for irrigation. In some evaluations of the groundwater flow system in the Pacific Basin (9533), León-Chinandega, there have been problems of overexploitation of groundwater, which could further affect groundwater quality (Vammen and Hurtado, 2010). New potable water systems using surface water are currently under construction on the Caribbean Coast of Nicaragua in Bilwi and Bluefields, since many excavated wells have been found to contain saline water.

Toxic Pollutants - Agrochemical and Metallic

Agrochemicals

Nicaragua is a predominantly agricultural country. According to ECLAC, in 2015, the agricultural sector accounted for 14.3% of the national GDP and employs 33.5% of the country's labor force. Agriculture therefore plays a very important role in the national economy. Domestic producers use pesticides to control pests to ensure their productive performance.

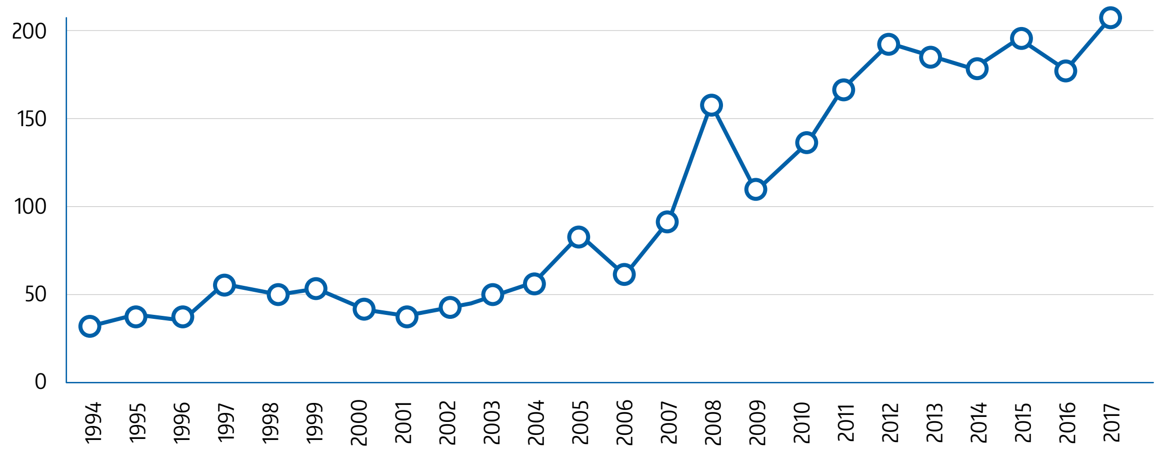
Nicaragua began pesticide importation and use in the 1950s, mainly for cotton cultivation. Although one of the first pesticides to be introduced into the country was Methyl Paration, most of the Persistent Organic Pollutants (POPs) were gradually introduced, such as DDT, toxaphene and others. These chemicals were not only used by cotton producers, but also by coffee, bananas, vegetables, rice, beans and corn farmers (UNDP/MARENA, 2004)

Between 2004 and 2009, Nicaragua imported 16,290,666.45 kilograms of pesticides, with a total of 249 active ingredients. The main ones observed were three weed killers (2,4-D, Glyphosate, Paraquat) and three fungicides (Chlorothalonil, Mancozeb and Carbendazim) (REPCAR, 2010).

In 2016, the main purchaser of agrochemicals by imported volume of insecticides, herbicides and fungicides in Central America was Panama with 34 thousand tons, followed by Costa Rica with 32 thousand tons; Guatemala, with 28 thousand tons; Nicaragua, with 23 thousand tons; Honduras with 21 thousand tons and El Salvador, with 13 thousand tons. As can be seen in **Figure 9**, CIF imports of fertilizers and agrochemicals in Nicaragua have increased approximately fourfold in the past 23 years.

The inappropriate, irrational use of these chemicals has impacted public health and the environment in Nicaragua. In the 2004-2009 period, an average of 1,361 cases of pesticide poisoning were registered per year, together with an average of 183 deaths per year. Unfortunately, due to poor preparation, use and storage practices of these chemi-

Figure 9. Development of CIF imports of fertilizers and agrochemicals from 1994 to 2017



Source: Central Bank of Nicaragua, CIF imports of intermediate goods.

cal substances, 10% of the poisonings registered during that period corresponded to children under 15. Pesticide-related deaths were caused by Paraquat (57%), Phosphine (36%), Chlorpyrifos and Methomil (MINSA, 2001). Studies undertaken in the western zone of Nicaragua have shown contamination in human blood, breast milk, cow's milk, food in general, water and sediments as a result of organochlorine pesticides, alpha-BHC, pp-DDE, pp-DDT, Chlordane and Toxaphene (REPCAR, 2010).

Residues from these pollutants has mainly been transported by runoff through the drainage basin, contaminating surface- and groundwater, coastal and marine water resources of both the Pacific and the Nicaraguan Caribbean. Various studies show the presence of residues from organochlorine insecticides, organophosphates, carbamates and triazine weed killers in rivers, aquifers and coastal areas of the Pacific and Caribbean zone of Nicaragua (Cuadra and Vammen, 2010, Delgado, 2003, Montenegro *et al*., 2009).

Metals – mercury and arsenic

Mercury is one of the metal pollutants with the greatest impact on the environment and human health worldwide. In Nicaragua, several sources of mercury have been studied and found to have contaminated some of the water resources. The three main causes are: artisanal gold mining in various rivers in the country, 2) industrial processes that discharged their effluents into Lake Xolotlán, and 3) natural geothermal sources due to the volcanism around Lake Xolotán.

The study on Environmental Pollution from Mercury in Lake Xolotlán, Nicaragua, in relation to the Evaluation of Human Health Risk showed results indicating levels of contamination from mercury in the soils and groundwater, in the land on the premises of the aforementioned factory and the surrounding area, specifically at the bottom of a channel used to discharge liquid waste into the lake (Peña *et al*., 2009).

Mercury has been used in industrial gold mining and artisanal activities in the central area of Nicaragua, in the department of Chontales, for example, in Santo Domingo and La Libertad, where concentrations in the water of the river Sucio have been found above what is allowed for human consumption and in sediments (André *et al*., 1997). A study (Picado *et al*, 2007) of the risk analysis for human health and aquatic organisms of the river Sucio in the municipality of Santo Domingo took into account the mercury concentrations found in the water (0.42-0.63ug.l^{-1}).) and sediments (1,14-11,07ug.g^{-1}) at a number of points downstream from an extraction site, concluding that the highest risk was for human health followed by aquatic organisms.

According to Altamirano, M. and Bundschuh, J. (2009), one of the environmental problems related to water quality in Nicaragua is the natural concentration of arsenic in certain areas, such as those in the northwest and southwest regions of Nicaragua, due to the dissolution of the geological medium close to mineralized structures, alterations by hydrothermal processes, which are usually in the proximity to tectonic structures parallel to the Nicaraguan depression, which reaches groundwater through faults and fractures. This will be discussed in more detail in relation to health later on.

Wastewater treatment in Nicaragua

"At the same time as the demand for water in agriculture, industry and domestic use grows, an acceleration is observed in the process of water pollution and the degradation of aquatic ecosystems due to the increase in the volumes of untreated wastewater" (United Nations Secretary General Antonio Guterres, United Nations, 2018).

According to the National Human Development Plan for Nicaragua (2012), sanitation coverage in urban areas was 35.6% (measured as connections to the sanitary sewer service) and 42.6% in rural areas; while the Rural Water and Sanitation Information System (SIASAR, 2018) reports that improved sanitation coverage amounts to 42.93% in rural areas. Improved sanitation is defined as a system that guarantees no human contact with human excreta.

According to the 2017 WHO and UNICEF Progress Report for Drinking Water, Sanitation and Hygiene (2017), Nicaragua slightly increased the percentage of wastewater treatment nationwide from 5% in 2000 to 8% in 2015 and for urban centers, an increase from 10% to 13% was indicated for the same period. This same report indicates that sewerage connections increased from 28% in 2000 to 39% in 2015 in urban centers.

At this time a sanitation coverage of 51% exists in 30 municipalities with Wastewater Treatment Plants (WWTP), with a generated flow of 366,000 m^3/d. It is important to mention that even these systems affect the water quality of receiving waterbodies due to the increase of nutrients such as nitrogen and phosphorus, sediments, pathogenic organisms and the organic load discharged through effluents from WWTP.

The percentage of the population that still practice open-air fecalism has been more than halved from 16% in 2000 to 7% in 2015 and has practically been reduced to just 1% in urban centers, although in rural settings, 15% of the population still engage in this practice (WHO and UNICEF, 2017).

ENACAL has defined its goals as "providing potable water service, and wastewater collection, treatment and disposal to the entire urban population of Nicaragua". Due to negotiations with various countries involved in International Cooperation in the water and sanitation sector, progress has been made over the past 10 years in the installation and modernization of WWTPs, the improvement of their operational management and wastewater collection in the sewerage system, mainly in urban areas. Efforts have focused on sanitation in urban areas, since 56% of the population live in cities, while 86% of the urban population live in 46 cities with over 10,000 inhabitants (INIDE, 2018). The goal is to accelerate sewerage coverage to improve the health levels of the population (ENACAL, 2014).

Managua and other municipalities

In 2009, a WWTP was installed in the capital city of Managua with a designed capacity of 182,000 m^3/d to process the domestic wastewater of multiple sectors of Managua (**Figure 10**). The plant consists of a system of mechanical grids, aerated sand traps, primary sedimentation tanks with inclined plates, filters and secondary settlers before their final disposal in Lake Xolotlán (Managua) through a submerged pipe. The WWTP is currently connected to 75% of the sewage system in the urban area of Managua (*La Prensa*, interview with Marvin Chamorro, KFW representative in Nicaragua, 05/07/2017).

The plant was designed to contribute to the restoration of the lake and has achieved a level that has made it possible to install and expand tourist centers such as Salvador Allende port and others, which facilitate recreation for the capital's population and domestic and international tourists.

The peri-urban municipalities of Managua, such as Ciudad Sandino, have a wastewater treatment system covering only 49,000 of the 108,000 inhabitants. Despite the treatment of the domestic wastewaters of Ciudad Sandino's inhabitants, which are discharged into a natural channel that eventually flows into Lake Xolotlán, there are free zones such as Alpha Textil and Saratoga, which discharge their wastewater and rainwater into this same channel. In the municipalities of Tipitapa and San Rafael del Sur, wastewater treatment consists of stabilization

Figure 10. Managua Treatment Plant

Source: Students visiting the WWTP.

ponds, which do not achieve the removal levels stipulated because they operate with much greater flow rates and organic loads than those for which they were designed.

Integral Sectoral Program for Water and Human Sanitation (PISASH)

There are currently problems to achieve the quality of the parameters stipulated in urban areas that have wastewater treatment systems, particularly systems with stabilization ponds that account for just over 55% of the systems installed in urban areas.

Since 2014, the Integral Sectoral Water and Sanitation Program (PISASH) has promoted water and sanitation programs implemented by ENACAL, with a $405 million USD budget for Phase I (2014-2021), including combined resources from the European Union, the Spain-Nicaragua Debt Conversion Program and the Spanish Agency for International Development Cooperation (AECID) in conjunction with the Inter-American Development Bank (IDB), the Central American Bank for Economic Integration (BCIE) and the European Investment Bank (EIB). The Program has planned the installation or renovation of treatment plants and sewerage systems in 14 urban centers with populations of over 5000 inhabitants, where there is low coverage or there was "very little public investment for basic services to guarantee the human right to water, as in the cities in the Caribbean and Central region of the country," where economic development is expected as well as in border cities that have not been prioritized in the past (ENACAL, 2014).

A second phase of the drinking water and sanitation program is currently being planned for an additional 22 cities throughout Nicaragua (Santo Domingo, Ocotal, Jinotepe, Isla de Ometepe, León, Tipitapa, Waspam, El Viejo, Mateare, Chichigalpa, Camoapa, San Jorge, Buenos Aires, Somotillo, El Sauce, Villanueva, Telica, La Paz Centro, Nagarote, San Benito, San Rafael del Sur and Chinandega).

The Special case of Masaya

The city of **Masaya** - with an urban population of 127 903 inhabitants in 2016 (INIDE, 2018) – and the fourth largest city in Nicaragua, has the support of AECID through the Cooperation Fund for Water and Sanitation (FCAS), with $19 million USD in financing, with the main objective of increasing sewerage service coverage through 6274 new connections, and improving wastewater disposal by means of rehabilitation and the expansion of treatment infrastructure. It is essential to eliminate the discharges into the Masaya Crater Lake, which has caused a major impact on its water quality for a number of decades. Plans are underway to divert effluent from the new treatment system in order to transfer it to a natural channel northwest of the city in an area known as Bosco Monge. The project and these changes are scheduled for completion in 2020 according to AECID authorities.

Special case of Granada

In July 2017, the potable water and sewerage project was inaugurated in **Granada** (with an urban population of 101 298, making it the seventh largest city in the country), one of the main cities in Nicaragua located on the shores of Lake Cocibolca. The city's wastewater has impacted the water quality of the lake as a result of the discharge of gray and industrial waters through a system of urban streams or channels (CIRA/UNAN, 1997) for many decades. This project included the expansion of the sewage network, a pumping station and the rehabilitation of a treatment plant that processes 6,000 to 6,200 m^3 a day. All this was possible due to cooperation funds from Germany (27 million Euros), Japan (4 million Euros) and Nicaragua's own contribution (>2 million Euros). Although this project has considerably reduced the contamination of Lake Cocibolca from the city's liquid waste, the city's storm drainage system has yet to be improved.

It is worth highlighting the importance of building *sanitary sewer systems combined with effective treatment plants in urban areas*, since in the rainy season, rainwater tends to combine with the wastewater that saturate latrines or septic tanks and then runs off into areas where it can cause health problems for the population. It is also known that "the fact that latrines are non-hermetic means that they severely contaminate the underlying aquifer in urban areas, where the concentration of infiltration is high" (POG, 2014). It should be noted that in many cities in Nicaragua where wastewater treatment plants existed, very few functioned properly. The modernization and renewal of the treatment system, coupled with the expansion of coverage and the rehabilitation or construction of efficient new treatment plants, is a step forward to ensuring effective treatment in the urban areas of Nicaragua.

The PISASH Project and other sanitation initiatives by ENACAL have a more complete strategy, which guarantees the management and construction of infrastructure, and the quality and continuity of the operation in conjunction with the maintenance of water quality in relation to its operation and final disposal, in other words, supplying quality water for human consumption, adequate treatment of wastewater and final disposal without affecting the water quality of the receiving waterbodies or areas (POG, 2014). It is important to evaluate and maintain the entire chain in order to guarantee adequate quality of all water sources.

Decree 21-2017 (*La Gaceta* No. 229, of November 30, 2017) enacts the Regulation establishing the provisions for the discharge of wastewater, which replaced the old Decree 33-95, Provisions for the Control of Contamination from Discharges of Domestic, Industrial and Agricultural Wastewater in Nicaragua (*La Gaceta*, 1995), as well as technical standard NTON 05 027-05, Nicaraguan Compulsory Technical Norm for Regulating Wastewater Treatment Systems and their Reuse (*La Gaceta*, 2006).

Wastewater in rural areas

In rural areas, particularly in scattered communities that do not have sanitary sewage systems, individual solutions are used, such as latrines or septic tanks. Gray water is poured directly to the ground or runs on the streets until it reaches a waterbody or natural channel. In places where latrines are not available, residents *still practice outdoor fecalism*.

With funds from the World Bank and CABEI, under the Alliances model, the government of Nicaragua plans to invest $160 million USD in integrated water and sanitation programs in rural areas of the country, in communities on the Atlantic Coast and in the Central Region of Nicaragua.

One of the targets of Goal 6 of the SDGs is 6.2: "to achieve access to adequate and equitable sanitation and hygiene services for everyone and to end open defecation by paying special attention to the needs of women, girls and people in situations of vulnerability" (UN, 2018). Given that in Nicaragua, 15% of the rural population engages in open defecation (WHO and UNICEF, 2017), there is an urgent need to design plans to ensure improved sanitation in rural communities.

The new projects will undoubtedly contribute to improving the health of the population by increasing and improving drinking water and sanitation coverage, which *will guarantee water quality*.

Solid Waste Collection and Treatment

The lack of efficient, adequate solid waste collection in Nicaragua remains a major problem and affects water quality, since garbage that is not collected ends up in urban watercourses and natural streams, eventually reaching waterbodies, and affecting possible water sources." Every day, on average, every inhabitant in the city of Managua produces 0.7 kg of solid waste, while inhabitants in the rest of the country produce an average of 0.50 kg/day of waste. On the basis of the above figures, experts estimate that the total production of solid waste nationwide amounts to 3,500 tons/day, equivalent to an annual production of 1.2 million tons. Only four out of ten households dispose of trash through a garbage truck, or deposit it in a dumpster or authorized container. This means that most households -56.6%- burn it, bury it, throw it into an empty lot or else dump it into a river or stream" (INIDE, 2005). Solid waste collection exists in 75 of the 153 municipalities in a collection system administered by municipal governments. A total of 94% of the waste collected in the country is disposed of in open dumps or landfills or burned to reduce its volume. Although here are still no special facilities for the specialized treatment of hospital and toxic industrial or hazardous waste, a number of companies have begun providing services to manage this special waste. Municipal landfills receive industrial and domestic solid waste that has not been classified, where it could affect groundwater or reach runoff water and subsequently be discharged into surface water.

Although there are three technical standards to regulate landfill design (*Gaceta*, 2002) -NTON 05 013-01: Technical Standard for the Environmental Control of Landfills for Non-hazardous Solid Waste; NTON 05 014-01: Nicaraguan Compulsory Environmental Technical Standard for the Management, Treatment and Final Disposal of Non-hazardous Solid Waste; and NTON 05 015-02: Technical Standard for the Management and Elimination of Hazardous Solid Waste (*Gaceta*, 2002) - there are very few landfills in Nicaragua. At present, there are only six municipalities that have built Sanitary Landfills (Managua, La Libertad, Ciudad Sandino, Bluefields, Boaco and Santo Domingo) which continue to operate. Most are associated with recycling projects, such as the one in La Chureca (Managua Landfill). Another four cities have waste recycling projects (Juigalpa, Matagalpa, Ocotal and Granada).

Good human waste management entails benefits for society as regards public health and the environment. It has been estimated that every $1 USD spent on sanitation returns $5.5 USD to society (Hutton, 2004). Other countries are interested in moving recyclable materials such as paper, scrap and plastic, while at the national level, this activity has attracted the interest of a number of enterprising companies working with plastic, paper and recycled glass (Styles, 2015).

Wastewater reuse

Water reuse is not common practice in Nicaragua because the quality of the discharges still fails to comply with official standards, making it impossible to use it in activities such as irrigation, cleaning or aquaculture. Another factor is that nowadays, nearly all the discharges from the systems that exist in the country, are eventually discharged into a receiving body of surface water as previously described in the case of Lake Masaya.

One example of industrial reuse takes place at the San Antonio Sugar Mill, which uses its previously treated effluent to irrigate sugarcane plantations in a ferti-irrigation system (SER, 2018), which has been adapted by other sugar mills in Nicaragua. This process is covered by the Technical Standard for the Use of Wastewater from Effluents from the Sugar Industry and Alcohol Distilleries for the Irrigation of Sugar Cane Plantations (*Gaceta*, 2010).

It is important to advance water reuse practices in Nicaragua, since impacts on the quality of water limit access to the latter by the population and wastewater of different qualities and characteristics could be used under controlled circumstances in agriculture and other industrial activities, to cope with drought in the Nicaraguan dry corridor and other impacts that limit water. Wastewater should be seen as a sustainable source of water, energy, nutrients and other byproducts, rather than a burden affecting water quality. Selecting the type of wastewater treatment system that could provide the most benefits depends on the site and countries should seek to develop the capacity to evaluate these opportunities (UN Water, 2017).

Box 1 shows an example of wastewater reuse in a municipal slaughterhouse in León, Nicaragua, with two-way reuse as fertilizer in urban orchards and for obtaining biogas used for incineration in the same slaughterhouse.

Target 6.3 of the SDGs to ensure the availability and sustainable management of water and sanitation addresses Wastewater Treatment as follows: Improve water quality by reducing pollution, eliminating dumping and minimizing the emission of chemical products and hazardous materials, halving the percentage of untreated wastewater and considerably increasing risk-free recycling and reuse worldwide. In Nicaragua, this issue should be prioritized at the national, urban and rural level.

3. Water quality and health

This section seeks to document two specific health problems related to water quality in Nicaragua: one due to bacterial contamination in surface water and the other due to toxic substances of natural origin in groundwater, particularly arsenic.

Impact on health due to natural contamination of drinking water by arsenic

In Nicaragua, one problem of great concern is water quality in relation to health due to high natural concentrations of arsenic (As), which affect the quality of groundwater and, consequently, the health of the populations that use it for consumption. Some studies have found groundwater with arsenic problems, mainly in the northwest and southwest regions of Nicaragua, caused by extinct volcanism, mainly where tectonic structures parallel to the Nicaraguan depression are located (Altamirano *et al.*, 2009).

Arsenic is classified in the WHO Guidelines for Drinking-water Quality (2018) as a substance of natural origin whose presence in drinking water can affect health and has been assigned a reference value with a maximum allowable limit of 10µg/l in water for human consumption. Nicaragua uses the CAPRE Standards (1993) and the WHO Guidelines for Arsenic in Drinking Water as a reference in environmental arsenic monitoring (4th Edition). "Generally speaking, the chemicals of greatest concern for health in certain natural waters are the excess of naturally occurring fluoride, nitrate/nitrite and arsenic" (WHO, 2018).

In May 1996, contamination of groundwater by arsenic was detected for the first time in a community artesian well in the community of El Zapote, in Sebaco Valley, in the north of the country, which contained 1320 µg of total As/l of water (Gómez, 2011).

Box 1. An Example of Wastewater Reuse in a Municipal Slaughterhouse

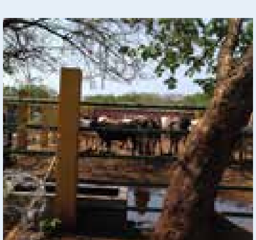
Use of anaerobic biodigestion for wastewater treatment in the Municipal Slaughterhouse of León, Nicaragua

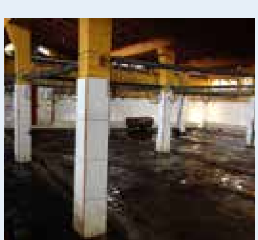
Anaerobic digestion not only makes it possible to treat wastewater with organic matter, but also to utilize the energy capacity of biogas and waste as biol (a natural fertilizer). The biodigester uses the anaerobic digestion (in the absence of oxygen) of bacteria in organic matter, transforming it into methane, treated water and organic fertilizer. Methane can be used as fuel in the kitchen or furnaces.

The Institution BORDA and the Universidad Politécnica de La Salle (ULSA) have achieved the sustainable management of wastewater and solid waste from the León Municipal Slaughterhouse, through the decentralized water treatment (not managed by the national treatment institution) of wastewater (DEWATS), reusing it in wetlands, in addition to sludge.

This treatment helps protect the Chiquito River, which crosses the city of León, into which the slaughterhouse originally dumped wastewater. This produced a foul odor, which harmed the population and affected the wastewater treatment ponds in the city.

The treatment system has two types of use: water treatment for agricultural use in urban gardens, and collecting biogas for use in the planned furnace for the incineration of cattle.


1. Cattle in slaughterhouse


2. Cleaning of rests of slaughterhouse


3. Biodigestor-Reactor for Biogas


4. Biodigestor treatment of waste Waters in 10 anaerobic chamberss


5. Irrigation with treated waste waters

Following this finding, various national and international institutions conducted new studies that confirmed the extent of the problem in neighboring communities and other regions of the country. According to the results of these studies, a total of 29 municipalities were detected, where certain water sources contained arsenic in concentrations higher than the national standard of 10 µg of As/l of water (Gómez, 2011, Barragne, 2004, Altamirano *et al*., 2009).

According to the results of the various studies carried out, water sources contaminated by arsenic have been identified in nine (52.9%) of the 15 departments and the two autonomous regions into which the country is divided. Most of the municipalities affected are located in the north-central region of the country (Departments of Nueva Segovia, Madriz, Estelí, Matagalpa), followed by municipalities located in the Western Region of the country (León, Chinandega) (CIEMA, 2009).

According to experts on the subject, the identification of new drinking water sources contaminated by arsenic in Nicaragua could increase as studies of natural water pollution by this element advance. Due to the broad distribution of arsenic as a natural water pollutant, it is currently considered necessary to introduce the permanent, routine analysis of this toxin in drinking water sources in Nicaragua, in order to guarantee safe water for exposed populations and contribute to improving their levels of health and quality of life. It is also recommended to undertake a geological and toxicological evaluation of the sites where drilling wells are planned to prevent unnecessary economic expense before drilling.

Leptospirosis in Nicaragua: Waterborne disease

Leptospirosis is a bacterial disease caused by *Leptospira* spp., clinically characterized by fever, headache, muscle aches, pulmonary hemorrhage, meningitis, myocarditis and uveitis (WHO, 2010). It is considered a zoonotic disease with epidemic potential, which has a significant impact on health in several parts of the world (MINSA, MAGFOR, UNAN León and PAHO, 2012), with greater incidence in tropical climates.

Leptospirosis outbreaks occur in people exposed to freshwater from rivers, streams, canals or lakes contaminated by the urine of domestic and wild animals, such as rodents, cattle, horses, pigs and dogs (WHO, 2010). It has been noted in recent years that the risk is increasing in urban areas, particularly during torrential rains, when flooding occurs (PAHO, 2005). Leptospirosis epidemics are often linked to heavy rainfall and flooding associated with extreme weather events.

The largest experience in the management of leptospirosis cases began in 1995, when a leptospirosis epidemic broke out after a tropical storm. Known in Nicaragua as Achuapa fever (after the city where it first appeared), it was diagnosed and treated with the support of Mexico, Cuba and the Center for Disease Control in Atlanta, Georgia. (Moreno, 2012). That year, 2,254 cases with 48 deaths were recorded.

As a result of this experience, capacities were built for the diagnosis and epidemiological surveillance of this disease, which made it possible to address the second largest outbreak, recorded in 1998, which occurred in the wake of Hurricane *Mitch*.

As regards to the temporal distribution of leptospirosis cases in Nicaragua, since the experience of Hurricane *Mitch*, small outbreaks have been reported with clear indications of high infestation of rodents in rice crops and other basic grains. During the period 2003-2006, 273 positive cases were reported, with no deaths from leptospirosis (MINSA, MAGFOR, UNAN León and PAHO, 2012).

In 2007, three outbreaks were again reported, the most significant one being in the month of November after Hurricane Félix. In the period 2008 to 2010, the number of cases of leptospirosis was similar to those reported during the inter-hurricane period, with the majority of cases being from rural areas (MINSA, MAGFOR, UNAN León and OPS, 2012).

In short, leptospirosis in Nicaragua displays endemic behavior with epidemic outbreaks that generally occur after floods caused by hurricanes and tropical storms, which is associated with the presence of the etiological agent in its reservoirs, the contamination of waterbodies and the exposure of the population to leptospirosis for various reasons, mainly in rural areas.

4. Role of women and water quality in Nicaragua

Within the water problem, women's participation is usually limited to obtaining water, focusing on the quantities available in the home. Although women are the ones who use water most for domestic tasks and the family, they also worry about obtaining good quality water for their families and nowadays they are the ones most interested in improving and expanding their knowledge on water quality to ensure the environmental sustainability of the distribution systems managed by the Potable Water Committees (CAPS) in rural or peri-urban areas. Ensuring water quality in the home is part of their role of ensuring hygiene in the home and the well-being and food security of their families.

In Nicaragua, water-related difficulties are not only related to the quantity, but also to the quality of the water. This is why, in many parts of the country, women are already breaking down gender barriers and taking specific actions to ensure that the highest quality water reaches their homes. In an initiative promoted by the Ecology and Development Association (Ecodes) and the León-Zaragoza Twin Cities in conjunction with the municipality of Achuapa, approximately 50 women are "using potabilization techniques in the community of El Porvenir and El Barro, from the municipality of Achuapa, in the department of León. With the support of Spanish cooperation workers, they built water purification filter systems" (González, 2017). For their construction, they used local stones, wood, pipes and plastic drums. The small filters are a mixed bed (several types of sand with a chlorine mixer) that eliminate pathogenic bacteria and certain solids present in the water of rivers and streams which have high levels of mineral salts and coliforms in these areas of the country (**Figure 11**).

Figure 11. Achuapa women's group building water purification filters

Photo by José Luis González, published in Nuevo Diario, July 5, 2017.

From building filters to examining the water quality of wells with portable laboratories, women are gradually reducing the gender gap in water culture (Gutiérrez, 2017). Walkiria Castillo of the Water and Sanitation Committee in the municipality of Villanueva, located in the north of Nicaragua near a gold mining operation, is concerned about the quality of the water consumed in the municipality: "We need a study to know whether our water can be drunk, because it has not been analyzed in the four years since we made the connection. They carry out explorations with cyanide and we should be aware of what we are drinking" (Gutiérrez, 2017).

The Spanish Agency for International Cooperation for Development (AECID, 2016) states that, "Women are worried about the future, they talk about climate change, and the fact that streams and wells are drying up". Likewise, nowadays they are also worried about the quality of the water their families consume, proving once again that water is a women's issue.

5. Water Quality Monitoring

As documented in this chapter, in Nicaragua, water quality is exposed to many types of impact in all sectors: urban and rural waters; surface and groundwater; potable water and its sources of mainland fresh water and underground aquifers; the environmental quality of aquatic ecosystems.

The lack of water quality monitoring in many parts of the world does not allow for an accurate global estimate of water pollution (United Nations, 2018). Although water quality monitoring programs in many countries are regarded as extremely expensive, compared to the value of water resources and what can be saved in making decisions based on scientific information, the costs are minimal (Lovett *et al*., 2007). The most important thing for water management in a country is the use of water of the right quality for consumption and the protection of the environmental quality of aquatic ecosystems. To ensure that drinking water is of the right quality, it is essential to have a monitoring system and a legal

Box 2. Need for water quality monitoring for community development in Rural Areas

"An essential component for planning community development is reliable information on the water resources it uses, particularly drinking water. Quality monitoring is an essential element for quality control and should be part of the efforts for the rational use and protection of water sources. Despite the high cost and insufficient coverage of the monitoring undertaken by institutions, whose responsibility is precisely to maintain updated water quality databases and to facilitate their access by interested parties, this information is essential and must be obtained by any possible means. Information on the quality of both surface and groundwater, is crucial to integral water resource management" (Salvatierra, 2018).

Water Quality Monitoring for Wetlands

The world's wetlands are disappearing due to the impact on water quality

"Owing to the degradation and loss of wetlands worldwide, particularly in Nicaragua, there is an urgent need for residents to monitor the water quality of wetlands for their current and future protection and conservation.

Monitoring water quality in the freshwater wetlands of Nicaragua is necessary, both for their use as drinking water sources and because of the ecological role of these wetlands and the ecosystemic services they provide. Unfortunately, traditional water quality monitoring using established laboratory techniques (microbiological assays and physical-chemical analysis) remain inaccessible in rural areas due to their high costs and lack of coverage in national health programs. Accordingly, the use of biological indicators contributes to the establishment of alternative forms of monitoring water quality.

International experience has shown that knowledge of the biological diversity of aquatic macroinvertebrate fauna facilitates knowledge of the ecosystem's conservation status and water quality. This monitoring can even be supported by building local capacities, through the training and organization of people who participate in the collection and classification of freshwater organisms under the guidance of specialists" (Maes and Salvatierra, 2014:2).

The Convention on Wetlands in Resolution VIII.14 mentions that "a monitoring program should be an integral part of any management plan. However, even when a management plan is not yet in place, it is possible to implement a monitoring program". The purpose of a monitoring program is to detect a "change or possible change in ecological characteristics" (Secretariat of the Ramsar Convention, 2010).

instrument that determines the guiding values to guarantee quality, as well as to protect ecosystems in existing water resources.

Box 2 highlights the enormous importance of monitoring water quality in rural areas in order to ensure integral water resource management, and in wetlands that play an essential role in maintaining water quality in coastal areas and surface water bodies.

There are currently a number of commercial and research laboratories to perform water analysis, including the following: Instituto de Capacitación, Investigación y Desarrollo Ambiental (CIDEA-UCA), Centro de Investigación en Recursos Acuáticos de la Universidad Nacional Autónoma de Nicaragua (CIRA-UNAN), Laboratorio Médico Químico Bengoechea, Laboratorio Químico S.A. (LAQUISA) and Universidad de Ingeniería (UNI); the Empresa Nicaragüense de Acueductos y Alcantarillados Sanitarios (ENACAL) and the Ministry of Health (MINSA).

7. Recommendations

The following recommendations have been prepared based on the need to comply with the SDGs and the conclusions related to the topics highlighted in the contents of this chapter have detailed the impacts on water quality and its causes, water and health, gender and water quality, and water quality monitoring. We have tried to present some measures that are urgent and necessary for the coming years in order to improve water quality in Nicaragua and prevent environmental and health crises:

1. Nicaragua needs to progress in accordance with SDG 6 (ensuring water availability and its sustainable management and sanitation for all) and recommendations based on the conclusions have been included for the specific targets of the SDGs, namely:
   - Improve water access and quality, especially in rural and peri-urban areas (Target 6.1).
   - Increase improved and adequate sanitation coverage that does not cause secondary impacts on receiving water bodies (Target 6.2).
   - Introduce measures to reduce contamination from agrochemicals, erosion in watersheds, improperly treated wastewater, and solid waste without management or control (Goal 6.3).
   - Introduce more innovation and use of appropriate techniques for the reuse and safe recycling of solid and liquid waste (Target 6.4).
   - Advance in integrated watershed management that includes a change in governance practices and a cooperation policy in transboundary basins (Target 6.5).
   - Introduce programs for the protection of ecosystems related to water resources such as wetlands and forests, paying special attention to tropical humid and dry forests, rivers, lakes, crater lagoons, coastal lagoons and aquifers (Goal 6.6).
2. Develop an integrated watershed management program with emphasis on the two Great Lakes of Nicaragua, which includes action plans in prioritized sub-basins to take steps to prevent diffuse pollution and thus stop the increase in erosion of the basin in order to address sedimentation and eutrophication in lakes. This program is urgent in the case of Lake Cocibolca, given that it is important to continue with its use as drinking water for the population that lives in its basin and with a view to other planned uses for the future. In the case of Lake Xolotlán, it is recommended to continue developing the plan to establish a more effective drainage system that will control the influx of rainwater mixed with sediments and wastewater that is not treated in the WWTP of Managua, with the aim of continuing to improve water quality to increase the recreational use of the lake.
3. ENACAL, with the aid of international cooperation, has increased sanitation coverage in urban areas throughout the country, especially on the Caribbean Coast of Nicaragua.

   Target 6.2 of the SDGs is, “To achieve access to adequate and equitable sanitation and hygiene services for everyone and to end open defecation by paying special attention to the needs of women, girls and people in situations of vulnerability”. Given that in Nicaragua, 15% of the rural population still practice open defecation, there is an urgent need to advance specific designs and plans for rural areas in order to increase the coverage of improved sanitation in communities and achieve the goal of eradicating open air fecalism in Nicaragua.
4. It is important to change the perspective on the ecological value and respective use of crater lakes, taking into account the quality of their waters, their particular biodiversity and the richness of the landscape. The Technical Standard for the Environmental Control of Crater lakes (NTON 05 002-99, 1998) clearly states that “Treated or untreated wastewater, of domestic, industrial or agricultural origin, or the channeling of rainwater carrying solid waste is not allowed in crater lakes, either directly or indirectly” (Section 5.1.1). Enforcement of this Standard must be promoted.
5. The implementation of an effective forest management plan is an integral part of integrated watershed management, which should be specifically developed according to the characteristics of the six watersheds of Nicaragua and their sub-basins. It is essential to introduce measures to protect rivers, lakes, wetlands and coastal lagoons to prevent the continued increase in sedimentation through an action plan based on results of diagnostics of the particular characteristics and possible solutions to the problems encountered. It is advisable to include the restoration of riparian zones and reforestation plans, especially in the upper basin, which could possibly be established as protected areas. It is important to include specific management plans for coastal lagoons, subject to silting up by the sediment swept in by tributaries.

6. The growth of urbanizations implies an increase in surface runoff and therefore greater erosion. Special attention should be paid to the basin around urban centers with land use control plans and to improving or establishing effective drainage systems.
7. There is an urgent need to prevent the continuation of deforestation throughout the country in general and in the Biosphere Reserves in particular. This depends on the will and action of government authorities and the implementation and/or renewal of management plans. The resolution of social conflicts over land in the reserves warrants special attention by all the parties involved. Entrepreneurial production projects should be introduced to take advantage of local resources and involve all parts of the communities.
8. Good agricultural practices and better pesticide management with better control and regulation should be implemented to prevent further contamination of water resources.
9. Although good solid waste management models already exist in a few cases, it is essential for Nicaragua to make more progress in streamlining urban and rural collection systems, the final disposal in garbage dumps organized in the form of landfills and increasing recycling. All this can benefit society as regards health and water quality as well as economically.
10. Wastewater should be seen as a source of water, energy and nutrients. It is important to advance in more reuse practices for these waters, particularly in dry areas, to cope with periods of drought and maintain agricultural production. It is obviously necessary to have a good monitoring system to evaluate quality according to its use perspective.
11. Given the volcanic nature of certain parts of Nicaragua, it is essential to control water quality due to the presence of arsenic and other metals. Better planning of well drilling zones on the basis of the geological and toxicological evaluations of the sites under consideration is also recommended.
12. Special attention should be paid to industrial and artisanal mining to control possible contamination processes, which are the result of the extraction steps and the elements used to facilitate the recovery of the metal.
13. In order to improve water quality in relation to microbiological contamination, better control should be exercised over wells dug in rural areas, which requires the introduction of protection measures at the farm level and in communities.
14. The transmission of disease agents through surface and groundwater has affected the health of the population in Nicaragua. It is important to improve protection measures for all sources of drinking water and water for recreation beginning at the watershed level.
15. It is essential to promote more training and involvement of women in water quality control measures in general and in domestic sources.
16. It is important to improve the water quality monitoring system to include all elements with a risk of impacting water for drinking and other uses.
    - It is advisable to include monitoring that controls the proper functioning of wastewater treatment plants in order to guarantee safe quality for disposal or reuse.
17. It is essential to increase scientific research to provide diagnostics and the necessary information for water quality control with a view to minimizing the impact on human health. In this respect, it is important to build institutional capacities to promote research and information analysis to improve environmental conditions and to offer solutions in order to avoid affecting the population due to the use of water of inadequate quality.
18. It is necessary to improve the implementation of environmental laws, particularly the General Law of National Waters, No. 620. Even though Law No. 620 was passed on September 4, 2007, the most important measures have yet to be implemented, such as:
    - Art. 114 of this Law, which states that at its first meeting, the National Council of Water Resources (CNRH), should create a Technical Committee from among its members to formulate and draw up a national plan for water resources with land management criteria and a basin approach for appropriate land use, and ensure the production and protection of water in the medium and long term. Art. 117, Law 620 stipulates that the National Plan for water production,

once approved by the National Council of Water Resources (CNRH), will become part of the National Water Resources Policy.

19. In order to promote scientific research and educate the population on the importance of every aspect of water quality, it is important to establish a database of information on water quality accessible to the public. Article 14 of the aforementioned Law 620 states that the following are water resource management instruments: The National Water Resource Information System. This system consists mainly of geographic, meteorological, hydrological and hydrogeological information and includes database management, network operation and maintenance and the dissemination of the information obtained.
20. In order to preserve the wealth of water resources in Nicaragua, it is essential to develop governance that takes into account the rational use of resources and their relationship with each other.

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References

Agencia Española de Cooperación Internacional para el Desarrollo (AECID) (2016). E*l agua es cosa de mujeres.* Nicaragua. Retrieved from: http://www.aecid.org.ni/wp-content/uploads/2016/03/El-agua-es-cosa-de-mujeres.-AECID.Nicaragua.pdf

Alianza Nicaragüense ante el Cambio Climático (ANACC) (2016). *Crisis Socio-ambiental de Nicaragua Post Sequía 2016.* Managua: Centro Humboldt.

Altamirano M. & Bundschuh J. (2009). Natural arsenic groundwater contamination of the sedimentary aquifers of southwestern Sébaco Valley, Nicaragua. *Geogenic Arsenic in Groundwater of Latin America.* CRC Press, Editors: J. Bundschuh, M.A. Armienta, P. Birkle, P. Bhattacharya, J. Matschullat & A.B. Mukherjee.

André L., Rosén K. & Torstendaho J. (1997). *Minor Field Study of Mercury and Lead from Gold Refining in Central Nicaragua.* Lulea Tekniska Universitet.

Autoridad Nacional de Agua (ANA), Instituto Nicaragüense de Estudios Territoriales (INETER), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Programa de Asistencia Técnica en Agua y Saneamiento (PROATAS) y Universidad Nacional de Ingeniería (UNI) (2014). *Cuencas Hidrográficas de Nicaragua bajo la metodología Pfafstetter.*

Barragne Bigot, P. (2004). *Contaminación natural por arsénico de las aguas subterráneas de Nicaragua.* United Nations International Children´s Emergency Fund-UNICEF. Retrieved from: http://unicef.org.ni/media/publicaciones/archivos/Arsenico_Afche.pdf

Bonell M. & Bruijnzeel L.A. (eds.) (2005). *Forests, water and people in the humid tropics: past, present and future hydrological research for integrated land and water management.* Cambridge: Cambridge University Press.

Bravo J., Orozco W. y Soto D. (2016). Desarrollo de un Sistema de Monitoreo Ambiental para Mejorar la Prevención y Capacidad de Adaptación al Cambio Climático de las Comunidades Pesqueras y Acuícolas: Caso de Estudio Estero Real Nicaragua. *Circular de Pesca y Acuicultura,* N°1112. Roma: FAO.

Briemberg, J. (1994). *An investigation of pesticide contamination of groundwater sources for urban water distribution systems in the Pacific Region of Nicaragua.* Final Report 3, CIDA Awards for Canadians.

Canadian Council of Ministers of the Environment (CCME) (2007). Canadian water quality guidelines for the protection of aquatic life and agriculture. En: *Canadian environmental quality guidelines.* Actualización 2007 de la versión 1999.

Winnipeg: Canadian Council of Ministers of the Environment.

Carlson R.E. (1977). A Trophic State Index for Lakes. *Limnology and Oceanography* 22(2):361-369.

Centro para la Investigación en Recursos Acuáticos (CIRA/UNAN) (1997). *Informe Final: Proyecto Generación de las Bases Científico-Técnicas y Sociales para la Formulación de un Plan de Saneamiento de Granada y su Área de Influencia.* Financiado por el Fondo Canadá-Nicaragua para el Manejo del Medio Ambiente y apoyado por la Alcaldía Municipal de Granada.

Centro para la Investigación en Recursos Acuáticos (CIRA/UNAN) (2008). *Informe final de Evaluación y monitoreo de la calidad del agua del lago de Managua.* Proyecto de apoyo a la ejecución del Programa de Saneamiento Ambiente del Lago y la Ciudad de Managua, Contrato de Préstamo BID 1060/SF-NI. Con colaboración de ENACAL e INETER.

Centro para la Investigación en Recursos Acuáticos (CIRA/UNAN) (2011). *Informe. Evaluación del Impacto de la Calidad de Agua del Lago Xolotlán sobre el Río Tipitapa y el Área inmediata en el Lago Cocibolca (Estación Lluviosa, diciembre 2010 y Estación Seca, abril 2011).* Retrieved from: http://www.bvsde.org.ni/Web_textos/ANA/ANA0017/11-EVALUACION-Cocibolca.pdf

Centro para la Investigación en Recursos Acuáticos de Nicaragua (CIRA/UNAN) (2013). *Informe Final. Establecimiento de Línea de Base sobre la Calidad Actual del Agua y Sedimentos de la Laguna de Masaya Año 2012-2013.* Informe sometido a la Empresa Nicaragüense de Acueductos y Alcantarillados (ENACAL) y la Agencia Española de Cooperación Internacional (AECID).

Centro para la Investigación en Recursos Acuáticos (CIRA/UNAN) y Center for Space and Remote Sensing Research (CSRSR) National Central University, Taiwán (2014-2016). *Proyecto – Monitoreo de los dos Grandes Lagos Nicaragüenses-Lago Xolotlán y Lago Cocibolca-con el fin de establecer un Sistema de Teleobservación por Satélite para Evaluaciones Futuras de la Calidad de Agua.*

Chacón M.C. (1994). *Evaluación Sanitaria en el Lago Tiscapa.* Monografía para optar al título de Licenciada en Biología. León, Nicaragua: UNAN.

Chang Ni-Bin, Bai Kaixu & Chen Chi-Farn (2017). Integrating multisensor satellite data merging and image reconstruction in support of machine learning for better water quality management. *Journal of Environmental Management* 201, 227-240. Retrieved from: https://www.researchgate.net/publication/318008592_Integrating_multi-sensor_satellite_data_merging_and_image_reconstruction_in_support_of_machine_learning_for_better_water_quality_management

Comisión Nacional de los Recursos Hídricos República de Nicaragua y Gobierno de Dinamarca Ministerio del Exterior (DANIDA) (1996). *Plan de Acción de los Recursos Hídricos en Nicaragua-PARH. Área Focal Cuenca del Río Escondido RAAS–Chontales.* Nicaragua.

Comité Coordinador Regional de Instituciones de Agua Potable y Saneamiento de Centroamérica, Panamá y República Dominicana (CAPRE) (1993). *Norma Regional CAPRE. Normas de Calidad del Agua para Consumo Humano.* Retrieved from: http://biblioteca.enacal.com.ni/bibliotec/Libros/pdf/CAPRE_Normas_Regional.pdf

Cuadra J. y Vammen K. (2010). Escurrimiento de Plaguicidas al Mar Caribe Nicaragüense – Establecimiento de un Sistema de Monitoreo Ambiental. UNAN- *Universidad y Ciencia* No 8, año 5. Retrieved from: https://www.lamjol.info/index.php/UYC/article/download/316/243

Decreto No. 21- 2017. Reglamento en el que se establecen las disposiciones para el vertido de Aguas Residuales. *La Gaceta* No. 229, November 30, 2017.

Decreto No. 33-95. Disposiciones para el Control Contaminación Provenientes Descargas de Aguas Residuales Domésticas, Industriales y Agropecuarias. *La Gaceta,* No. 118. (1995) Retrieved from: http://legislacion.asamblea.gob.ni/normaweb.nsf/($All)/138A846C29F5F0760625717900509FA4?OpenDocument

Delgado V. (2003). *Groundwater Flow System and Water Quality in a Coastal Plain Aquifer in Northwestern Nicaragua.* M.Sc thesis. University of Calgary. Calgary, Alberta. Retrieved from: http://repositorio.unan.edu.ni/2649/

Eckman R. (1893). *Estudios de la Laguna de Tiscapa.* Actas de la Embajada Alemana en Managua.

Empresa Nicaragüense de Acueductos y Alcantarillados Sanitarios (ENACAL) (2008). *Plan de Desarrollo Institucional 2008-2012: Estrategia Sectorial de Agua Propuesta por ENACAL.* Managua.

Retrieved from: http://www.enacal.com.ni/media/imgs/informacion/LIBRO%20ENACAL%20CAMBIO%20ENERO-05.pdf

Empresa Nicaragüense de Acueductos y Alcantarillados (ENACAL) (2014). *Plan Operativo General-POG, Plan Operativo Anual 1-POA 1 en el marco del, Programa Integral Sectorial de Agua y Saneamiento Humano (PISASH)-Fase I.* Retrieved from: http://www.aecid.es/Centro-Documentacion/Documentos/FCAS/Proyectos/POG/POG_NIC-013-B.pdf

Environmental Performance Index (EPI) (2018). *Report Center for International Earth Science Information Network.* Earth Institute in collaboration with World Economic Forum. Yale University, Center for Environmental Law & Policy & Columbia University. Retrieved from: https://epi.envirocenter.yale.edu/epi-country-report/NIC

Food and Agriculture Organization of the United Nations (FAO-AQUASTAT) (2013). *Country Profile, Nicaragua.* Retrieved from: http://www.fao.org/nr/water/aquastat/countries_regions/Profile_segments/NIC-WR_eng.stm

Fuentes C. (2015). *Reconstrucción cualitativa de algunos cambios limnológicos recientes (últimos 130 años) de laguna de Masaya, Nicaragua.* Tesis de maestría en Ciencias del Agua del CIRA/UNAN. Retrieved from: http://repositorio.unan.edu.ni/4888/

Gómez A. (2011). *Impacto de la ingesta de agua contaminada con arsénico en la salud de la población de comunidades rurales del territorio Nº 2 del municipio de Telica, León.* Nicaragua: Estudio financiado por OPS/OMS. Retrieved from: http://nuevasesperanzas.org/documents/03%20Project%20reports/Arsenic%20study%20PAHO%20epidemiological%20report%202011%20ESP.pdf

González J.L. (July 5, 2017). *El Nuevo Diario.* Retrieved from: https://www.elnuevodiario.com.ni/nacionales/432922-mujeres-achuapa-elaboran-filtros-agua/

González L.I. (1997). *Diagnóstico Ecológico de las Zonas Costeras de Nicaragua. Programa de Manejo Integral de las Zonas Costeras.* Managua: MAIZCo, MARENA.

González O., Aguirre J., Saugar G., Orozco L., Álvarez G., Palacios K. y Guevara O. (2007). Diagnóstico de la Calidad del Agua de Consumo en las Comunidades del Sector Rural Noreste del Municipio de León, Nicaragua. *Universitas*, Volumen 1, Año 1, 7-13. León: UNAN Editorial Universitaria. Retrieved from: http://revista.unanleon.edu.ni/index.php/universitas/article/view/1

Hazen y Sawyer (1964). *Informe sobre fuentes de abastecimiento de agua potable para Managua.* Preparado para la empresa aguadora de Managua.

Hutton A. (2004). Beyond financial reporting an integrated approach to disclosure. *Journal of Applied Corporate Finance,* vol. 16, No. 4, pp. 8–16.

Instituto Geográfico Nacional (1972). Mapa Batimétrico del Lago Nicaragua.

Instituto Nacional Forestal (INAFOR) (2008). *Programa Forestal Nacional.* Retrieved from: http://www.magfor.gob.ni/prorural/programasnacionales/planforestal.pdf

Instituto Nacional de Estadísticas y Censos (INIDE) (2005). *VIII Censo de Población y IV de Vivienda.* Retrieved from: http://www.inide.gob.ni/censos2005/VolPoblacion/Volumen%20Poblacion%201-4/Vol.IV%20Poblacion-Municipios.pdf

Instituto Nacional de Información de Desarrollo (INIDE) (2000). *Posición Geográfica, límites del territorio continental y composición de la superficie del territorio de Nicaragua.* Retrieved from: http://www.inide.gob.ni/compendio/pdf/inec111.pdf

Instituto Nacional de Información de Desarrollo (INIDE) (2018). *Anuario Estadístico 2016.* Retrieved from: http://www.inide.gob.ni/Anuarios/Anuario%20Estadistico%202016.pdf

Instituto Nicaragüense de Acueductos y Alcantarillado Sanitario (INAA) y Agencia de Cooperación Internacional del Japón (JICA) (1993). *Proyecto de Abastecimiento de Agua en Managua. Informe Final.* Managua: INAA.

Instituto Nicaragüense de Estudios Territoriales (INETER) y Agencia Suiza para el Desarrollo y la Cooperación (COSUDE) (2004). *Estudio de Mapificación Hidrogeológica e Hidrogeoquímica de la Región Central de Nicaragua.* Retrieved from: http://www.bvsde.org.ni/Web_textos/COSUDE/0002/0002GESTIONRECURSOSHIDRICOS.pdf

Instituto Nicaragüense de Estudios Territoriales (INETER) (2010). *Boletín hidrogeológico anual.* Managua: Dirección de Hidrogeología, INETER.

Instituto Nicaragüense de Estudios Territoriales (INETER) (2015). *Ubicación de Lagunas Cratéricas de Nicaragua.* Managua: Dirección de Recursos Hídricos, INETER.

Instituto Nicaragüense de Estudios Territoriales (INETER) (2016). *Red Nacional de Acuíferos de Nicaragua.*

Jorgensen S.E., Tundisi J.G. & Matsumura-Tundisi (2012) *Handbook of Inland Aquatic Ecosystem Management.* CRC Press, Octubre 17, 2012.

Lovette G.M., Burns D.A., Driscoll C.T., Jenkins J.C., Mitchell M.J., Rustad L., Likens G.E., & Haeuber R. (2007). Who needs environmental monitoring? *Frontiers in Ecology and the Environment*, Volume 5, Issue 5, June 2007, pp. 253-260. Washington D.C.: Ecological Society of America.

Losilla M., Rodríguez H., Schosinsky G., Stimson J. y Bethune D. (2001). *Los Acuíferos Volcánicos y el Desarrollo Sostenible en América Central.* San José: Editorial de la Universidad de Costa Rica.

Martínez V., Vammen K., Sánchez-Cabeza J.A., Alonso-Hernández C. y Quejido-Cabezas A. (2014). Flujo Cronológico de Metales en Sedimentos y la Sedimentación en la Bahía de Bluefields, Nicaragua. *Revista Agua y Conocimiento.* Vol.1, No.1. July-December.

Ministerio de Agricultura y Forestal (MAGFOR) (1983) y (2000). *Mapa de Cobertura Vegetal.* Managua: MAGFOR.

Ministerio de Agricultura y Forestal (MAGFOR) (2002). *Mapa agroecológico de uso potencial de suelos.* Managua: MAGFOR.

Ministerio de Agricultura y Forestal (MAGFOR) (2011). *Mapa de Cobertura Vegetal Actual.* Managua: MAGFOR. Recuperado de: http://www.tortillaconsal.com/analisis_uso_suelo_1.pdf

Ministerio de Ambiente y Recursos Naturales (MARENA) (1999). *Norma Técnica Obligatoria Nicaragüense para el Control Ambiental de las Lagunas Cratéricas.* NTON 05 002–99. Managua: MARENA. Retrieved from: http://legislacion.asamblea.gob.ni/Normaweb.nsf/($All)/3C9CE07C25D44E18062573F3005F43BA?OpenDocument893

Ministerio del Ambiente y los Recursos Naturales (MARENA) (2011). *Estudio de Uso del Suelo de la Cuenca del Lago Cocibolca.* Managua: MARENA.

Ministerio del Ambiente y los Recursos Naturales (MARENA) (2017). *Estrategia Nacional de Bosques y Cambio Climático para Enfrentar la Pobreza.* ENDE-REDD. Retrieved from: http://enderedd.sinia.net.ni/Docs/Doc_PaqueteR/1.%20Estrategia_Nacional_ENDEREDD.pdf

Ministerio de Salud (MINSA) (2001). Investigación Nacional sobre incidencias de intoxicaciones agudas por plaguicidas y estimaciones de subregistros en Nicaragua. *Boletín Epidemiológico e Informativo* #19, año 12 Pág. #2. Base de datos del Programa Nacional de Plaguicidas. Managua: Centro Nacional de Toxicología, MINSA Central. Tomados de Pavón, Karla y Ortega, Ana (2001). *Intoxicaciones por plaguicidas en menores de 15 años.* Trabajo Monográfico. Enero de 1995 a diciembre de 2001. Nicaragua.

Ministerio de Salud de Nicaragua (MINSA), MAGFOR, UNAN León, OPS (2012). *Foro Nacional de Leptospirosis de Nicaragua y Reunión Internacional de países que están enfrentando brotes de leptospirosis en las Américas.* Retrieved from: https://www.paho.org/hq/index.php?option=com_content&view=article&id=7868:2012-situacion-actual-paises-seleccionados&Itemid=39698&lang=es

Moncrieff J., Bentley L. & Calderón Palma H. (2008). Investigating pesticide transport in the León-Chinandega aquifer, Nicaragua. *Hydrogeology Journal.* Issue 1/2008. Springer Professional. Wiesbaden GmbH.

Montenegro Guillén S. y Jiménez García M. (2009). Residuos de plaguicidas en agua de pozos en Chinandega, Nicaragua. *Universidad y Ciencia.* UNAN-Managua. Año 4, No. 7, julio-diciembre de 2009. Retrieved from: http://repositorio.unan.edu.ni/2461/1/1000.pdf

Montenegro S. (2016). *Agua y desarrollo en Nicaragua.* Presentación del 26 de enero del 2017. Aquastat de la FAO. Perfil Nicaragua. Retrieved from: www.fao.org/nr/water/aquastat/data/queryresults.html

Moreno A.G. (2012). *Sistema Local de Atención Integral en Salud-León (SILAIS León).* Foro Internacional de Leptospirosis. León: MINSA.

Norma Técnica Ambiental para el Manejo, Tratamiento y Disposición Final de los Desechos Sólidos No-Peligrosos, NTON 05 014-01. Aprobado el día 3 de agosto del 2001, Publicado el día 24 de mayo del 2002. *La Gaceta,* No. 96 (2002). Retrieved from: http://legislacion.asamblea.gob.

ni/Normaweb.nsf/($All)/3D7B0C9BF4C1867 90625764E005D16F4?OpenDocument

Norma Técnica para el Control Ambiental de los rellenos Sanitarios para Desechos sólidos No Peligrosos, NTON 05 013-01. Aprobado el día 5 de diciembre del 2000. Publicado el día 22 de abril del 2002. *La Gaceta*, No. 73 (2002). Retrieved from: http://legislacion.asamblea.gob.ni/normaweb.nsf/($All)/68722115E0E27F-50062573610072A1AB?OpenDocument

Norma Técnica para el Manejo y Eliminación de residuos Sólidos Peligrosos, NTON 05 015-02. Aprobado el 13 de septiembre del 2001. Publicado 5 de noviembre del 2002. *La Gaceta*, No. 210 (2002). Retrieved from: http://legislacion.asamblea.gob.ni/normaweb.nsf/bbe90a5bb646d50906257265005d21f8/f124ab4e19e485950 625728a005c2c3f?OpenDocument

Norma Técnica para el Uso de las Aguas Residuales de los Efluentes Provenientes de la Industria Azucarera y Destilerías de Alcohol para el Riego de las Plantaciones de la Caña de Azúcar. Aprobada el 07 de agosto del 2007. Publicada del 5 de julio del 2010. *La Gaceta,* No. 126 (2010). Retrieved from: http://legislacion.asamblea.gob.ni/normaweb.nsf/($All)/B648272FD35AB76D062 577A6005C6332?OpenDocument

Organización Mundial de la Salud (OMS) (2018). *Guías para la Calidad del Agua de Consumo Humano que incorpora la primera adenda.* 4ª Ed. Ginebra. ISBN 978-92-4-354995-8. Retrieved from: http://apps.who.int/iris/bitstream/handle/10665/272403/9789243549958-spa.pdf?ua=1

Organización de las Naciones Unidas (ONU) (1975). *Investigaciones de aguas subterráneas en zonas seleccionadas de Nicaragua.*

Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO) (1994). *Water quality for agriculture. Irrigation and drainage paper.* 29 Rev. 1. California, USA. Retrieved from: www.fao.org/docrep/003/t0234e/t023 4e00.htm

Organización Panamericana de Salud (OPS) (2005). El Control de las Enfermedades Transmisibles. *Publicación Científica y Técnica* No. 613. Informe Oficial de la Asociación Estadounidense de Salud Pública. David L. Heymann Editor. 18 ed. Washington, DC: OPS. Retrieved from: https://eliochoa.files.wordpress.com/2014/05/transmisibles-ops.pdf

Parello F., Aiuppa A., Calderon H., Calvi F., Cellura D., Martinez V., Militello M., Vammen K., Vinti D. (2008). Geochemical characterization of surface waters and groundwater resources in the Managua Area (Nicaragua, Central America). *Applied Geochemistry,* doi:10.1016/j.apgeochem.2007.08.006

Peña Torrez E., Montenegro S., Pitty J., Matsuyama A. y Yasuda Y. (2009). Contaminación por Mercurio en Nicaragua el caso de la Empresa Pennwalt, *Revista Científica Universidad y Ciencia* (7). pp.1-4. ISSN 2074-8655. Retrieved from: http://repositorio.unan.edu.ni/2448/

Picado F., Mendoza A., Cuadra S., Barmen G., Jakobsson K. & Bengtsson G. (2010). *Ecological, Groundwater, and Human Health Risk Assessment in a Mining Region of Nicaragua.* Retrieved from: https://www.researchgate.net/publication/43246262_Ecological_Groundwater_and_Human_Health_Risk_Assessment_in_a_Mining_Region_of_Nicaragua

Programa de Investigación, Estudios Nacionales y Servicios del Ambiente, Universidad Nacional de Ingeniería (CIEMA, UNI) (2009). *Arsénico en agua para consumo humano. Presencia y experiencias en remoción.* Simposio Arsénico. Managua, 2 de julio de 2009. Retrieved from: http://ribuni.uni.edu.ni/218/2/1Simpo-042.pdf

Programa de Naciones Unidas para el Desarrollo (PNUD) y el Ministerio de Ambiente y Recursos Naturales (MARENA) (2004). *Inventario de Plaguicidas COP en Nicaragua.*

Proyecto Reduciendo el Escurrimiento de Plaguicidas al Mar Caribe (REPCAR) (2010). *Informe de País Sobre Importaciones de Plaguicidas Correspondiente al Periodo 2004 – 2009, Nicaragua.* Retrieved from: http://www.cep.unep.org/repcar

Red Interamericana de Academias de Ciencias (IANAS) (2015). Agua Urbana en Nicaragua. En *Desafíos del Agua Urbana en las Américas. Perspectivas de las Academias de Ciencias.* México: IANAS-UNESCO-IAP. Retrieved from: https://www.ianas.org/docs/books/Desafios_Agua.html

Salvatierra Suárez, Thelma (2018). *Gestión integral de los recursos hídricos como herramienta para facilitar el desarrollo territorial comunitario en dos Humedales de Importancia Internacional Ramsar de Nicaragua.* Tesis doctoral. Managua: UNAN.

Sandoval E. y Saborío A. (2008). Calidad bacteriológica del agua en los sitios de recolección de "conchas negras" (Anadara tuberculosa y Anadara similis) en Chinandega. *Revista Encuentro.* 2008/ Año XL, N° 81, 30-47. Managua: UC.

Schwoerbel, J. (1987). *Einführung in die Limnologie.* Stuttgart: Gustav Fisher Verlag.

Secretaría de la Convención de Ramsar (2010a). Manejo de humedales: Marcos para manejar Humedales de Importancia Internacional y otros humedales. *Manuales Ramsar para el uso racional de los humedales*, 4ª ed., vol. 18. Gland (Suiza): Secretaría de la Convención de Ramsar.

SER San Antonio (2018). *Acerca de SER San Antonio.* Retrieved from: http://www.nicaraguasugar.com/index.php?option=com_content&view=article&id=8&Itemid=175

Sistema de Información de Agua y Saneamiento Rural (SIASAR) (2018). Retrieved from: http://www.siasar.org/es/paises/nicaragua

Stelzer R.S., Heffernan J. y Likens G.E. (2003). The influence of dissolved nutrients and particulate organic matter quality on microbial respiration and biomass in a forest stream. *Freshwater Biology,* 48(11), pp.1925-1937.

Styles L. (2015). *Gestión de Residuos y Proveedores de Desechos.* Retrieved from: https://dlca.logcluster.org/pages/releaseview.action;jsessionid=1270838B1EB9202214A1E5FD2737CB44?pageId=7897123

Toledo A.P, Agudo E.G., Tolarico M., Chinez S.J. (1984). *Aplicação de modelos simplificados para avaliação da eutrofização em lagos e reservatórios tropicais.* CETESB.

United Nations (UN) (2018). Sustainable Development. *Goal 6 Synthesis Report 2018 on Water and Sanitation.* New York: UN. Retrieved from: http://www.unwater.org/publication_categories/sdg-6-synthesis-report-2018-on-water-and-sanitation/

United Nations Environmental Programme (UNEP) (2016). *A Snapshot of the World's Water Quality: Towards a Global Assessment.* Nairobi: UNEP. Retrieved from: https://uneplive.unep.org/media/docs/assessments/unep_wwqa_report_web.pdf

UN Water (2017). Aguas Residuales. El Recurso Desaprovechado. *Informe Mundial de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos 2017.* Paris: UNESCO, Retrieved from http://unesdoc.unesco.org/images/0024/002476/247647s.pdf

Vammen K., Pitty J. y Montenegro Guillén S. (2006). Evaluación del proceso de eutrofización del Lago Cocibolca, Nicaragua y sus causas en la cuenca. En *Eutrofización en América del Sur, Consecuencias y Tecnologías de Gerencia y Control.* Instituto Internacional de Ecología, Interacademic Panel on International Issues, 35-58.

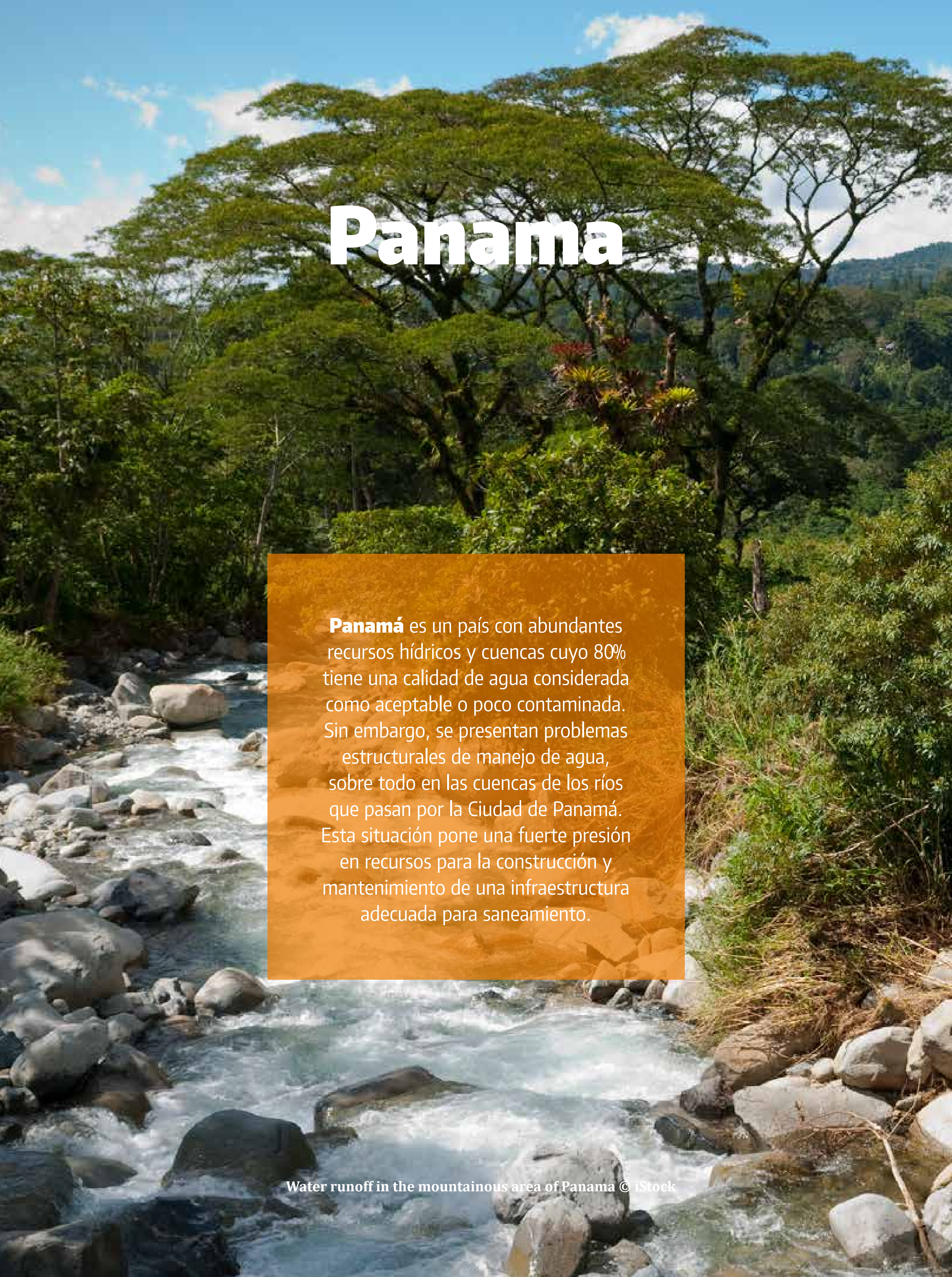
Vammen K. y Hurtado I. (2010). *Los recursos hídricos de Nicaragua.* CEPAL. Retrieved from: http://coin.fao.org/coin-static/cms/media/5/12820625348650/fao_nic_recursoshidricos_cepal.pdf

Vammen K. (2012). Conclusiones del Estudio "Calidad y Disponibilidad de los Recursos Hídricos en la Subcuenca del Río Viejo". Aporte para Lograr un Estado Ambientalmente Equilibrado en Beneficio a la Población. *Universidad y Ciencia* Vol. 6, Núm. 9 (2012). Retrieved from: https://www.lamjol.info/index.php/UYC/article/view/1953

World Health Organization (WHO) (2010). *Report of the First Meeting of the Leptospirosis Burden Epidemiology Reference Group.* Geneva. Retrieved from: http://apps.who.int/iris/bitstream/handle/10665/44382/9789241599894_eng.pdf?sequence=1

World Health Organization (WHO) y UNICEF (2017). Progreso para Agua Potable. *Saneamiento e Higiene 2017.* Geneva. Retrieved from: https://www.unicef.org/spanish/publications/index_96611.html

Panama



Panamá es un país con abundantes recursos hídricos y cuencas cuyo 80% tiene una calidad de agua considerada como aceptable o poco contaminada. Sin embargo, se presentan problemas estructurales de manejo de agua, sobre todo en las cuencas de los ríos que pasan por la Ciudad de Panamá. Esta situación pone una fuerte presión en recursos para la construcción y mantenimiento de una infraestructura adecuada para saneamiento.

Water runoff in the mountainous area of Panama © iStock

Water Quality in Panama

José Fábrega, Elsa Flores, Manuel Zárate, Miroslava Morán, Denise Delvalle, Argentina Ying, Marilyn Diéguez, Euclides Deago and Kathia Broce

Abstract

The current status of water quality in Panama is analyzed from different perspectives, showing that despite having abundant water resources, Panama has a series of structural problems in the context of water quality. This situation is exacerbated by the strong demographic growth in urban areas, making attention to sewerage an increasingly important issue. Given the challenges posed by the future, integrated water resource management is regarded as the most sustainable option for maintaining and improving the water quality of our rivers. However, in order for it to be successful, a modern regulatory framework and the allocation of sufficient resources for the construction of new infrastructure and the maintenance of the existing one are required.

1. Introduction

1.1 Background

Panama is a country whose per capita water availability in 2014 was approximately 34,990 m^3/inhabitant/year (http://data.worldbank.org/indicator/ER.H2O.INTR.PC). Moreover, according to the National Water Security Plan (PNSH) 2015-2050: Water for Everyone, the total supply of fresh water in Panama is 119,500 million m^3/year, 25% of which is used. This demand is distributed as follows: energy use 89.6%; transportation through the Panama Canal 7.4%; food safety 1.7%, human consumption 1.3%; industry and other items less than 0.05% (MiAMBIENTE, 2016b).

Although the isthmus installed its first water treatment plant in the mid-19th century in the city of Colón with the construction of the transisthmian railway, it was not until the beginning of the 20th century, when the Panama Canal was constructed, that the first drinking water distribution and wastewater management networks were built in the cit-

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ies of Panama and Colón. The Aguas Claras water treatment plants were built in Colón (1911), Monte Esperanza (1914) and Miraflores (1915), which supplies Panama City (MiAMBIENTE, 2016b). However, wastewater and storm water ran directly into the rivers, flowing into the bays of Panama in the Pacific and Manzanillo in the Caribbean.

Previously, the multiple sub-basins of Panama City-those of the Matasnillo, Río Abajo and Curundú rivers-were the sources of water supply for the population using carriage systems for transportation; latrines were the main receivers of excreta, while domestic wastewater and garbage were discharged onto the beaches, swamps and mangroves. In the rest of the country, the first aqueducts were only built between 1914 and 1920, in the cities of Aguadulce, Pesé and Las Tablas (MiAMBIENTE, 2016b) - areas closely linked to the metropolis as sources of agricultural supplies - all private, while the rural sector was generally overlooked.

Panama has 56 drinking water treatment plants and 2,830 Rural Water and Sewerage Boards with legal status (JAAR) (MiAMBIENTE, 2016b), albeit with an extremely heterogeneous distribution. Cities in the inter-oceanic corridor, for example, are endowed with significant infrastructure capacity, while there is a major deficit in the provinces of Los Santos, Herrera and Darién, as well as the indigenous districts of Guna, Ngábé-Büglé and Emberá-Wounana, which have the most precarious service conditions. The proper management and final disposal of wastewater (whether domestic or industrial) poses an enormous challenge for Panama (Fábrega *et al.*, 2015). However, there is also a significant disproportion between the urban and rural population in this respect. According to the World Bank, 80% of the urban population in Panama has access to improved sanitation facilities, including sewerage systems, septic tanks and latrines (http://data.worldbank.org/ indicator / SH.STA.ACSN.UR).

Specifically, regarding the coverage of sewerage services, the IDAAN Statistical Bulletin N° 26 (2010-2012) shows that the percentage of the population with a sewerage system (in populations with fewer than 1,500 inhabitants) -for which the IDAAN is responsible - is 57%, which translates into approximately 45% of the country's total population (Fábrega *et al.*, 2013). As for treatment plants, Panama has nearly 100 secondary treatment plants concentrated mainly in the cities of Panama, La Chorrera and Arraiján, benefitting nearly 100,000 people (FOCARD-APS, 2013).

Moreover, in 2006, the Bay Sanitation Project was begun, marking the first phase of a large wastewater treatment plant in Panama which provides services to approximately 250,000 people and receives 1.8 m^3/s (FOCARD-APS, 2013).

Likewise, there is a single sanitary landfill, which is moderately environmentally friendly. These projects (Bay Sewerage and landfill) are located in Panama City. Again, there is a striking difference in investment between the urban area at the ends of the Canal Basin compared with urban centers in the rest of the country, where major structural transformations, together with the densification of the urban population due to de-ruralization processes, have occurred in various cities (Colón, Santiago, David, Penonomé, Changuinola and others).

1.2. Main water quality problems

The main water pollution problems are found in the Pacific regions, particularly in the marine-coastal zones due to the greater demographic concentration and the dense hydrographic network that feeds into them,[1] in addition to the technological backwardness in the agrarian and industrial productive processes, and the existing deficits in the domestic infrastructures of wastewater management, particularly on the coasts of Panama Bay.

Equally worrying is the pressure on water resources in the Panama Canal Basin, especially due to the rapid increase in the urban population, which is supplied by the same water used for navigation processes in the canal.

1.3 Objectives and scope of the chapter

The main objectives of this chapter are to:

1. Provide an up-to-date portrayal of the status of Water Quality in the country from various points of view (such as governance, health, pollution and Sustainable Development Goals).
2. Establish possible causes of the situations found.

1. Panama has 52 basins comprising 350 rivers on the Pacific coast (70% of the total) and 150 on the Caribbean coast.

2. Water quality authorities and governance

Water governance in Panama is contained in a series of sectorial laws and norms (political constitution, formal laws, executive decrees, regulations, resolutions, national policies, etc.) comprising the guidelines that govern the quality levels for mainland waters for recreational use, with and without direct contact, and the rules for reusing treated water and water quality standards for human consumption.

However, the evaluation of water quality (physical, chemical and microbiological) for human consumption (drinking) is continuously undertaken by the most important suppliers, such as the Institute of Aqueducts and Sewerage Systems (IDAAN) and the Panama Canal Authority (ACP). For communities with populations of less than 1,500 people, JAARs are the water suppliers for human consumption. The JAAR is run by the Ministry of Health (MINSA), which only has laboratories in certain regions of the country, as a result of which, in many cases, these boards are unaware of the exact quality of the water delivered.

According to the 2010 Census, conducted by the Comptroller General of the Republic, from 2000 to 2010, the Panamanian population increased from 2,839,177 to 3,405,813; 12.3% of this total corresponds to various indigenous populations (INEC, 2012). When we explore the issue of water quality in indigenous areas, the situation is different, since, due to their ancestral cultural patterns, these groups "consider that water is fundamental for life, but that its greatest power is manifested when it flows" (MINSA, 2016). Accordingly, any human intervention that interrupts this flow is considered unnatural. The construction of water intakes for aqueducts, for example, is seen as a limitation on the use of water for personal hygiene and healing activities (PAHO/WHO/MINSA, 2016).

2.1 Legal framework

Regarding the governance of water quality, the Political Constitution of Panama (2004) -in Title II Duties and Individual and Social Rights, Chapter 7 Ecological Regime, Articles 118 to 121- establishes, among other things, that "it is the fundamental duty of the State to ensure that the population lives in a healthy, pollution-free environment, where air, water and food meet the requirements for the proper development of human life". The constitutional establishment of the responsibility of the state regarding water and sanitation means that the other laws of the country must be in accordance with it. This general legal framework is developed in another set of norms which, although of lower hierarchy, also seek to guarantee the rights protected in the Constitution. In this respect, the regulations issued by the Ministry of Health, the Ministry of Commerce and Industries (MICI) and the Ministry of the Environment (MiAMBIENTE), listed in **Table 1**, should be highlighted.

There are other types of sectoral norms that establish the framework for the operation and development of the water and sanitation sector, such as the 1996 Law No. 26 that created the Regulatory Entity, whose functions would include the regulation, control, supervision and oversight of public service provision for the supply of drinking water and sewerage in Panama. Decree Law 10 of 2006 modified this law, renaming the entity as the National Authority of Public Services (ASEP), whose regulations (Executive Decree No. 279, 2006) grant it functions for coercive collection, inter-institutional coordination and the control of public service provision.

Another fundamental sectoral norm is the General Environmental Law (Law No. 41, 1998), which created the National Environmental Authority (ANAM), which in turn was modified by Law No. 8, 2015 created by the Ministry of Environment (MiAMBIENTE) as the state governing body for environmental protection, conservation, preservation and restoration and the sustainable use of natural resources to ensure compliance with and enforcement of laws, regulations and the National Environmental Policy. The Ministry of Environment must monitor activities that modify the water quality regime and is also responsible for making water the domain of all the citizens in the country. Within the monitoring of the water quality of the rivers, it also has the responsibility of monitoring the quality of the wastewater discharged into them. These regulations are valid for both the public and private sectors.

Panama also has a National Water Resources Policy formalized through Executive Decree No. 84, 2007. Likewise, Decree 202, 1990, as amended by Executive Decree 441, 2008, created the Inter-institu-

Table 1. Water Quality Regulations in Panama

Name (Institution)	Aspect covered	Reference
Technical Regulation DGNTI-COPANIT 21-393-99 (MICI)	Sampling	Official Gazette No. 23.41, December 6, 1999.
Technical Regulation DGNTI-COPANIT 22-394-99 (MICI)	Sampling for biological analyses	Official Gazette No. 23.949, December 17, 1999.
Technical Regulation DGNTI-COPANIT 23-395-99 (MICI)	Physical, chemical, biological and radiological requirements drinking water must meet	Official Gazette No. 23.942, December 7, 1999.
Resolution No 507 December 30, 2003 (MINSA)	Procedure to control drinking water quality	Official Gazette No. 24.970, January 20, 2004.
Technical Regulation DGNTI-COPANIT 24-99 (MICI)	Reuse of treated wastewater	Official Gazette No. 24.008, March 13, 2000.
Technical Regulation DGNTI-COPANIT 35-2000 (MICI)	Discharge of liquid effluents directly into water bodies and surface and groundwater bodies	Official Gazette No. 24.115, August 10, 2000.
Technical Regulation DGNTI-COPANIT 39-2000 (MICI)	Discharge of liquid effluents directly into wastewater collection systems	Official Gazette No. 24.115, August 10, 2000.
Technical Regulation DGNTI-COPANIT 47-2000 (MICI)	Uses and disposal of sludge	Official Gazette No. 24.115 August 10, 2000.

tional Committee on Drinking Water and Sanitation, bringing together the main institutions in the sector, at both the operating and regulatory levels, and other research and education institutions. Lastly, it should be noted 2016 saw the passage of the National Water Security Plan 2015-2050 (MiAMBIENTE, 2016b): Water for Everyone, through Cabinet Resolution 114, 2016. This plan identifies specific goals to be achieved in water management, such as: i) Universal access to quality water and sanitation services, ii) Water for inclusive socioeconomic growth, iii) Preventive risk management, iv) Healthy river basins and v) Water sustainability. This 2016 resolution created the National Water Council (CONAGUA) and its Technical Secretariat, whose functions include guaranteeing the implementation of the actions of the PNSH 2015-2050.

2.2. Relations with Non-governmental Organizations (NGOs) and universities

The structure and organization of the water and sanitation sector of Panama is complex, as a result of the multiplicity of institutions and actors that are part of it. **Figure 1** shows the composition of the sector, from the intervention of international cooperation agencies and national institutions that accompany this management, to relations with universities and private companies.

At the level of universities and technical training centers, the public sector includes the University of Panama (UP), the Technological University of Panama (UTP), the Autonomous University of Chiriquí (UNACHI) and the National Institute of Vocational Training and Training for Human Development (INADEH). The private sector includes the Santa María La Antigua University (USMA) and the Universidad Latina.

Here, management participates through human resource training and scientific research. Research at universities is conducted through undergraduate theses, master's degrees, and research projects on issues chosen by their faculties or research centers, as in the case of the Center for Hydraulic and Hydrotechnical Research (CIHH) of the UTP.

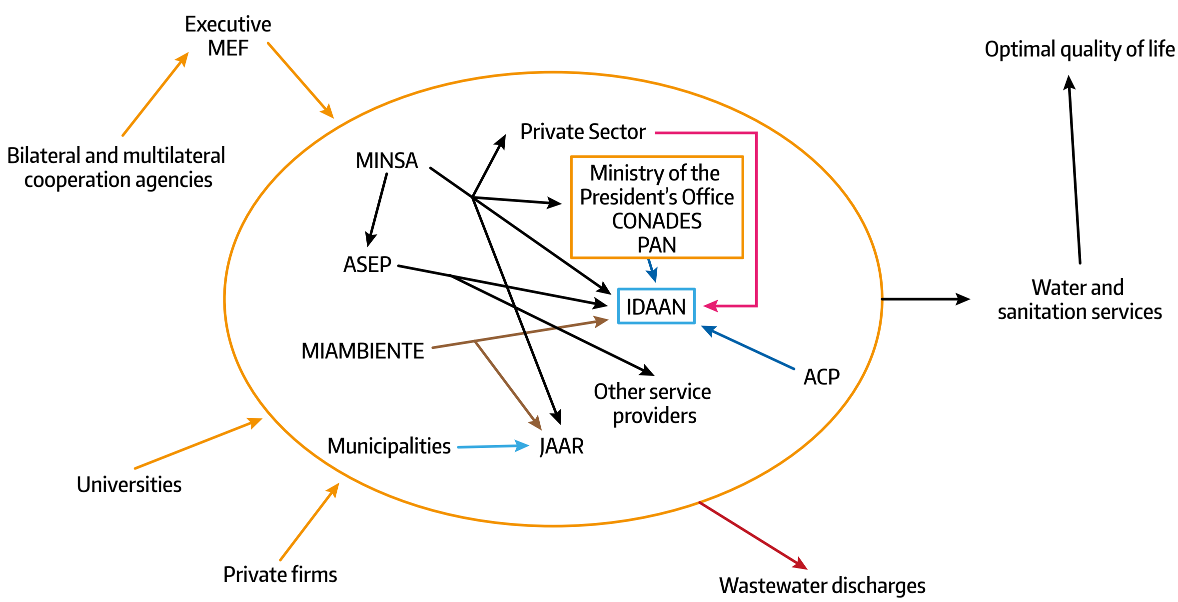
From a regulatory and quality management point of view, it is worth mentioning the services provided by the laboratories or university institutes such as the Industrial Water and Environmental Quality Laboratory (LABAICA) of the UTP, the Specialized Institute of Analysis (IEA) of the UP and the Laboratory of Water and Physical Chemical Services (LASEF) of the UNACHI. It is also important to mention that there are at least a dozen private laboratories that also perform water quality analyses.

Non-Governmental Organizations (NGOs) and bilateral and multilateral credit and international cooperation agencies participate in the water and sanitation sector mainly through training, technical advice and investment financing.

2.3. Monitoring, database and availability of information

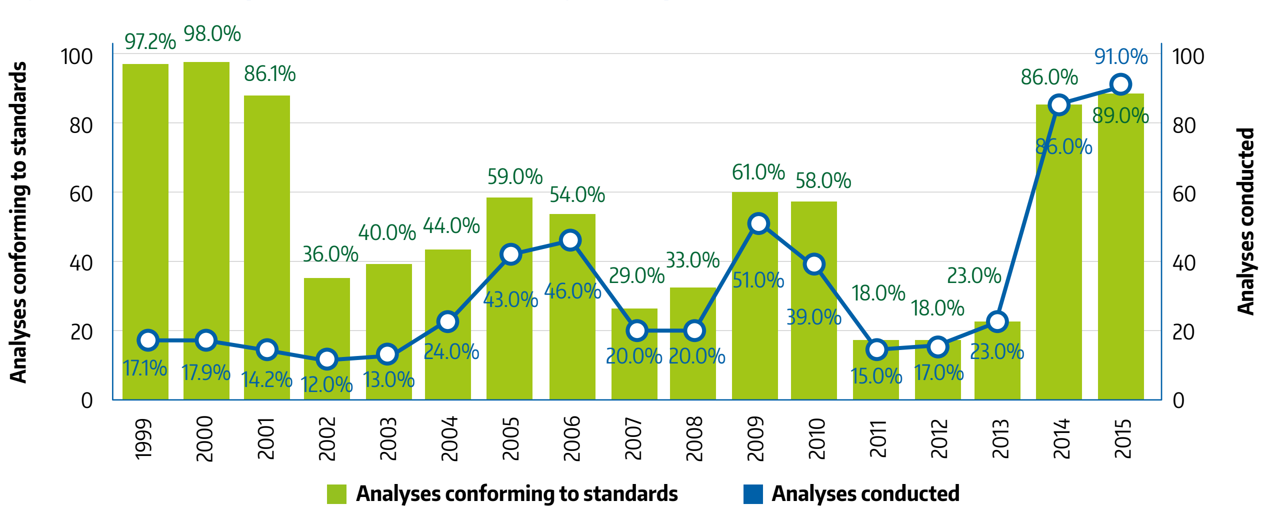
Water quality in the country's watersheds is monitored by MiAMBIENTE, MINSA, IDAAN and ACP, the latter within its exclusive competence over the Panama Canal watershed. In the case of IDAAN, **Figure 2** shows the behavior regarding compliance between the years 1999-2015.

Figure 1. Composition of the Drinking Water and Sanitary Sewer Subsector



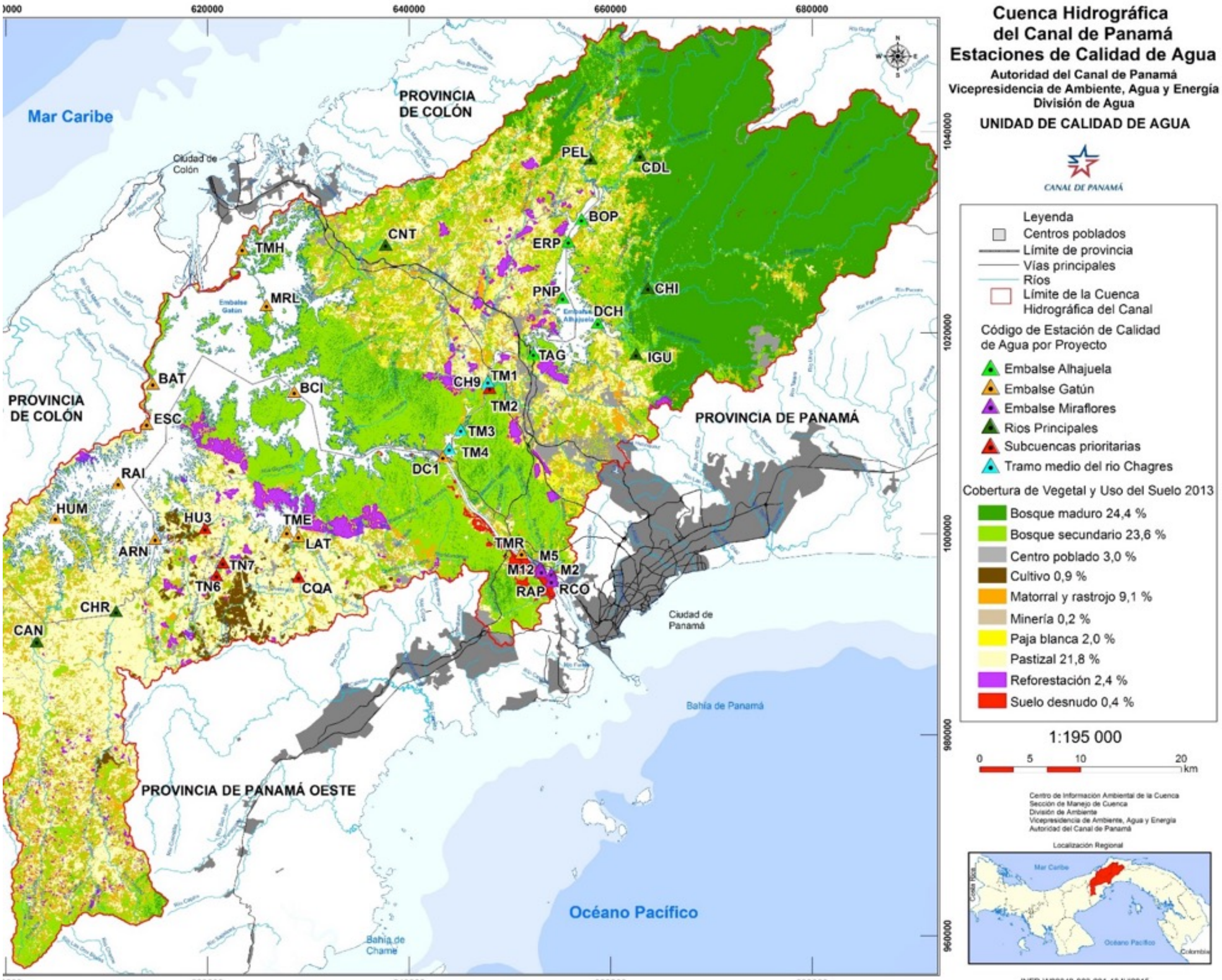
Prepared by: Darío Delgado (OPS/OMS/MINSA, 2016).

Figure 2. Record compliance with IDAAN drinking water quality standards 1999-2015



Source: Public Services Authority (ASEP, 2016).

Figure 3. Water quality stations in the Panama Canal Hydrographic Basin



Source: http://micanaldepanama.com/nosotros/cuenca-hidrografica/

In the case of MiAMBIENTE (formerly ANAM), a water quality monitoring network was established in 16 watersheds nationwide in 2002. This network became operational (through the provision of equipment and training) in late 2003, largely thanks to the Water Quality Monitoring Techniques Project (PROTEMOCA), sponsored by the Japan International Cooperation Agency (JICA) (ANAM, 2013). The last of the water quality monitoring reports presented by the then ANAM collected information for the period 2009-2012, on 35 basins on the Pacific slope and 10 basins on the Atlantic slope. In total, 100 rivers in the country were monitored by 277 monitoring points located in the upper, middle and lower parts of the watersheds involved. This report presents Water Quality Index (WQI) values comprising 10 water quality parameters: pH, conductivity, temperature, turbidity, total dissolved solids, dissolved oxygen (DO), biochemical oxygen demand (BOD5), nitrates, phosphates and fecal coliforms. The values corresponding to this monitoring are available at: http:/miambiente.gob.pa/index.php/es/2013-02-20-08-51-24/biblioteca-virtual

In 2015, in the Panama Canal watershed (CHCP), the ACP undertook measurements at 38 monitoring stations located in reservoirs, rivers and priority sub-basins (see **Figure 3**). Twenty-five parameters were analyzed: OD, BOD5, orthophosphates, nitrates, total coliforms, *E. coli*, total suspended solids, chlorides, sodium, total alkalinity, calcium, chlorophyll, conductivity, total hardness, potassium, magnesium, nitrites, pH, salinity, sulphates, total and dissolved solids, temperature, transparency, total organic carbon and microcystins.

3. Social and Health Aspects

When we regard the environment as a system, we find that any environmental alteration is concatenated in some way with society. We cannot, therefore, address water quality problems without locating them within their close relationship with the paradigms and arrangements that dominate social life.

3.1 Rural and urban areas

The countryside currently suffers from low human growth in general, which as a result of the abandonment of agricultural activity by young farm workers and emigration to cities in the quest for social mobility, experiences low densities of rural population, allowing natural resilience factors to adequately control polluting social processes through self-subsistence practices.

At the same time, this abandonment is being replaced by large land units with intensive land use, which create new water quality problems. Private agribusiness has introduced the intensive use of soil, which is usually deficient in nutrients. Soils in Panama are predominantly acidic (IDIAP, 2006) and, due to the abundant rainfall, easily leach calcium, potassium and nitrogen, while their high phosphorus fixation capacity leads to a lack of phosphorous in production. This requires improving fertilization processes through good management technologies.

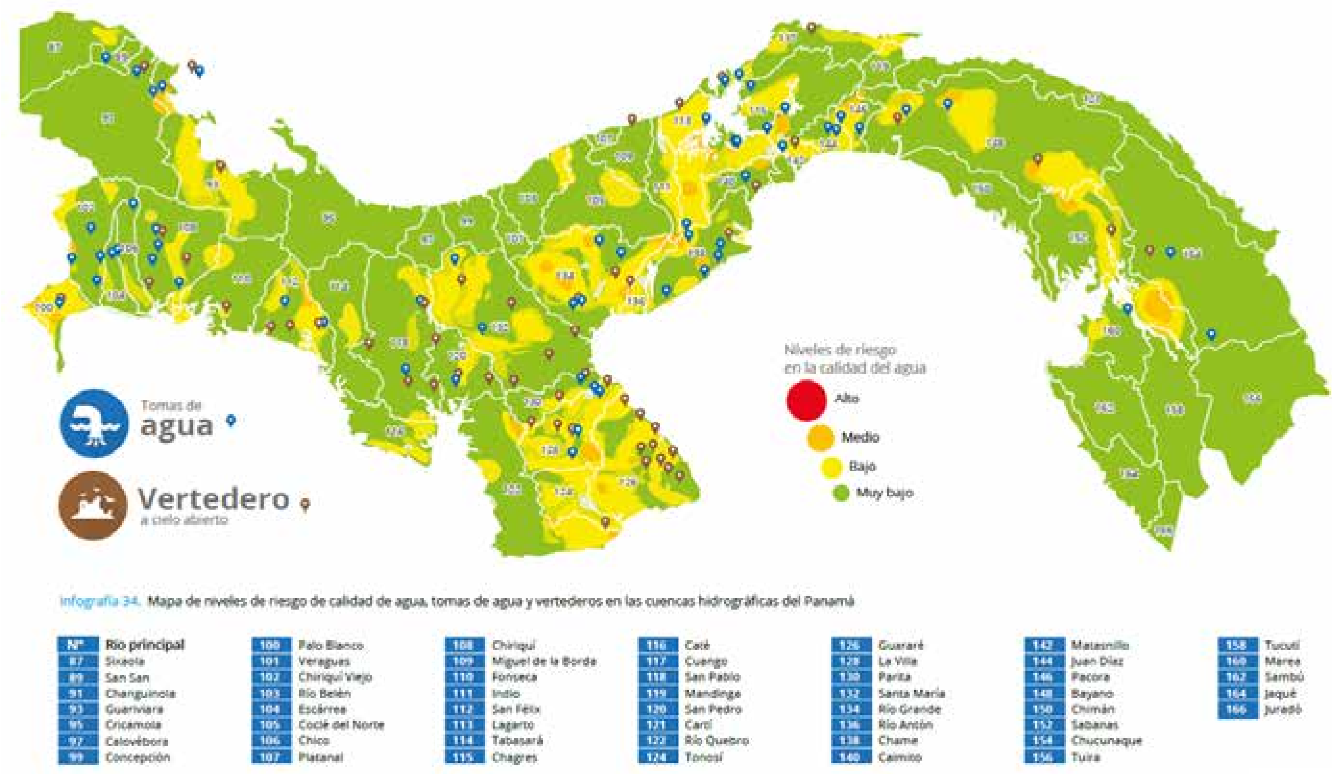
Another problem of the Panamanian productive scheme is the extensive transformation of natural ecosystems into simplified agroecosystems. Panama is located in the region with the highest biodiversity in the world (ANAM/CBD, 2014), which implies the existence of complex, intense natural metabolisms, which are also fragile. This transformation

Table 2. Percentage of the population with access to drinking water, according to the population censuses of 1990, 2000 and 2010

Provinces and indigenous regions	Population with and without access to drinking water by Census					
	1990*		2000		2010	
	Yes	No	Yes	No	Yes	No
Total	**81.2**	**18.8**	**90.2**	**9.8**	**92.9**	**7.1**
Bocas del Toro	60.2	39.8	74.1	25.9	74.6	25.4
Coclé	75.9	24.1	91.5	8.5	95.1	4.9
Colón	83.3	16.7	92.0	8.0	93.5	6.5
Chiriquí	65.3	34.7	82.3	17.7	87.9	12.1
Darién	31.9	68.1	58.4	41.6	72.4	27.6
Herrera	78.4	21.6	93.6	6.4	96.6	3.4
Los Santos	85.7	14.3	96.1	3.9	98.6	1.4
Panamá	93.7	6.3	97.1	2.9	98.6	1.4
Veraguas	57.4	42.6	83.3	16.7	88.8	11.2
Kuna Yala			67.7	32.3	77.8	22.2
Emberá			10.7	89.3	27.6	72.4
Ngäbe-Buglé			29.9	70.1	38.6	61.4

*Indigenous territories had not been created and indigenous areas were included in the provinces surrounding these regions.
Source: MEF, *Atlas Social de Panamá*, Chapter 3.

Figure 4. Infographic No. 34 of the PNSH 2015:2050 showing risk levels in terms of water quality in the river basins, in relation to the location of open-air dumps and water intake



Source: MiAMBIENTE, 2016b.

inevitably drives the growth of opportunistic and undesirable species, which can only be controlled using pesticides or herbicides which, without proper supervision, cause high levels of contamination in natural water bodies, through organochlorines, phosphorous chlorides, and so on. This happens at the same time as devegetation and mechanization are leading to an increase in erosion, producing soil losses and high degrees of turbidity and sedimentation in rivers and estuaries.

Today, Panama City has more than 1.5 million inhabitants and only recently has a large-scale water treatment plant begun to operate as part of the Panama Bay Sanitation Project. A worrying aspect of the District of Colón is that rivers and streams flow directly into the Bay of Manzanillo or into the Gatun reservoir, so that any contaminant they contain goes is significantly diluted in their waters. It is also true that the lacustrine load accumulates in the bay itself due to the effects of the Canal locks in the Atlantic area. The same happens in David city, 50 km from the border with Costa Rica, crossed by several important rivers, but currently surrounded by broad stretches of squatters, extensive agricultural and livestock production, albeit with intensive use of agrochemicals and industries with extremely poor environmental management, in addition to a deficient sanitary landfill and a total lack of wastewater treatment plants. **Figure 4** shows the risk map of water quality in rivers in relation to the location of landfills in the country.

3.2 Health

The Panama chapter of the book Urban Water Challenges (IANAS, 2015) addresses key aspects related to urban water and health until 2014. On this occasion, the information presented has been updated with a more holistic approach. According to the "Análisis de Situación de Salud" (Health Status Analysis) (MINSA, 2015) report, and on the basis of the

2010 census, it is estimated that 91.8% of the Panamanian population has access to potable water (**Table 2**). However, in indigenous areas, over 50% of the population does not enjoy water in hygienic conditions, or in accordance with international health agency regulations. The alleged causes range from the dispersion of the inhabitants, scant access to populated areas, to internal migration processes and the cultural influence of first peoples. In this article, we use the definition of "access to drinking water" of the World Health Organization (WHO), in other words, a source of water less than one kilometer from the place of use and the ability to obtain 20 liters a day for each family member. It was estimated that, by 2014, 25% of homes located in rural areas would not have access to an adequate potable water service and that 0.7% of homes would not have any access to water (INEC, 2010).

MINSA (2015) attributes the above to several factors: poor soil management, deforestation, sedimentation, pesticide contamination, inadequate wastewater disposal, ecosystem deterioration (exacerbated by severe forms of environmental pollution), unplanned urbanizations on the banks of river basins or rivers, a sustained increase in the demand for water resources to meet the needs of the population, in addition to the lack of controls to prevent losses in the aqueduct network. Regarding the latter, in the provinces of Panama and Colón alone, losses reach percentages of over 40% due to the lack of a culture of rational water use coupled with the lack of family consumption meters.

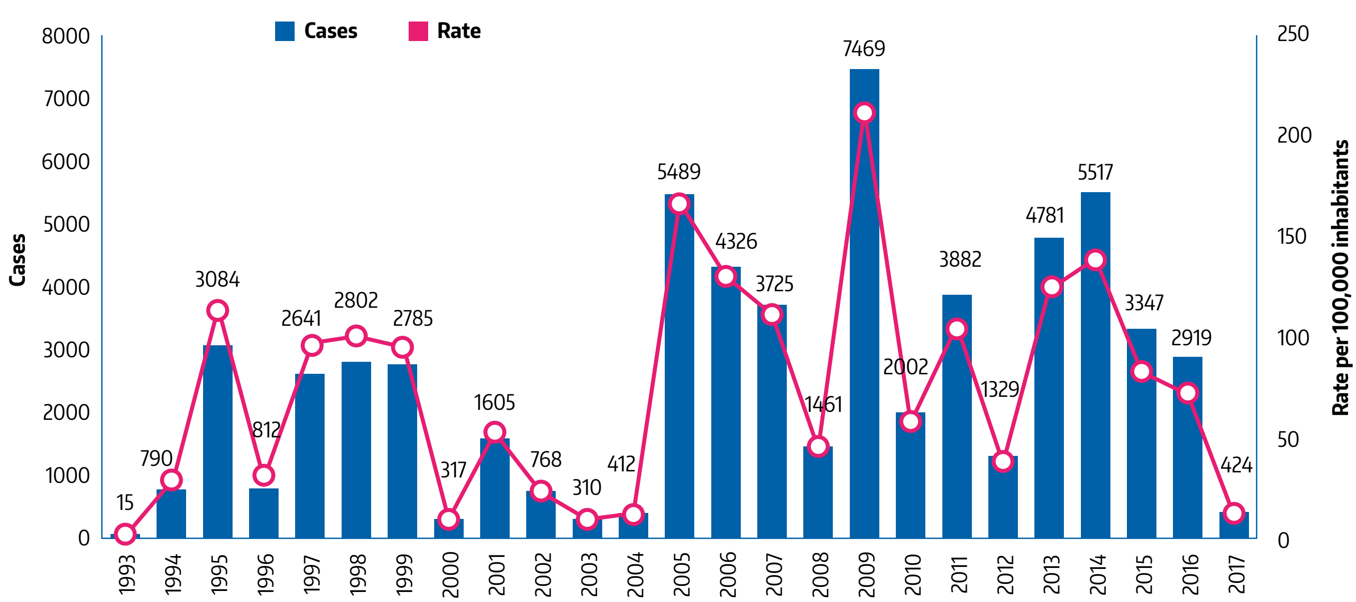
Diseases transmitted by vectors associated with water

In Panama, the main diseases of this type are: dengue, chikungunya, Zika and malaria. Their percentages of incidence are still significant and mainly due to the lack of drinking water, a condition that requires people to store water in vessels that serve as effective breeding grounds for these diseases.

Figure 5 shows a sustained decrease in dengue from 2014 to the present, from 5,517 cases in 2014 to 2,917 in 2016.

The Chikungunya virus (**Figure 6**) was introduced in Panama in 2014, when 68 cases were reported (26 indigenous and 42 imported). In 2015, there were 181 confirmed cases (162 native and 19 imported); in 2016 there were 11 positive cases (6 indigenous and 5 imported); whereas in 2017, only 2 of the 317 suspected cases were positive. Since week 47 of 2015, there have been cases of infection with

Figure 5. Dengue cases and incidence rate according to year of occurrence in Panama 1993-2017



Source: MINSA, 2017b

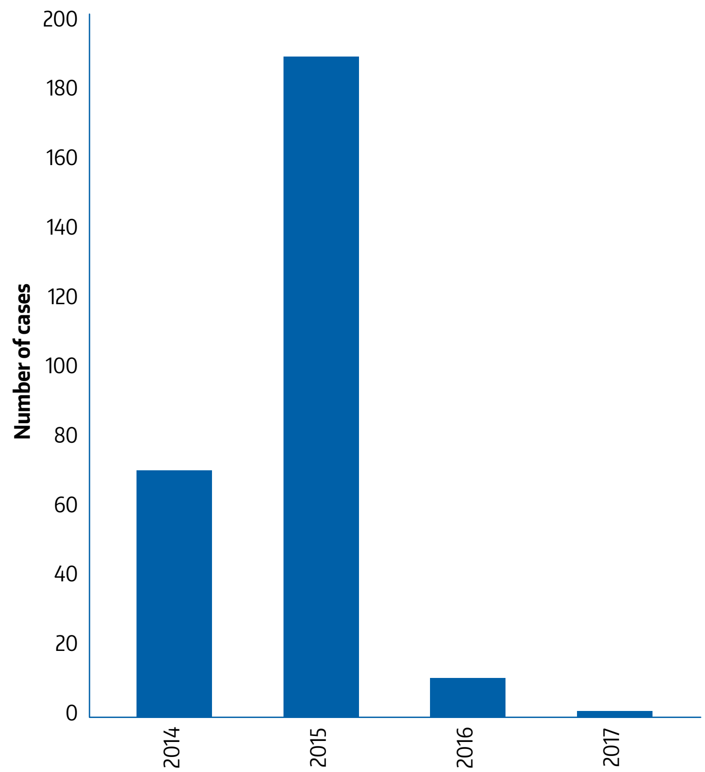
Zika virus in Panama, another arbovirus transmitted by mosquitoes of the genus Aedes, with symptoms very similar to those produced by Dengue and Chikungunya viruses, in addition to the fact that it is associated with Guillain-Barré syndrome in people who have suffered the infection and with microcephaly in children born to mothers who have been infected during pregnancy. On March 15, 2016, the National Liaison Center of Panama informed PAHO/WHO of a case of Guillain-Barré syndrome (GBS) with concomitant Zika virus infection. From the end of 2015 to week 11 of 2017, 52 positive cases of pregnant women were reported, one of which was from Guna Yala with a positive result in 2015; together with 45 (one with a positive result from abroad) in 2016 and 6 (MINSA, 2017d) in 2017.

Malaria is a parasitic disease transmitted by females of the genus Anopheles. It is endemic in Panama, with five foci located east of the cities of Panama and Colon, specifically in the Ngäbe-Buglé and Guna Yala Counties, in the Bayano, Mortí, Jaqué and Puerto Piña area. From 2001 to 2017, the morbidity and mortality rate has remained low with a stable trend in recent years (**Figure 7**).

Moreover, it is estimated that 88% of diarrheal diseases are the result of an unsafe water supply and poor sanitation and hygiene (WHO, 2004). According to the WHO, the improvement of water supply reduces between 6% and 21% of morbidity due to diarrhea, if serious consequences are accounted for. In Panama, there are no up-to-date statistics on the etiology of diarrhea due to water consumption contaminated with bacteria, enteroviruses, helminths, free-living organisms and protozoa. The last cholera epidemic was registered from 1991 to 1993, after which no cases have been reported, nor have studies been conducted to determine the presence of free-living amoebae in recreational waters, and no cases of primary amoebic meningoencephalitis or granulomatous amebic encephalitis have been documented.

Studies such as the one by Álvarez *et al*. (2010), which included several regions in the country, found a prevalence of 6.4% of *Cryptosporidium* sp. in children under five, showing that La Chorrera and Panama Metro had the highest prevalences with 16% and 11%, respectively. Another article by Arosemena *et al*. (2014) detected enteroparasitosis in three indigenous communities, finding that 100% of the water samples were positive for some form of parasites, particularly *Giardia* spp. in 35% and *Blastocystis* spp. in 33%. These values confirm the deficient health conditions present in indigenous communities.

Figure 6. Incidence of cases of Chikungunya from 2014 to 2017 in Panama



4. Main problems impacting water quality in Panama

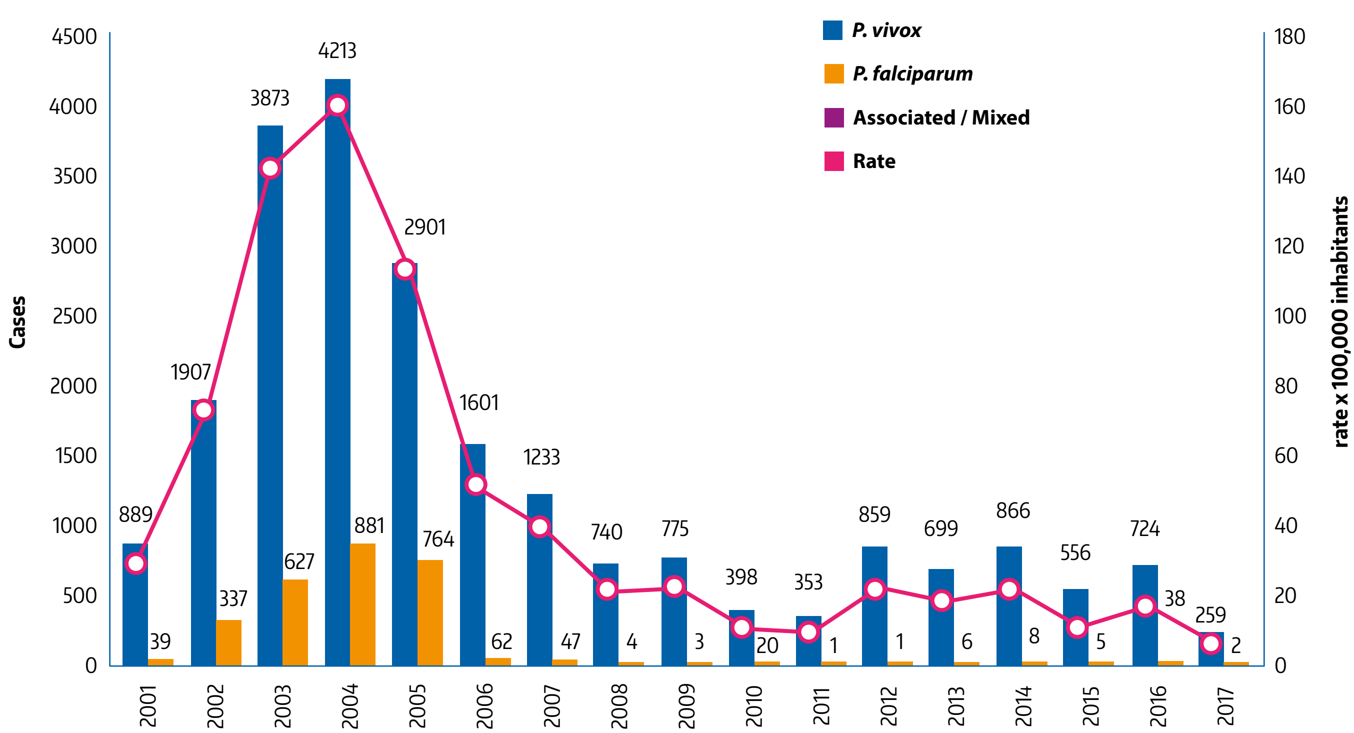
4.1 Eutrophication

Eutrophication, which occurs naturally in aquatic ecosystems, consists of their evolution towards terrestrial conditions due to nutrient accumulation, the vigorous development of vegetation and sediment accumulation. Eutrophication can be summarized as the flow of fertilizers and plant nutrients from human and agricultural sources with consequences for the structural characteristics and functioning of the aquatic system. Reservoirs are classified as oligotrophic, mesotrophic or eutrophic according to their degree of eutrophication, (Margalef, 1983, Carlson and Simpson, 1996). Oligotrophic reservoirs have little or no aquatic vegetation and are relatively clear while mesotrophs are water bodies with an intermediate level of productivity. They usually have clear waters and maintain beds of submerged aquatic plants and medium levels of nutrients; while eutrophic ones tend to receive large amounts of organisms, including algal blooms. Each trophic class has different types of fish and other organisms (Margalef, 1983).

During its construction, and subsequently during the operation of the Panama Canal, the Gatún reservoir experienced problems of growth of aquatic vegetation, initially with native species and subsequently with foreign ones. The then recent conditions, created by the release of nutrients derived from the decomposition of organic matter that was exposed, led to the exponential development of a vegetable biomass of alarming proportions (Von Chong, 1986). The first aquatic plants to appear in an obstructive form (Von Chong, 1986) were the rooted species of water hyacinth (*Eichornia azurea*), followed by the floating species of water hyacinth (*E. crassipes*). Then, in the natural succession of the aquatic species that occurred in the reservoir, they were followed by water lettuce (*Pistia stratiotes*) together with a varied number of grass species and other broadleaf species, as well as submerged species (*Hydrilla verticilata*).

In 1948, in order to control aquatic plants, the specific herbicide 2,4 D was introduced for water hyacinth (*E. crassipes*), which had replaced "water thyme" (*Hydrilla verticillata*) in areas where it had been kept under control through the use of copper sulphate (Von Chong, 1986). From 1951 to 1964, it was the only herbicide used, specifically to control water hyacinth. This period saw the phenomenon of the ecological succession of vegetation, when *Hydrilla* invaded and seized the operating areas kept under a water hyacinth control program. In 1964, several manatees of the species *Trichechus manatus* and *T. inunquis* were introduced into areas of the Panama Canal in order to control certain aquatic plants, hosts of the *Mansonia* mosquito. At the time, it was determined that approximately 2,000 manatees would be needed for an impact on controlling

Figura 7. Número de casos y tasas de incidencia de paludismo en Panamá 2001-2017 semana 15



Source: MINSA, 2017c.

vegetation in the Gatún reservoir to begin to be noticed (Von Chong, 1986).

In 1977, the former Panama Canal Company reported that "colonies of aquatic macrophytes in Lake Gatún were preventing the operation of the Canal. *Hydrilla verticillata*, a submerged species, posed the greatest danger to navigation in Gatún Lake" (PCC, 1977, Dardeau, 1983, Clark, 2015). The introduction of the herbivorous carp, in the Gatún reservoir, met the need to control *Hydrilla verticillata* (Custer *et al*., 1979, in Clark, 2015). In 1977, the *Neochetina bruchi* weevil was introduced to control the floating hyacinth species, was introduced, and in 1979, the *Sameodes albiquitallis* butterfly attacked the floating species of water hyacinth. It is important to note that in the process of natural succession of aquatic vegetation, other plants have been replacing those that were controlled. In 1978, over 250,000 fingerlings of the herbivorous carp *Ctenopheryngodon idella* were introduced as biological control for *Hydrilla*, with no reduction in the biomass of this plant being observed in the reservoir (Von Chong, 1986).

Between 1986 and 1988, a person who was unaware of the "voracious herbivore" characteristics of the giant snail *Pomacea* sp., introduced it into the Gatún reservoir, in the area of La Arenosa, La Chorrera (Gutiérrez, 1991). Its effect as a controller of the *Hydrilla* became visible a few months later. Human activity was largely responsible for spreading it throughout the entire reservoir. This is confirmed by Clark (2015), who states that a snail (*Pomacea* sp.) and a moth larva (*Parapoynx* sp.), whether introduced accidentally or intentionally, have been the biological controls that could explain the changes that occurred after almost 20 years.

Lastly, a comprehensive study of the aquatic vegetation in the Gatún reservoir has not been undertaken since 1994. However, there have been short studies on water quality, (Jara, 2012) and trips to the Chagres River for the identification/location of species using the photogrammetric method (Jaramillo, 2013). Other studies concern the regular management of vegetation which, in the case of *Hydrilla*, has been reduced since the appearance of the snail mentioned earlier. Finally, since 2003 the ACP, through the Water Quality Unit, has been implementing the Water Quality Monitoring and Monitoring Program, which, since 2009, has calculated the Carlson Trophic Status Index (TSI) for the Gatún and Alhajuela reservoirs (Panama Canal Authority, 2010). In the evaluation of the trophic state of the Gatún and Alhajuela reservoirs, the chlorophyll-based trophic status index (ChlorTSI) is used as the main index, because this is the best estimator of the algal biomass (Carlson and Simpson, 1996). Secchi Transparency or Depth Evaluation (STDE) and Total Phosphorus Surface Concentrations (totTPSC) have also been considered as complementary. The index provides values that may vary between 0 (oligotrophy) and 100 (eutrophy), 50 being the limit with mesotrophy.

As shown in **Table 3**, and based on the results of the ChlorTSI, the Gatún and Alhajuela reservoirs are generally classified as mesotrophic. In the Gatún reservoir the values of the ChlorTSI vary in the water quality stations, between 25 (minimum in BAT-2014) and 50 (maximum in HUM-2016), and in the Alhajuela, between 32 (minimum in BOP-2011) and 51 (maximum in ERP-2010 and PNP-2010). In terms of spatial distribution, it is possible to distinguish areas where the ChlorTSI values are lower on average: in the Gatún reservoir, towards the ARN (38), RAI (37), ESC (34), BAT (34), MLR (38), TME (36) and TMR (38) stations, and in the Alhajuela reservoir, towards the mouths of the Boquerón and Pequení rivers where the BOP station (37) is located. In both reservoirs, the STDE is influenced by suspended inorganic solids.

The high level of water renewal, as a result of its use for locks, as well as the removal of aquatic vegetation, creates less eutrophy. However, the increase in suspended solids may have a negative impact on water quality, which could lead to an increase in the cost of treating raw water for purification. In addition, carrying total suspended solids has a negative impact on the ecosystem with effects on the aquatic fauna and flora.

4.2 Natural contaminants

As shown in section 2.3, in 2013 the ANAM (currently MiAMBIENTE) prepared its last monitoring report in the period 2009-2012, on 35 basins and 100 rivers. Measurements were made in the high, middle and lower parts of each river, to evaluate the Water Quality Index (WQI). The WQI classifies water quality on a scale of 0 to 100. Qualitatively, these indices rate the quality of the river as between ex-

Table 3. Annual average of trophic states (ChlorTSI) for the period 2009-2016

Year	Gatún Reservoir a/	Alhajuela Reservoir b/
2009	43	47
2010	42	48
2011	39	40
2012	37	44
2013	36	44
2014	34	42
2015	37	47
2016	41	44
Average	**39**	**44**

Observations: a) The annual averages indicate that, from 2009 to 2016, the annual average of TSI in the Gatún reservoir remains in a mesotrophic state. The T test for independent samples, with an alpha of 0.05, indicates that there are no significant differences in the TSI value of 2009 and 2016. b) The annual averages indicate that, from 2009 to 2016, the annual average of TSI in the Alhajuela reservoir remains in a mesotrophic state.
Source: Prepared by Marylin Diéguez (2018) based on data from the ACP.

Table 4. Ranges and ratings for WQI values used by MiAMBIENTE

Intervals	Rating (descriptor)
91-100	Excellent/Unpolluted
71-90	Good/Fair
51-70	Moderate/Not very polluted
26-50	Poor/Polluted
0-25	Very bad/Highly polluted

cellent or uncontaminated and very poor or highly contaminated. **Table 4** presents the quantitative and qualitative correlation of this index. **Table 5** gives a summary of the indices found in the 100 rivers evaluated.

Hydrographic Basin of the Panama Canal (CHCP)

In 2015, a total of 683 water quality indices for a similar number of samples were calculated at the CHCP. As shown in Table 6, the results obtained are very similar to the results for the period 2003-2013 (ACP, 2016). The percentage distribution of the ICA in the monitored reservoirs of Gatún, Alhajuela and Miraflores, the main rivers and the middle section of the Chagres River and the priority sub-basins of the CHCP are summarized in Figure 8. This figure emphasizes the good water quality of the various water bodies of the CHCP. The values of the of Alhajuela and Gatún reservoirs, which serve as a source of drinking water for the majority of the population in the main metropolitan areas of the country (Panama and Colón), warrant particular attention.

Regarding the seasonal variation of the WQI in the CHCP, in the historical period 2003-2013, higher average values (85-87) are observed in the dry season (January-April) with a peak in March (87), which fall between May and June (83 and 82), coinciding with the start of the rainy season. Finally, a slight decrease is observed between August and December with values of between 80 and 81, and lower average values in November (80) (ACP, 2016).

4.3. Heavy metals

Rapid population growth worldwide, the industrialization of coastal areas, pollution, overexploitation of resources and low environmental protection contribute to the deterioration of marine ecosystems, creating public health problems and considerable economic losses (Tayeb *et al.*, 2015; Chen and Broce, 2015). In Panama, various ecosystems have been affected by anthropogenic activities, creating an environmental problem, particularly in marine-coastal ecosystems. The impact on these areas is directly caused by mechanisms such as the accumulation of potentially dangerous substances in marine sediments, such as heavy metals, organic pollutants, radionuclides, etc., as well as the entry of numerous outfalls, containing pollutants of various origins (industrial, agricultural, urban, etc.) (Benali *et al*., 2015).

Among the heavy metals[2] or trace elements[3], mercury (Hg), cadmium (Cd) and lead (Pb) stand out because of their toxicity and greater presence in the environment (Orozco *et al*., 2003). Even though many heavy metals enter the marine environment, mainly as a result of anthropogenic activities (domestic, industrial and agricultural waste), they are usually transported through the water cycle by natural processes (Montero and Tenorio, 2010).

Cd, copper (Cu) and Pb are used in industries such as mining, metal smelting and paint manufacturing. The residual discharges of these activities without previous treatment may reach the atmosphere and be transported by the winds, while the runoff produced by the rains and rivers may go beyond the local source that produces them (Barría and Barría, 2004). Heavy metals may also be produced by geochemical processes such as weathering, diagenesis, desorption and ion exchange (Chen, 2017). In the case of estuaries and coastal areas, many chemical agents enter these systems through the transport of continental sediments, which becomes the main route of entry into the marine environment. Thus, the anthropic or natural nature of the entry of chemical agents into coastal areas makes it difficult to determine the origin of the pollution produced. Hence the importance of identifying the activities developed in areas surrounding the water bodies, which makes it possible to correlate this activity and the concentrations of determined metals in a set place.

At the same time, domestic waters constitute the largest individual source of metals such as Cu, Pb, zinc (Zn) and Cd in rivers, lakes and, in some cases, coastal areas. Elements such as chromium (Cr), nickel (Ni) and tin (Sn) are regarded more as indicators of industrial pollution (Montero and Tenorio, 2010). Metals such as Pb and its salts are generated by paint factories, pottery with enameling, photothermography, pyrotechnics, coloring glass, or chemical industries producing tetraethyl lead and certain mining activities (http://www.sagan-gea .org/hojared/CAgua.html). Pb was included in the list of priority hazardous substances of the III Conference of the North Sea and confirmed in the IV Conference held in Denmark (1995), where it was agreed to reduce the environmental concentrations of Pb to levels close to natural concentrations (Montero and Tenorio, 2010). In Panama, the grad-

Table 5. Summary of WQI results in 100 rivers, within 35 hydrographic basins in the Republic of Panama for the period 2009-2012

Water Quality Index a/	No. of rivers
Excellent	0
Excellent/Good	4
Good	40
Good/Medium	34
Middle	3
Medium/Bad	8
Poor	1
Bad/Very bad	1
Very bad	1
Not reported b/	1
Other c/	7
Total	**100**

a/ Given that many rivers presented different but adjacent categories, in their different sections (high, medium and low), it was decided to insert intermediate categories. Thus, a Good/medium category, for example, means that in certain sections of the river, the WQI was good and that in others it was fair.
b/ Río Chagres Basin, monitored by the ACP and described separately in this section.
c/ Results for the Tocumen, Tapia, Guararé, Mensabe, Caimito, Río Abajo and Juan Díaz rivers, which have good WQI in their upper sections; although their middle and/or lower sections show variations with more than one classification. For example: i) Middle section: Medium WQI and Low Section: Poor WQI, ii) Medium and low section: Poor WQI, ii) Medium and low section: Good WQI, Low section: Poor WQI.
Source: Data obtained from the Water Quality Monitoring Report on the Panama watersheds. Compendium of results 2009-2012 (ANAM, 2013).

Table 6. Percentage distribution of WQI in the Canal Hydrographic Basin, 2015 and period 2003-2013

WQI	2015	2003-2013
Moderate	2%	3%
Good	78%	77%
Excellent	20%	20%

Source: ACP, 2016.

2. Highly dangerous environmental pollutants, because they are not biodegradable and because of their potential for bioaccumulation in living organisms.

3. So-called because of their presence in small concentrations.

ual elimination of the use and sale of leaded gasoline (Montero and Tenorio, 2010) (Law 36 of May 17, 1996) has been a key factor in the gradual reduction of the concentration of this material in the city' air and the consequent improvement of environmental quality.

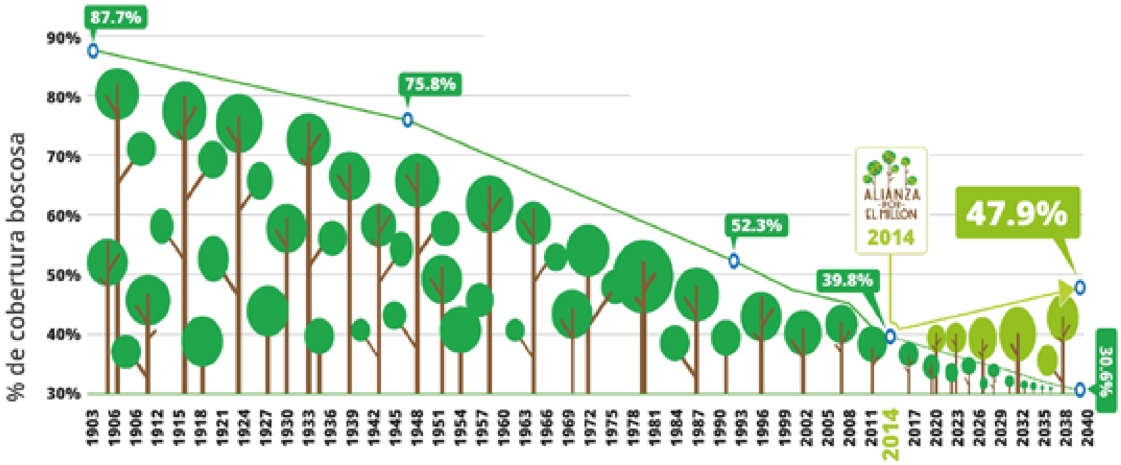
Cd, a metal that is basically produced by anthropogenic activities, is associated with the exploitation of Zn and waste from the plastics industry, paints and metal alloys. Since it is not biodegradable, its uptake by phytoplankton can be of great ecological significance. Moreover, it interacts with calcium metabolism in animals, creating a series of health problems in fish (Rodríguez, 2008, Montero and Tenorio, 2010).

Iron (Fe), manganese (Mn) and Zn are considered essential microelements, especially in the functioning of enzymes. Fe is found in lower concentrations in water and in higher concentrations in particulate matter and marine sediments (Chen, A., 2017). Cu is also essential because of its function within organisms. However, in high concentrations, it may affect the photosynthesis and development of algae, as well as the development of marine animals during their early stages (eggs, larvae, etc.), which can cause their death (Chen, A., 2017). In Panama, several studies have been undertaken in coastal areas to determine the concentration of polluting substances. These studies have used various analytical matrices to determine the concentrations of certain heavy metals in water, marine sediments, fish, mollusks and leaf tissue (Rodríguez, 2008).

The study undertaken by Rodríguez (2008) on *Rhizophora mangle L* in the forest located on Cañas Island, Tonosí, Los Santos Province, found Cu concentrations of over 10 μg/g (in both the rainy and the dry season, which exceeds the limits allowed for natural settings. The concentrations of Fe, Mn and Zn in mangrove sediments were below the limit for unpolluted sediments. Likewise, the concentration of heavy metals in leaf tissue (especially roots) of Rhizophora mangle L. yielded higher Mn values than those found in the sediment. This finding is an indicator of the bioaccumulation capacity of roots. For Fe and Cu, it was determined that the highest concentrations were present in the foliar tissue compared to the sediment and water of the estuarine channel. In the case of Mn and Cu, the comparison of concentrations between the sediment and water in the estuarine channel of the mangrove showed high levels of these metals in the sediments, which is generally the case (Rodríguez, 2008).

Figure 8. Percentage distribution of WQI in priority dams, rivers and sub-basins and in the entire CHCP in 2015 (ACP, 2016)

Figure 9. Infographics No. 32 of the PNSH 2015:2050. Projections of recovery of forest cover in Panama through the plan "Alliance for the Million Reforested Hectares"



Source: MiAMBIENTE, 2016b.

Another key study was conducted by Quiñones (2011) on the Catival River, on the island of Coiba, in which the heavy metals analyzed had very low values, with the exception of lead (0.05 ppb)[4] (Quiñones, 2011). Another research project on the mangrove swamp of Tamborcillo Island in Punta Chame studied the presence of Cd, Pb and Cu in the *Anadara tuberculosa* mollusk, finding that the most abundant metal in its tissue was Pb, with Cu being the scarcest. Cd and Cu showed a seasonal pattern of accumulation, but not Pb, which seems to be transferred to seawater by anthropic sources (Barría and Barría, 2004).

Studies on the Juan Díaz River, which flows into the Bay of Panama, showed Cr concentrations ranging from 0.3 to 0.7 ppm. Zn and Cu concentrations were 4.302 ppm and 0.296 ppm, both below the norm values (5.0 ppm and 3.0 ppm, respectively) (De Gracia-Nieto, 2003). In the case of Cd and Pb, it was not possible to make a comparison with the norm (De Gracia-Nieto, 2003). However, in the case of Pb, they did not exceed the value of 1.0 ppm.

4.4 Deforestation

Forest cover is essential for the health of basins and their water quality. A deforested basin means lower concentration times and a greater amount of sediment reaching the rivers, which reduces their quality. Likewise, evapotranspiration decreases, making the basin more vulnerable to extreme events. Figures 9 and 10, taken from infographics 32 and 33 of the PNSH 2015-2050 (MiAMBIENTE, 2016b), show the expected recovery of forest cover in the basins of the various rivers in the country due to the implementation of the Public-Private Initiative called "Alliance for the million hectares of Reforested Hectares" (**Figure 9**), as well as the current forest cover status per basin (**Figure 10**).

It is important to note that forest cover status is an aspect that is within the scope of the country to reverse through medium- and long-term commitments, and policies in harmony with sustainable development.

4.5 Wastewater

Background

According to projections of the National Institute of Statistics and Census of the Comptroller General of Panama (INEC, 2012), by 2015 it was estimated that the Panamanian population would amount to 3.98 million, with 67% (2.66 million) concentrated in urban areas and the remaining 33% (1.31 million) in rural areas (UNICEF, 2016).

A comparative analysis of drinking water and sewerage coverage in Panama at the national level showed that the total unattended population

4. The author cites contamination with diesel during the storage of this fuel in the working boat as a possible cause for this finding.

has been considerably reduced in the past three decades. From 1990 to 2015, the percentage of the population with access to improved drinking water sources[5] increased by 11%, bringing the coverage of this service from 84 to 95% (98 and 89% in urban and rural populations, respectively), while access to improved sanitation services[6] rose by 16%, from 59 to 75% (84 and 58% in urban and rural populations, respectively) (UNICEF & WHO, 2015). These differences could be due to the scattered nature of the rural population in the country, the lack of investment in rural areas and the lack of established goals for this sector (DISAPAS, 2013). Very little information is available on the percentage of wastewater treated in Panama. Authors such as Lentini (2011) placed Panama together with Bolivia, Colombia, Peru and Venezuela as treating between 20% and 30% of their wastewater. However, as a result of the entry in operation in 2013 of the first phase of the Juan Diaz Wastewater Treatment Plant, which currently receives 2.2 m3/s, this percentage must have increased from 5 to 10% (Panama Sanitation Program, 2017).

Causes of the limited sanitation infrastructure in Panama

The complexity of the problems posed by wastewater and its treatment nationwide is due to the interdependence of factors. For example, in the past 60 years, the population has quadrupled, with the urban proportion multiplying by more than sevenfold during the same period (DISAPAS, 2014). This has led, among other things, to a lag in the continuous supply and quality of drinking water and sanitation services, particularly wastewater treatment (Mejía and Rais, 2012).

Historically, by formulating laws and creating institutions, governments have introduced policies and strategies to address the needs of the drinking water and sanitation subsector. As mentioned in section 2, institutions such as IDAAN, MINSA, ASEP and MiAMBIENTE are responsible managing various aspects of the sector. However, a better definition of institutional roles is needed, which is reflected in the duplication of roles in governance and services, and gaps in regulation (DISAPAS, 2014). Likewise, wastewater and its treatment have been subject to the vision and criteria of the political authorities during each period of government. Consequently, current legislation on sanitary sewerage and control of the discharge of pollutant loads into water bodies is not applied due to the lack of regulation (Quiroz, 2004). In the case of wastewater, the passage in 2000 of COPANIT[7] standards (currently under review) has succeeded in regulating this subsector.

On the other hand, investment allocated for wastewater collection and treatment had been minimal until 2003, when the Sanitation Project of Panama City and Bay of Panama began, with an investment of over $600 million USD. This lack of investment contributed significantly to the marked insufficiency of sanitation infrastructures and the severe deficiencies in existing infrastructure, mainly in the country's district capitals. In the 1970s and 1980s, a number of wastewater treatment systems (STAR) were built, which have since collapsed due to the lack of resources to guarantee their proper operation and maintenance (DISAPAS, 2014). STARs, built after the DGNTI-COPANIT Technical Regulations in 2000, are subject to the same conditions.

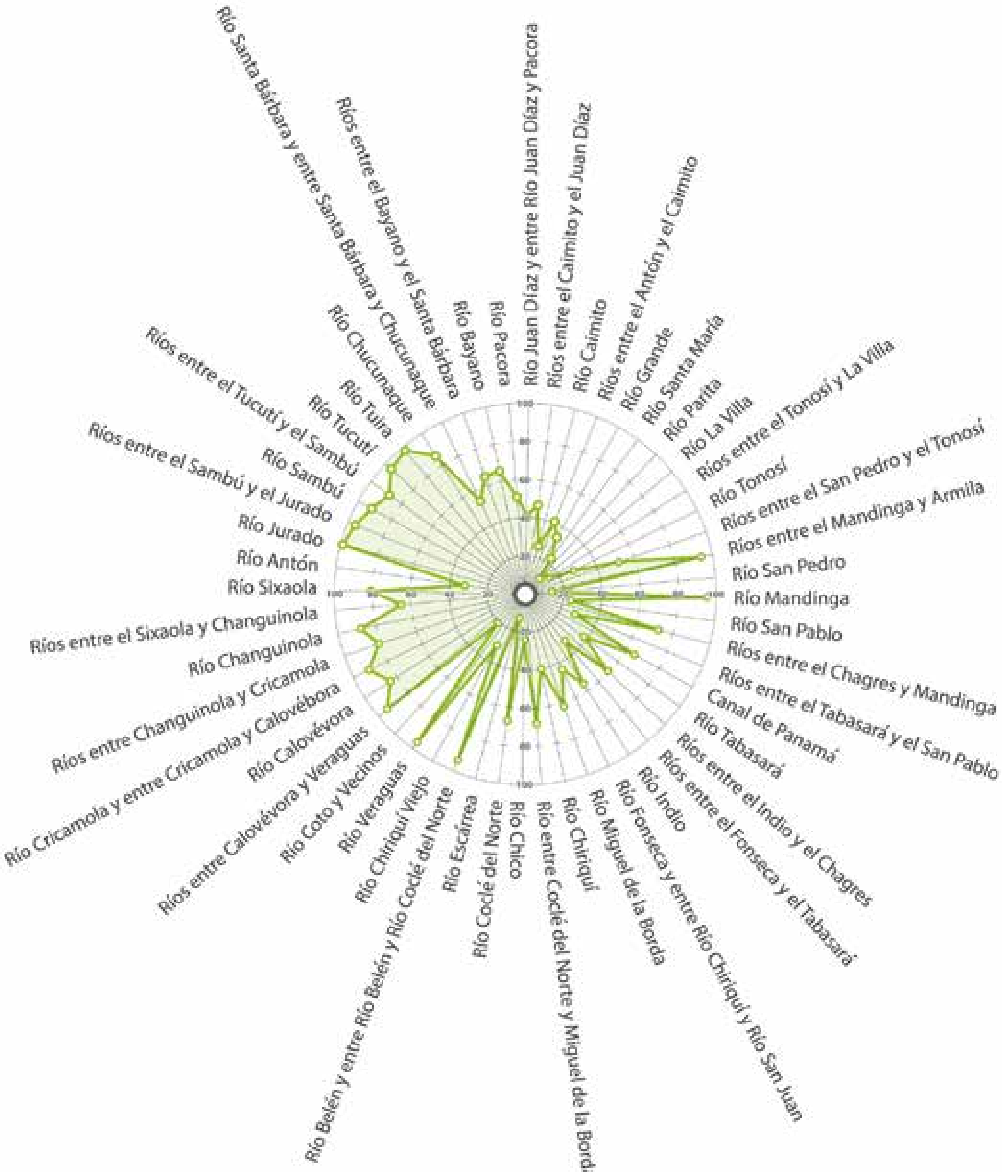
IDAAN, as the main provider of the urban sanitation service with 47.8% coverage, is the entity in charge of receiving, operating and maintaining in optimum conditions all the STARs delivered by the promoters of urban projects and state institutions that develop and promote this type of project (Executive Decree No. 268 of 2008). However, due to financial constraints, it has been almost impossible for the agency to assume this role. This has mean that, in certain cases, promoters cede the responsibility for their operation to the owners, which causes handling and maintenance problems, until the STARs eventually collapse (Silva, 2014). In addition to this situation, the IDAAN does not enforce the collection of sanitary tariffs associated with the

5. According to the WHO (http://www.who.int/water_sanitation_health/monitoring/jmp2012/fast_facts/es/), an improved source of drinking water is one which, due to the type of construction, appropriately protects water from the external contamination, particularly from fecal matter.

6. According to the World Bank, In addition to health services (sewerage systems, septic tanks or pit latrines), this included solutions such as improved ventilated pit latrines, pit latrines with slabs and composting toilets (http://data.worldbank.org/indicator/SH.STA.ACSN.UR).

7. See Table 1.

Figure 10. Infographics N° 33 of the PNSH 2015:2050 showing the current status of forest cover in Panamanian river basins



Source: MiAMBIENTE, 2016b.

provision of sanitary sewer service and wastewater treatment, which help offset the operating costs of the latter.

Projections for the drinking water and sanitation sector

In recent years, major efforts have been made to increase and improve potable water and sanitation services throughout the country, and considerable investments have been programmed for sanitation, especially wastewater collection and treatment. At present, 18.9% of public investment is allocated to the drinking water and sanitation sector, and 8.4% to the health sector, which makes them priority areas within the Government's Strategic Plan (MEF, 2014). To undertake this investment and achieve the proposed goals, institutions such as MINSA, IDAAN and the National Council for Sustainable Development (CONADES) work together, developing potable water and sanitation projects throughout the country.

The various institutions implement programs such as the Panama Sanitation Program (PSP), which depends hierarchically on the MINSA and whose goal is to clean up the wastewater of the 23 townships of the district of Panama and the nine townships of the special district of San Miguelito, as well as to improve the sanitary conditions of the two main districts of the province of West Panama: Arraiján and La Chorrera (PSP, 2017). Others include the Basic Health Program of CONADES, whose goal for 2020 is to build 300,000 hygienic bathrooms in homes which have latrines, and the Complementary Water and Sanitation Program, created to meet the demands of the aqueduct systems and Sewers of the City of Panama that could not be covered (CONADES, 2014).

The Ministry of the Presidency, through CONADES, also undertakes rehabilitation projects and improvements to oxidation ponds, construction of sanitary and STAR networks and sewage systems in various communities in the interior of the country (CONADES, 2017). For its part, IDAAN plans to build sewerage systems in various districts and provincial capitals. Some of these projects include the construction of the corresponding STAR (IDAAN, 2016).

Lastly, 2015 saw the entry into force of the National Water Security Plan (PNSH), which, through CONAGUA, seeks to coordinate and implement inter-institutional efforts related to the water sector. In this respect, CONAGUA indicates that in the short term, the PNSH 2015:2050 contemplates (2015-2019) the construction of new STARs at the national level (MiAMBIENTE, 2016b).

5. Sustainable Development Goal 6

5.1 Improve water quality by reducing pollution

In 2016, the Millennium Development Goals (MDGs) were replaced by the Sustainable Development Goals (SDGs), which are broader and easier for developing countries to achieve. According to Professor Jeffrey Sachs, "The world has entered a new era, in fact a new geological epoch, in which human activity is playing a threatening role in the basic dynamics of the Earth" (Sachs, 2012).

The growing urban population, together with the more complex problems of air, water and soil pollution, have required cities to implement a Sustainable Urban Water Management System (SUWM). A key factor for the above is for there to be water policies and regulations. The Law for the Regulation of Water Resources of Panama, passed

Box 1. Microplastics (Author: Denise Delvalle)

Origin: In 1935, Wallace Carothers of DuPont Enterprises invented the first synthetic polymer and called it nylon. Today, the following types predominate in the market: polyethylene (PE, high and low density), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS, including EPS expanded) and polyurethane (PUR). Current plastic production worldwide is approximately 300 million metric tons per year (Rocha Santos and Duarte, 2017). More than seven decades after its invention, scientists estimate that approximately 4.8 to 12.7 million metric tons of plastic end up in the oceans (Rocha Santos and Duarte, 2017). It is difficult to calculate the exact figure because plastics are constantly degraded under physicochemical conditions (radiation, erosion, wind, temperatures, friction, acidity, chemicals) into smaller fragments called microplastics or nanoplastics. Microplastics are defined as small plastic particles or fragments less than 5 mm in diameter. Primary microplastics are manufactured for industrial and domestic purposes and added to cosmetics and personal care products. Secondary microplastics are the result of the effects of climate and the fragmentation of larger plastic objects. We can also classify plastics by their origin from larger plastic objects (macroplastic) from land-based sources and marine sources such as fishing and the maritime sector, including their use in maintenance processes, such as abrasives for blasting in shipyards. Microplastics are not detected by wastewater treatment plants, and have significant differences in their concentration and a variety of distributions. Nanoplastics are found in the size range <100 nm, which is invisible to the human eye, yet present in the digestive systems and muscle tissues of benthic and marine microorganisms.

Plastic use, production and recycling in Panama: The use of plastic products in Panama is estimated at 54.6 (thousands of tons), with PET products being the most common. Average production for the period 2013-2014 was estimated at 2.3% of the total production of the national manufacturing industries (Environmental Company Gatún https://empresaambientalgatun.wordpress.com/category/plastico/). However, there are eight "Recycling companies in Panama", most of which export plastics to other countries, Plastiglas, SA and Reciclas (SIP, 2009), which are the only ones that recycle this product. Globally, it is estimated that only 5% of the plastic produced is recycled, a small amount is reused, approximately half is buried in landfills while the remainder ends up in the environment and eventually enters the aquatic ecosystems. According to the Comptroller General of the Republic, between 1997 and 2010, Panama exported 42 million kg (net weight) of used plastic materials (Rivas, 2011). Recently, the Urban Home Cleaning Authority (AAUD) launched a project financed by a private company to collect PET bottles in public places (Rodríguez, 2016).

Impact of microplastics: The impacts are closely related to the chemical properties of plastic polymers. For example, they can absorb persistent organic pollutants on their surface, filter them into the water, transport harmful bacteria, alter entire food chains in marine ecosystems and bioaccumulate in the muscle tissue of fish and other seafood. In 2017, the Technological University of Panama undertook a research project to calculate a national base line of microplastics present in sediments and water. The project began taking samples in the Panama Canal watershed, in places in the Atlantic and Pacific Oceans, and will be extended to other provinces during its second phase. It will also analyze water samples from the Juan Díaz Wastewater Treatment Plant, in order to determine the volume of primary plastics in wastewater in the country. The amount of this emerging pollutant that will enter the ocean will largely depend on the scope and effectiveness of wastewater treatment. Solid waste collection is crucial to prevent more plastics from entering the oceans. Waste management should take the life cycle of plastics into account and create strategies according to circular economy models backed by new and better standards regarding plastic use in the country.

in the mid-1960s (MICI, 1966), does not consider the elements of sustainability, urban planning, the economy, or aspects related to climate change. All these variables must be taken into account to achieve sustainability.

The regulations regarding land use and air quality have not been put into effect (MEF, 2009a, b, c). On the other hand, regulations regarding water quality have been in force since 2000 (see Table 1) and the recent construction of a mega Wastewater Treatment Plant (WWTP) has contributed to reducing the discharge of effluents into Panama Bay and partly improved the quality of most river basins. The government plans to build another WWTP in the short term.According to the authorities, a water quality monitoring program is to be implemented in certain rivers and streams in 2017 (Molina, 2017).

Due to the population growth in Panama City, the degradation of urban fluvial ecosystems has endangered sustainable urban development. A recent economic study conducted in China (Chen, 2017) reveals that property value increases by almost 5% if rivers can be regenerated by removing the concrete structures that were built in the past to correct their courses, as well as if "green" practices are implemented on the banks of these rivers and the final quality of the water is improved through the restoration of the initial environmental conditions.

Panama City was selected to participate in the International Development Bank (IDB) initiative known as the "Emerging and Sustainable Cities Program" (IDB, 2017). One of the three pillars of this Program focuses on environmental aspects such as water, air quality, energy, greenhouse gas emissions, and noise and solid waste management, culminating in the recovery of the spaces of the city to turn them into sustainable centers again. The Municipality of Panama launched a pilot plan in 2015, which includes a high-density municipality (Exposición-Calidonia), an old logistics and industrial area (Curundú) and the banking district (HYPERLINK "http://mupa.gob.pa/urban-interventions"). It also created an Urban Laboratory to guarantee the participation of universities in urban planning processes.

5.2 Increasing the efficiency of water use

The purpose of Sustainable Development Goal (SDG) 6.4 is to "significantly increase the efficiency of water use in all sectors, ensure the sustainable extraction and supply of fresh water to address the problem of water scarcity, and considerably reduce the number of people suffering from a shortage of this liquid by 2030" (http://datatopics.worldbank.org/sdgatlas/sustainable-development-goals.html).

Average annual rainfall in Panama is 2928 mm (http://datos.bancomundial.org/indicador/AG.LND.PRCP.MM?name_desc=true&view=map). Its economy depends mainly on the Panama Canal, whose activity relies on water. Fifty-five million gallons of freshwater are pumped into the oceans for each ship that crosses the Canal. The Panama Canal was recently expanded through the construction of a third set of locks. A key factor in this project was the preservation of water resources through a recycling system and the optimization of future efficiency by reducing total water use by 7% (http://eird.org/americas/news/the-panama-canal-example-of-sustainability-and-water-use-efficiency.html#.WRmjjUjGyI)) in each of the locks in the new set. It is necessary to address the relationship between drinking water, wastewater and rainwater to restore the urban water cycle (Hoban and Wong, 2006).

Wastewater re-use and rainwater management are increasingly important and necessary elements to achieve efficient water use. An important advance in Panama has been its leadership in Energy and Environmental Design or LEED certification (Leadership in Energy and Environmental Design) for buildings and infrastructures. In Panama, this ecological construction initiative has been supported by the Law on the Use and Rational and Efficient Regulation of Energy (UREE) since 2012 (National Secretariat of Energy, HYPERLINK "http://www.energia.gob.pa/ "). The National Energy Secretariat is the government institution responsible for its implementation. Panama currently has 94 projects waiting to be awarded the LEED certificate and 23 buildings in various categories that have already been certified (Pellicer, HYPERLINK "https://noticias.gogetit.com.pa/edificios-verdes/"). Panama is also part of the World Green Building Council, a global network of more than 70 Councils of this kind around the world (World Green Building Council, HYPERLINK "http://www.worldgbc.org").

In the rural environment, the Ministry of Agriculture (MIDA) has undertaken initiatives to implement the use of rainwater collection for use in agriculture and livestock. However, there is still a need for regulations designed to achieve efficient water management in irrigation networks (http://www.fao.org/3/a-i3442s.pdf Panamá).

5.3 Integrated water resource management at all levels

Panama has initiated truly integrated water resources management (IWRM) since the development, approval and implementation of its National Water Security Plan (PNSH) 2015-2050: Water for Everyone and the creation by Cabinet Resolution No. 114, August 23, 2016, of the agency responsible for monitoring this, CONAGUA.

The PNSH was built after a national consultation and the contributions of more than 1,500 people. This National Plan has five goals for achieving the ultimate goal of guaranteeing that water improves the quality of life, supports inclusive economic growth and ensures the integrity of the environment in the country. They include the following: 1) Having universal access to quality water and sanitation services; 2) Having the water required for inclusive economic growth; 3) Preventive risk management; 4) Healthy hydrographic basins, and 5) Water sustainability (normative and institutional framework and education and awareness). The PNSH contemplates short, medium and long term actions that have been identified following an IWRM approach. This approach is understood at three levels of integration. A first level within each user sector of water should consider actions in three directions: supply management (protection of water sources[8] and development of water infra-

8. Alliance for a Million Hectares Program:Emblematic MiAMBIENTE program, designed to reforest one million hectares by 2025, with the broad participation of society and the private sector.MIAMBIENTE is advancing in the elaboration of detailed water measurements in the basins of La Villa, Santa Maria, Rio Grande, Chiriquí, Chiriquí Viejo and Chico.With these studies, Panama will be able to prioritize the use of water, using high scientific standards and applying criteria of equity, solidarity, inclusion and sustainability.

structure[9]), demand management (education,[10] regulation,[11] financial mechanisms) and capacity building (development of human resources, information systems,[12] process improvement[13], among others); a second level of integration refers to the coordination of multisectoral actions and it is precisely at this level that CONAGUA operates.[14] At this level, actions related to various sectors are coordinated, such as feasibility and prefeasibility studies for the establishment of multipurpose reservoirs in six watersheds in the country (Bayano, Indio, Santa María, La Villa, Parita rivers and the Perales River sub-basin), protocols for improving the exchange of information between sectoral institutions with respect to surface and underground water intakes (location of wells), and the control and registration of water users and concessions.

The third level of integration of water management is related to the rest of the powers of the state. In Panama, in addition to the Executive Power, the National Assembly of Deputies has adopted the theme of water in its work agenda and promotes numerous initiatives designed to improve water governance. Examples of these initiatives include the updating of the 1966 Water Law and the modernization of the legal framework of the main water supplier in the country. In water governance, it is also necessary to understand how different levels of management are presented by territorial scale, in order to legally recognize what works and strengthen it or seek alternatives.

The first level of water management is private, i.e. domestic. At this level, all people without exception decide on efficient use, pollution and payment, whether at home or in industry. Most of the irrigation systems at the farm level in Panama are also at this level. One form of integration, for example, which would be following the runoff of the basin, is still pending,[15] although for this purpose, work is being promoted, such as those already mentioned by MiAMBIENTE through the ACP.

At the community level in the rural area, the work of the JAAR has been recognized in Panamanian legislation by Executive Decree No. 1839, issued December 5, 2014, which defines their regulatory framework as co-responsible agencies with the state for the administration, operation, maintenance and expansion of rural potable water supply systems, serving populations of up to 1,500 people. These are attended by the Directorate of the Sub-sector of Drinking Water and Sanitary Sewerage (DISAPAS).

Moving up the territorial scale, municipalities have gradually been strengthened by Decentralization Law No. 66 (2015), which states that resources from property tax may be allocated to areas such as aqueducts, waste management and others that affect water resources. Traditionally, the population resorts to municipalities as the first site for finding solutions to their problems; hence their enormous potential as pillars of good water management. Strengthening municipal management has begun to be promoted by the Decentralization Secretariat in coordination with the Association of Municipalities of Panama (AMUPA).

9. On behalf of MiAMBIENTE, the ACP undertakes feasibility and pre-feasibility studies for the establishment of multipurpose reservoirs in six basins in the country (Bayano, Indio, Santa María, La Villa and Parita basins and Perales River sub-basins).At the same time, institutions such as IDAAN, CONADES, Sanitation of Panama and others, also implement investment projects in water and sanitation.The Ministry of Agricultural Development, for its part, is developing the construction of drinking troughs, reservoirs, minidams and irrigation systems.

10. Within the PNSH, the need has been anticipated to strengthen human resources in issues related to water management.

11. Work is currently being done to reform the legal framework of IDAAN and the Forestry Incentives Act, which will make it possible to compensate conservation actions and sustainable management of natural resources and water sources.

12. MiAMBIENTE is developing a Watershed Information System and plans to have an Integrated Monitoring and Alert System for the National Civil Protection System (SINAPROC) designed to achieve better management and response to disasters, including those of a hydrological nature.

13. An Investment Monitoring System is being developed for all water management in Panama, which is expected to improve the design and planning of actions.

14. The National Water Council (CONAGUA), chaired by the Ministry of Environment, comprises the Ministry of Health (responsible for the Potable Water sub-sector), the Ministry of Agricultural Development, the Ministry of the Presidency, the Ministry of Economy and Finance, Public Services Authority, the Panama Canal Authority and the National Aqueduct and Sewer Institute.

15. Some systems are operating with various difficulties, such as Remigio Rojas in the Province of Chiriqui, which suffers from water shortages, sedimentation and problems of distribution and access to farms.

At the metropolitan level, the Panama Sanitation Unit of has been strengthened, and is responsible for the expansion of sewage networks, construction of sewage collectors and the operation of the treatment plant to serve the municipalities of Panama, San Miguelito, Arraiján and La Chorrera. A bill is currently being drafted to enable it to maintain the high standard of performance achieved to date (accredited three times by ISO 9001, ISO 14001 and OHSAS 18001).

At the basin level, the MiAMBIENTE formalizes water management through basin organizations. In this regard, 23 basin committees have already been formalized, six of which already have management plans and two of which have Regulation Plans as management tools. The mandate of the basin committees and the ordinance tools are based on Law 44 of August 5, 2002 and its regulations through Executive Decree 479, 2013.

A regional or subnational scale involves zoning by climatic regions. At this level, management systems linked to the protection of ecosystems are also usually established, for example, in protected areas, which has direct implications for the conservation of water sources. Panama has 89 protected areas, with an area equivalent to 34.43% of the country. These measures are reinforced by the approval of the text of the Executive Decree creating the National System of Protected Areas, in January 2007, and Law 41 of 1998 (General of Environment) and Law 8 of 2015 (which created MiAMBIENTE).

At the same time, also within the landscape level, there is the National Action Program (NAP) to Combat Drought and Desertification aligned with the ten-year UNCCD[16] strategy, which includes a diagnosis and an action plan already being implemented for critical areas: Cerro Punta, Sabana Veragüense, Comarca Ngäbe-Buglé and Arco Seco.

At the national or centralized level, IDAAN is the main drinking water supplier. Energy sector policies (including those involving the hydroelectric sector) are issued by the Energy Secretariat. Both services (water and energy) are regulated by the Public Services Authority (ASEP). Another aspect of water management is related to risks, an issue handled by the National Civil Protection System (SINAPROC).

16. United Nations Convention to Combat Desertification.

In the international context, Panama has mainly two large transboundary basins with Costa Rica (Sixaola and Changuinola). For the Sixaola basin, in 2009, the Binational Commission of the Sixaola River Basin (CBCRS) was created as a Special Binational Technical Commission, approved within the framework of the Agreement between the Government of Costa Rica and the Government of Panama on Cooperation for Border Development, ratified by Law No. 7518, July 10, 1995 in Costa Rica and Law No. 16, August 10, 1994 in Panama. This Commission already has its operating regulations.

Lastly, there are the agreements and advances Panama has made within the commitments it has assumed as a member of the United Nations Framework Commission for Climate Change.[17] In this regard, Panama has a National Climate Change Strategy, which includes 11 aspects and has a plan to reduce greenhouse gas emissions, as indicated in the document "Nationally Determined Contribution to Mitigation of Climate Change (NDC)" of Panama to the United Nations Framework Convention on Climate Change (UNFCCC) "(MiAMBIENTE, 2016a).

6. Conclusions

Despite being a country with abundant water resources, Panama has a series of structural problems in the context of water quality. A rapidly growing urban population and equally swift economic development place enormous pressure on the country to be up to date in the construction of proper infrastructure for sanitation. Moreover, pressure on water quality in our rivers and lakes is increasing. All this, coupled with poor resource distribution, means that most of the opportunities are concentrated in the metropolitan area, which in turn means that more development hubs are required in the country.

In relation to water quality, 80% of Panamian watersheds have a WQI equivalent to acceptable or only slight polluted water quality. However, the rivers flowing through Panama City tend to have good water qualities in their upper part, which deterio-

17. Recognizing that Water Security is at the heart of climate change adaptation.

rate in their middle and lower sections. In the case of the Panama Canal, water quality in the reservoirs and rivers is good to excellent.

As regards health, dengue continues to be the main health problem related to water, although in recent years there has been a steady decrease in the number of new cases. Similar behavior has been observed for Chikungunya, which after reaching a peak in 2015, has declined in recent years.

Regarding the issue of heavy metals, most studies cite lead and copper as the main pollutants in ecosystems. Another important point is that many of the studies have been conducted on mangroves.

Regarding the issue of sanitation conditions in the country, it is important to emphasize the importance that the issue of water is acquiring. Investments in the country can be seen in both new water treatment plants, wastewater treatment plants and sewerage systems in the main provincial capitals. Although the National Water Security Plan is a step in the right direction, it should be periodically reviewed.

Likewise, the issue of Integrated Water Resource Management should be reinforced, ideally at the basin level, as the most sustainable way to keep Panamanian surface water bodies in good condition over time. In terms of meeting Sustainable Development Goals, it is important that we all better understand the challenges we are facing (climate change, population growth, etc.). It is therefore up to the state to propose a modern regulatory framework and not only allocate resources to the construction of new works, but also to the maintenance of existing infrastructure.

References

Álvarez, D.; Pineda, V.; Mendoza, Y.; Santamaría, A.; Pascale, J.M.; Calzada, J.; Saldaña, A. (2010). *Identificación y Caracterización molecular de las especies* Cryptosporidium sp *circulantes en niños menores de cinco años de diversas regiones de Panamá.* Tesis de grado de Maestría en Ciencias Biomédicas con Especialización en Parasitología. Panamá: Facultad de Medicina, Universidad de Panamá.

Arosemena, V.; Castillo, C. y Guerra G. (2013). *Detección de parásitos en los moradores del Río Chagres y sus fuentes de Contaminación ambiental.* Trabajo de graduación. Panamá: Facultad de Ciencias Naturales Exactas y Tecnología, Escuela de Biología, Universidad de Panamá.

Autoridad del Canal de Panamá (ACP) (2010a). Calidad de Agua en la Cuenca Hidrográfica del Canal de Panamá (CHCP). En: *Agua y Bosques en la Cuenca del Canal: Tendencias a largo plazo,* pp. 52-94.

Autoridad del Canal de Panamá (ACP) (2010b). *Informe de Calidad de Agua 2008-2009.* Panamá: División de Agua, Unidad de Calidad de Agua.

Autoridad del Canal de Panamá (ACP) (2016). *Informe de Calidad de Agua 2015.* Panamá: División de Agua, Unidad de Calidad de Agua.

Autoridad Nacional de Ambiente (ANAM) (2013). *Informe de monitoreo de la calidad del agua en las cuencas hidrográficas de Panamá.* Compendio de resultados 2009-2012. Panamá: ANAM.

Autoridad Nacional de Ambiente (ANAM) y Convention on Biological Diversity (2014). Quinto informe nacional de biodiversidad de Panamá ante el convenio sobre diversidad biológica. Panamá: ANAM.

Autoridad Nacional de los Servicios Públicos (ASEP) (2016). Datos obtenidos en entrevista con el Ing. Carlos Gómez de la ASEP, el 7 de marzo de 2017.

Barría, F. y Barría, S. (2004). *Contaminación por metales pesados (Zn, Cu y Cd) en sedimentos marinos.* Tesis de licenciatura. Panamá: Universidad de Panamá.

Benali, I., Boutiba, Z. Merabet, A. & Chèvre, N. (2015). Integrated use of biomarkers and condition indices in mussels (*Mytillus galloprovincialis*) for monitoring pollution and development of biomarkers index to assess the potential toxic of coastal sites. *Marine Pollution Bulletin*, vol. 95(1), pp. 385-395.

Carlson, R. E. & Simpson, J. (1996). *A Trophic State Index. A Coordinator's Guide to Volunteer Lake Monitoring Methods.* North American Lake Management Society. 96 pp. Retrieved from http://dipin.kent.edu/tsi.htm

Chen, A. (2017). *Estudio comparativo entre el Artificial mussel y el Bioindicador* Anadara tuberulosa *para la determinación de cadmio, cobre y cromo en la zona costera de Soná, provincia de Veraguas, República de Panamá.* Tesis de doctorado. Panamá: Universidad Tecnológica de Panamá.

Chen, A y Broce, K. (2015). Artificial Mussel: Una herramienta complementaria para el monitoreo de la contaminación por elementos traza en zonas costeras. *Prisma Tecnológico*, vol. 6: (1), pp. 24-28.

Chen, WY (2017). Environmental externalities of urban river pollution and restoration: A hedonic analysis in Guangzhou (China). *Landsc Urban Plan* 157:170-179

Clark, M. (2015). Presencia de *Hydrilla verticillata* (L.f.) Royle 1839, en el lago Gatún (Canal de Panamá). Informe del Programa de Control de Vegetación Acuática (OPPD-C/AF-14). Panamá. Autoridad del Canal de Panamá. *Documento de uso interno con permiso de IANAS para ser publicado.*

Consejo Nacional para el Desarrollo Sostenible (CONADES) (2014). *Programa de Sanidad Básica 100/0.* Panamá: CONADES. Retrieved from https://goo.gl/EupdNW

Consejo Nacional para el Desarrollo Sostenible (CONADES) (2017). Sección Noticias. Panamá: CONADES. Retrieved from http://www.conades.gob.pa/Noticias

De Gracia, L.E. (2003). Determinación de metales pesados y fenoles en el río Juan Díaz (tesis de licenciatura). Panamá: Universidad de Panamá.

Dirección del Subsector de Agua Potable y Alcantarillado Sanitario (DISAPAS) (2014). *Monitoreo de los Avances del País en Agua potable y Saneamiento (MAPAS).* Panamá: Ministerio de Salud. Recuperado de www.abes-sp.org.br/arquivos/viissr/monitoreo-de-avances-de-pais-en-agua-y-saneamiento-luis-romero-quezada-conasa.pdf

Fondo de las Naciones Unidas para la Infancia (UNICEF)/Organización Mundial de la Salud (OMS) (2015). *Progresos en materia de saneamiento y agua potable: Informe de actualización 2015 y evaluación de los ODM.* Retrieved from https://www.wssinfo.org/fileadmin/user_upload/resources/JMPreport_Spanish.pdf

Fondo de las Naciones Unidas para la Infancia (UNICEF) (2016). *Estado Mundial de la Infancia 2016: Una oportunidad para cada niño.* Retrieved from https://www.unicef.org/spanish/publications/files/ UNICEF_SOWC_2016_Spanish.pdf

Foro Centroamericano y República Dominicana de Agua Potable y Saneamiento (FOCARD-APS) (2013). Situación actual y perspectivas en *Gestión de las Excretas y Aguas Residuales.* Panamá. 32 pp.

Gutiérrez, R.M. (1991). *Evaluation of an Integrated Control Method for the Aquatic Vegetation Management in the Panama Canal. Aquatic Vegetation and Oil Pollution Control Management Branch.* Dredgind Division. PCC. (Informe interno)

Hoban, A., & Wong, THF (2006). *WSUD resilience to Climate Change.* In: 1st International Hydropolis Conference. Perth, W.A.

IANAS (2015). Panama in Urban Water Challenges in the Americas. *Urban Waters.* Autores: Fábrega, JR, Morán, M, Flores, EL, Márquez, II, Ying, A, Saavedra, C, Olmedo, B, López, P. IANAS/UNESCO, pp. 448-473.

Instituto de Acueducto y Alcantarillados Nacionales (IDAAN) (2012). *Boletín Estadístico* No. 26. 2010-2012.

Instituto de Acueducto y Alcantarillados Nacionales (IDAAN) (2016). *Informe de Ejecución Físico-Financiera del Presupuesto de Inversiones.* Retrieved from https://idaan.gob.pa/wpcontent/uploads/2017/04/Proyectos_informe_fisico_financiero_enero_y_febrero_2017.pdf

Instituto de Investigación Agropecuaria de Panamá (IDIAP) (2006). *Zonificación de suelos de Panamá por niveles de nutrientes.* Retrieved from http://www.cich.org/publicaciones/05/idiap-mapas-fertilidad.pdf

Instituto Nacional de Estadística y Censo (INEC) (2010). Diagnóstico de la población indígena de Panamá. Retrieved from http://www.contraloria.gob.pa/INEC/archivos/P6571INDIGENA_FINAL_FINAL.pdf

Instituto Nacional de Estadística y Censo (INEC) (2012). *Censo 2010.* Panamá: Contraloría General de la República/Censo de Población y Vivienda.

Instituto Nacional de Estadística y Censo (INEC) (2012). *Estimaciones y proyecciones de la población en la república, provincia, comarca indígena por distrito, según sexo y edad.* Boletín 15. Panamá: Contraloría General de la República. Retrieved from https://www.contraloria.gob.pa/inec/Publicaciones/Publicaciones.

aspx?ID_SUBCATEGORIA=10&ID_PUBLICACION=499&ID_IDIOMA=1&ID_CATEGORIA=3

Jara, Y. (2012). *La vegetación acuática y su relación con la calidad de agua en diferentes puntos del embalse Gatún.* Informe de práctica profesional para optar por la Licenciatura en Biología. Panamá: Universidad de Panamá/ ACP-Unidad de Calidad de Agua.

Jaramillo, B.Y.Y. (2013). Estudio de la vegetación acuática mediante imágenes satelitales y datos de campo en el tramo medio del Río Chagres. Informe de práctica profesional para optar por la Licenciatura en Biología. Panamá: Universidad de Panamá/ ACP-Unidad de Calidad de Agua.

Lentini, E. (2011). *Servicios de agua potable y saneamiento: lecciones de experiencias relevantes.* Retrieved from http://archivo.cepal.org/pdfs/Waterguide/lcw0392s.PDF

Margalef, R. (1983). *Limnología*. Barcelona: Ediciones Omega, S.A. 1010 pp.

Maturell, J. y Salazar, A.J. (1994). *Aspectos de la introducción y diseminación del caracol gigante* Pomacea *sp., en el lado Gatún y sus efectos sobre la abundancia de* Hydrilla verticillata. XII Congreso Científico Nacional. Universidad de Panamá (21-23 marzo 1994). Pradepesca Informa. Temas de acuicultura, Nos. 4-5: pp. 29-33.

Mejía, A. y Rais, J. (2012). La infraestructura en el desarrollo integral de América Latina. Diagnóstico estratégico y propuesta para una agenda prioritaria. Agua y saneamiento. *IDeAL 2011.* Caracas: CAF-Banco de Desarrollo de América Latina.

Ministerio de Ambiente (MiAMBIENTE) (2016a). Contribución Nacionalmente Determinada a la Mitigación del Cambio Climático (NDC) de la Republica Panamá ante la Convención Marco de Naciones Unidas sobre Cambio Climático (CMNUCC). Retrieved from https://www.slideshare.net/DanielDelgado2/contribucin-nacionalmente-determinada-a-la-mitigacin-del-cambio-climtico-ndc-panama-2016

Ministerio de Ambiente (MiAMBIENTE) (2016b). *Plan Nacional de Seguridad Hídrica 2015-2050: Agua para Todos.* Panamá: MiAMBIENTE/CONAGUA/Comité de Alto Nivel de Seguridad Hídrica.

Ministerio de Economía y Finanzas (MEF) (s/f). *Atlas Social de Panamá.* Capítulo 3: Desigualdades en el acceso y uso del agua potable en Panamá. Autora: Liseth M. Tejada Soto. Panamá: MEF. Retrieved from http://www.mef.gob.pa/es/informes/Paginas/Atlas-Social.aspx

Ministerio de Economía y Finanzas (MEF) (2014). *Plan Estratégico de Gobierno 2015-2019.* Retrieved from http://www.mef.gob.pa/es/Documents/PEG%20PLAN%20ESTRATEGICO%20DE%20GOBIERNO%202015-2019.pdf

Ministerio de Salud (MINSA) (2015). *Análisis de la situación de salud.* Panamá: MINSA. Retrieved from https://www.minsa.gob.pa/sites/default/files/publicaciones/asis_2015.pdf

Ministerio de Salud (MINSA) (2017a) *Boletín epidemiológico Nº 11: Chikungunya.* Panamá: Ministerio de Salud-Dirección General de Salud-Departamento de Epidemiología. Retrieved from http://www.minsa.gob.pa/sites/default/files/publicacion-general/ boletin_11_chikv_1_0.pdf

Ministerio de Salud (MINSA) (2017b). *Boletín epidemiológico Nº 11: Dengue.* Panamá: Ministerio de Salud-Dirección General de Salud-Departamento de Epidemiología. Retrieved from http://www.minsa.gob.pa/sites/default/files/publicacion-general/boletin_11_dengue_1.pdf

Ministerio de Salud (MINSA) (2017c). *Boletín Epidemiológico Nº 11: Malaria.* Retrieved from http://www.minsa.gob.pa/sites/default/files/publicacion-general/boletin_11_malaria_2.pdf

Ministerio de Salud (MINSA) (2017d). *Boletín Epidemiológico de Zika Nº 11.* Panamá: Ministerio de Salud-Dirección General de Salud-Departamento de Epidemiología. Retrieved from http://www.minsa.gob.pa/epidemiologia/zika-2017

Molina, U. *La Prensa online 2017.* Retrieved from http://impresa.prensa.com/panorama/Verificaran-calidad-rios-quebradas_0_4723777597.html

Montero, J.A. y Tenorio, D.L. (2010). *Análisis de metales pesados (Bb, Cd y Cu) en agua y sedimento durante las estaciones lluviosa y seca en Playa Bique, Arraiján.* Tesis de licenciatura. Panamá: Universidad de Panamá.

Organización Mundial de la Salud (OMS) (2004). *Agua, saneamiento y salud.* Retrieved from http://www.who.int/water_sanitation_health/facts2004/es/

Organización Panamericana de la Salud (OPS), Organización Mundial de la Salud (OMS) y Ministerio de Salud (MINSA) (2016). *Análisis de la* *organización del Sector Agua y Saneamiento de Panamá.* Panamá: OPS/OMS/MINSA.

Orozco, C.; Pérez, A.; González, M.N.; Rodríguez F.J. y Alfayate, J.M. (2003). *Contaminación ambiental: Una visión desde la Química.* Madrid: Editorial Thomson.

Programa Saneamiento de Panamá (PSP) (2017). *Plan maestro.* Retrieved from http://saneamientodepanama.gob.pa/plan-maestro/

Quiñones, M.P. (2011). *Análisis ambiental de los parámetros fisicoquímicos, metales pesados y plaguicidas organoclorados del Río Catival en el Parque Nacional Coiba (PNC).* Tesis de licenciatura. Panamá: Universidad de Panamá.

Quiroz, F. (2004). *Manejo de las aguas residuales en la Ciudad de Panamá.* Ponencia.

Rocha, T. & Duarte, A.C. *Characterization and Analysis of Microplastics.* Retrieved May 22, 2017 from https://goo.gl/NnmUhc

Rodríguez, E.A. (2008). *Caracterización del bosque de* Rhizophora mangle *L. en el Refugio de Vida Silvestre Isla Cañas, provincia de Los Santos, República de Panamá.* Tesis de maestría. Panamá: Universidad de Panamá.

Rodríguez, M. (2016). *La Estrella de Panamá.* 17 de Junio de 2016. Retrieved from http://laestrella.com.pa/vida-de-hoy/planeta/impulsan-reciclaje-botellas-plastico/23946182

Sachs, JD. (2012). *From millennium development goals to sustainable development goals.* Lancet (London, England). 379(9832):2206-2211. Doi: 10.1016/SO140-6736(12)60685-0.

Silva, H. (2014). Evaluación de línea base gestión de aguas residuales Panamá. *Caribbean Regional Fund for Wastewater Management.* 47 pp.

Tayeb, A.; Chellali, M.R.; Hamore, A. & Debbah, S. (2015). Impact of urban and industrial effluence on coastal marine environment in Oran, Algeria. *Marine Pollution Bulletin,* vol. 98: (1-2), pp. 281-288.

Von Chong, H. C. (1986). Manejo de la vegetación acuática en el Canal de Panamá. *Revista Lotería* No. 372 (sept.-oct.): pp.108-121.

Legislación consultada

Constitución Política de la República de Panamá de 1972 (2004). Edición ajustada a los Actos Reformatorios de 1978, al Acto Constitucional de 1983, a los Actos Legislativos No. 1 de 1993 y No. 2 de 1994, y al Acto Legislativo No. 1 de 2004. *Gaceta Oficial* No. 25.176, November 15 2004.

Decreto Ejecutivo No. 279 de 2006. Reglamentación de la Ley 26 de 1996, reformada por el Decreto Ley 10 de 2006, “Que reorganiza la estructura y atribuciones del ente regulador de los servicios públicos”. *Gaceta Oficial* 25.677, November 22, 2006.

Decreto Ejecutivo No. 268 del 6 de junio de 2008. Que reglamenta el traspaso de los sistemas o plantas de tratamiento de las aguas residuales, de conformidad a los artículos 41 y 52 de la Ley 77 de 28 de diciembre de 2001, que reorganiza y moderniza el Instituto de Acueductos y Alcantarillados Nacionales y se dictan otras disposiciones., N°268 C.F.R. 2008. *Gaceta Oficial* 26.068 24 2008.

Decreto Ejecutivo No. 441 de 2008 que modifica el Decreto Ejecutivo 202 de 1990. *Gaceta Oficial* No. 26.145 October 13 2008.

Decreto Ejecutivo Nº 1.839 del 5 de diciembre de 2014 que dicta el nuevo marco regulatorio de las juntas administradoras de acueductos rurales (JAAR) como organismos co-responsables con el estado de la administración, operación, mantenimiento y ampliación de los sistemas de abastecimiento de agua potable rural. *Gaceta Oficial* Nº 27.678-A, December 11 2014.

Decreto Ejecutivo No. 84 de 2007, por el cual se aprueba la política Nacional de Recursos Hídricos, sus principios, objetivos y líneas de acción. *Gaceta Oficial* 25.777, April 24 2007.

Decreto Ejecutivo 479 de 2013, “Que reglamenta la Ley 44 de 5 de agosto de 2002 que establece el Régimen Administrativo Especial para el manejo, protección y conservación de las cuencas hidrográficas de la República de Panamá”. *Gaceta Oficial* 27.273-A, April 24 2013.

Ley No. 36 del 17 de mayo de 1996, “Por la cual se establecen controles para evitar la contaminación ambiental ocasionada por combustibles y plomo”. *Gaceta Oficial*, República de Panamá, May 211996.

Ley No. 41 de 1998. Ley General de Ambiente de la República de Panamá y se crea la Autoridad Nacional del Ambiente. *Gaceta Oficial* No. 28.131ª, October 4 2016.

Ley No. 44 de 2002, “Que establece el Régimen Administrativo especial para el manejo, protección y conservación de las cuencas hidrográficas de la República de Panamá". *Gaceta Oficial* 24.613 August 6, 2002.

Ley No. 8 de 2015, que crea el Ministerio de Ambiente (MiAMBIENTE). Gaceta Oficial 27.749-B.

Ley No. 66 de 2015, que reforma la ley 37 de 2009, que descentraliza la administración pública, y dicta otras disposiciones (MEF). *Gaceta Oficial* 27.901-A October 30, 2015.

Ministerio de Agricultura Comercio e Industrias (MICI) (1966). Ley que regula el uso de las aguas. *Digital* GO. Panama: MICI. 1-23.

Ministerio de Economía y Finanzas (MEF) (2009a). Decreto "Por el cual se establece la norma ambiental de calidad de suelos para diversos usos". *Gaceta Oficial Digital.* Panama: MEF, 2009:1-26.

Ministerio de Economía y Finanzas (MEF) (2009b). Decreto "Por el cual se dictan normas ambientales de emisiones para vehículos automotores". *Gaceta Oficial Digital*. Panama: MEF, 2009:1-8.

Ministerio de Economía y Finanzas (MEF) (2009c). Decreto "Por el cual se dictan normas ambientales de emisiones para emisiones de fuentes fijas". *Gaceta Oficial Digital.* Panama: MEF, 2009:1-15.

Reglamento Técnico DGNTI-COPANIT 21-393-99 (MICI) sobre toma de muestras. *Gaceta Oficial* N° 23.941, Decembe 6,1999.

Reglamento Técnico DGNTI-COPANIT 22-394-99 (MICI) por el cual se reglamenta la Toma de muestras para análisis biológicos. *Gaceta Oficial* N° 23.949, December 17,1999.

Reglamento Técnico DGNTI-COPANIT 23-395-99 (MICI) por el cual se reglamentan los Requisitos físicos, químicos, biológicos y radiológicos que debe cumplir el agua potable. *Gaceta Oficial* N° 23.942, 7 1999.

Reglamento Técnico DGNTI-COPANIT 24-99 (MICI) sobre la Reutilización de las aguas residuales tratadas. *Gaceta Oficial* N° 24.008, March 13 2000.

Reglamento Técnico DGNTI-COPANIT 35-2000 (MICI) sobre la Descarga de efluentes líquidos directamente a cuerpos de agua y masas de agua superficiales y subterráneas. *Gaceta Oficial* N° 24.115, August 10 2000.

Reglamento Técnico DGNTI-COPANIT 39-2000 (MICI) sobre la Descarga de efluentes líquidos directamente a sistemas de recolección de aguas residuales. *Gaceta Oficial* No. 24.115, August 10 2000.

Reglamento Técnico DGNTI-COPANIT 47-2000 (MICI) sobre usos y disposición de lodos. *Gaceta Oficial* No. 24.115 , August 10, 2000.

Resolución No 507 de 30 de diciembre de 2003 (MINSA) sobre el Procedimiento para controlar la calidad del agua potable. *Gaceta Oficial* N° 24.970, January 20 2004.

Resolución de Gabinete N° 114 del 23 de agosto de 2016, "Que aprueba el Plan Nacional de Seguridad Hídrica (PNSH) 2015-2050: Agua para todos y crea el Consejo Nacional del Agua (CONAGUA) y su Secretaría Técnica". *Gaceta Oficial* No. 28.104ª, August 26, 2016.

Internet References

http://data.worldbank.org/indicator/SH.STA.ACSN.UR (Retrieved July 31 2014)
http://data.worldbank.org/indicator/ER.H2O.INTR.PC (Consultado en octubre de 2016)
http://datatopics.worldbank.org/sdgatlas/sustainable-development-goals.html
http://datos.bancomundial.org/indicador/AG.LND.PRCP.MM?name_desc=true&view=map
http://eird.org/americas/news/the-panama-canal-example-of-sustainability-and-water-use-efficiency.html#.WRmjj-UjGyI
http://www.fao.org/3/a-i3442s.pdf
http://www.energia.gob.pa/
http://www.iadb.org/en/topics/emerging-and-sustainable-cities/responding-to-urbanisticas
http://www.industriales.org/economia/perfil-de-la-industrimanufacturera-en-panama. octubre 26 2009
http://miambiente.gob.pa/index.php/es/2013-02-20-08-51-24/biblioteca-virtual
http://micanaldepanama.com/nosotros/cuenca-hidrografica/
http://www.sagan-gea.org/hojared/CAgua.html
http://www.worldgbc.org
https://agua.org.mx/biblioteca/contaminacion-del-agua-por-metales/
https://apronadpanama.blogspot.com/2011/10/el-mercado-de-reciclaje-de-plastico-en.html/
https://empresaambientalgatun.wordpress.com/category/plastico/
https://noticias.gogetit.com.pa/edificios-verdes/

Peru

Peru ranks 17th worldwide in terms of the amount of water available to its inhabitants. However, there is a huge asymmetry between the water supply of Peru and its distribution, since 62% of the population can only access 1.8% of the available water in the country, 34% has access to 97.7% and 4% to 0.5%. The greatest demand for water is for agricultural, industrial and mining activities, leaving only 7% for human consumption. Added to the problems of water pollution, in the past 30 years, water availability has been drastically reduced and its quality has been affected by population growth and the lack of water management.

Parón lagoon in the Huascarán National Park, Peru © iStock

Peru: the double challenge of water quality and water security

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1. Introduction

a. Background

The twentieth largest country in the world, Peru is home to 0.4% of the world population. Although it possesses 5% of the world's surface waters, the combination of the asymmetry of water supply and population distribution means that the United Nations Food and Agriculture Organization (FAO) ranks Peru 17th worldwide as regards the amount of water available per person. In fact, the local situation is very different for the 62% of the population of the country concentrated in the Pacific region, which only has access to 1.8% of available water; the 34% who live on the Atlantic slope with access to 97.7% of available water; and the 4% who live on the slopes of Titicaca and have access to 0.5% of available water nationwide. The greatest demand for water is in the agricultural sector, which accounts for 86%, followed by population use with 7%, industrial use with 6% and mining use with 1% (ANA, 2017). "Water pollution in Peru is as old as the existence of cities, because rivers and seas have served and continue to serve as final disposal points for sewage" (ONERN, 1985). This is due to the impact of the development process, particularly mining, the fishing industry and agriculture, as well as the role of industrial complexes and large cities. The problem was largely overlooked in a country where annual per capita resource availability was extremely high (120,032 m^3/inhabitant/year). However, in the following three decades, as a result of population growth and the lack of water management, water availability was drastically reduced while its quality was also affected (**Table 1**).

The National Institute of Statistics and Informatics of Peru estimates that by 2021, the country will surpass 33 million inhabitants and that by 2050 the population will reach 40 million, which will lead to a greater demand for water and an increasing contribution of

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pollutants to waterbodies. The National Water Resources Plan acknowledged that, "The intensive use of water resources seriously affects the quality of water itself and its environmental environment, and jeopardizes the continuity of undertaking activities that are sustained by water and guarantee its availability" (ANA, 2013: 16).

b. Main water quality problems

Information has been scarce and unreliable for decades. It was only in 1979 that the volume of effluent was acknowledged in an extremely preliminary way. The amount of domestic wastewater discharged into seawater was 503 million m^3/year, followed by discharge from the mining industry into surface water with 244 million m^3/year and industry with 44'650,000 m^3/year. In 1981, effluent from the mining industry into seawater amounted to 43,616,400 m^3/year while effluent from the fishing industry into these same waters totaled 38,590,000 m^3/year (ONERN, 1985). It was also noted that a new type of pollution had emerged in the country as a result of oil exploitation in the rainforest. This occurs as a result of eliminating the saltwater that is extracted together with oil, which is discharged into rivers, affecting the hydrobiological fauna. A case in point is Corrientes River-Loreto, into which 1,300,000 m^3 of saltwater was dumped in a single year (1984).

Figure 1 summarizes the complexity of the problems of water quality, increased by informality, which not only increases the cost of water purification, but also causes several acute territorial conflicts, over either water quality or its quantity.

c. Objectives and scope of the chapter

This chapter describes the state of the art of water quality in Peru, the multiplicity of existing deficiencies, gaps in knowledge, management shortcomings and recent advances. Emphasis is placed on certain successful experiences and possible strategies to replicate in order to reverse water quality problems, thus improving the health of ecosystems and populations, with the aim of achieving water security at all levels.

2. Regulatory framework for water quality and governance

a. Legal framework

The rules for protection and conservation of natural water sources in Peru were instituted in 1969 by the General Water Law (D.L. No. 17752) and its Regulations (D.S. N °261-69-AP), which established six types of water according to their type of use, in addition to the limit values of 23 parameters established for the different types of water. In 1989 this Regulation was modified (D.S. N °007-83-SA), leaving the six classes of water according to their type of use, but modifying the limit values of certain parameters, such as the BOD for Class II.

The bodies responsible were in the Health and Agriculture sectors. However, since 1999, interest in protecting the environment has increased. The Environment and Natural Resources Code was enacted (D.L. No. 613) and fifteen years later, in 2005, the General Environmental Law (Law No. 28611) was passed. Subsequently, in 2008, with the creation of the Ministry of the Environment (MINAM), the Environmental Quality Standards (ECA) for Water were enacted (D.S. N°002-2008-MINAM), in which four categories of use and 16 subcategories were established. These standards were updated several times, most recent-

Table 1. Water Resource Distribution in Peru, 1985-2013

Slope	Population (Inhabitants)		Drained volume (Million m^3)		Availability vs. population ratio (m^3/inhabitant/year)	
	1985	2013	1985	2013	1985	2013
Pacific	10'274,838	18'801,417	34,624.64	34,136.00	3,370	1,816
Atlantic	5'931,366	10'018,789	1'998,751.68	1'895,226.00	336,980	189,167
Titicaca	818,820	1'246,975	10,171.94	6,259.00	12,423	5,019
Total	**17'025,024**	**30'067,181**	**2'043,548.26**	**1'935,621.00**	**120,032**	**64,376**

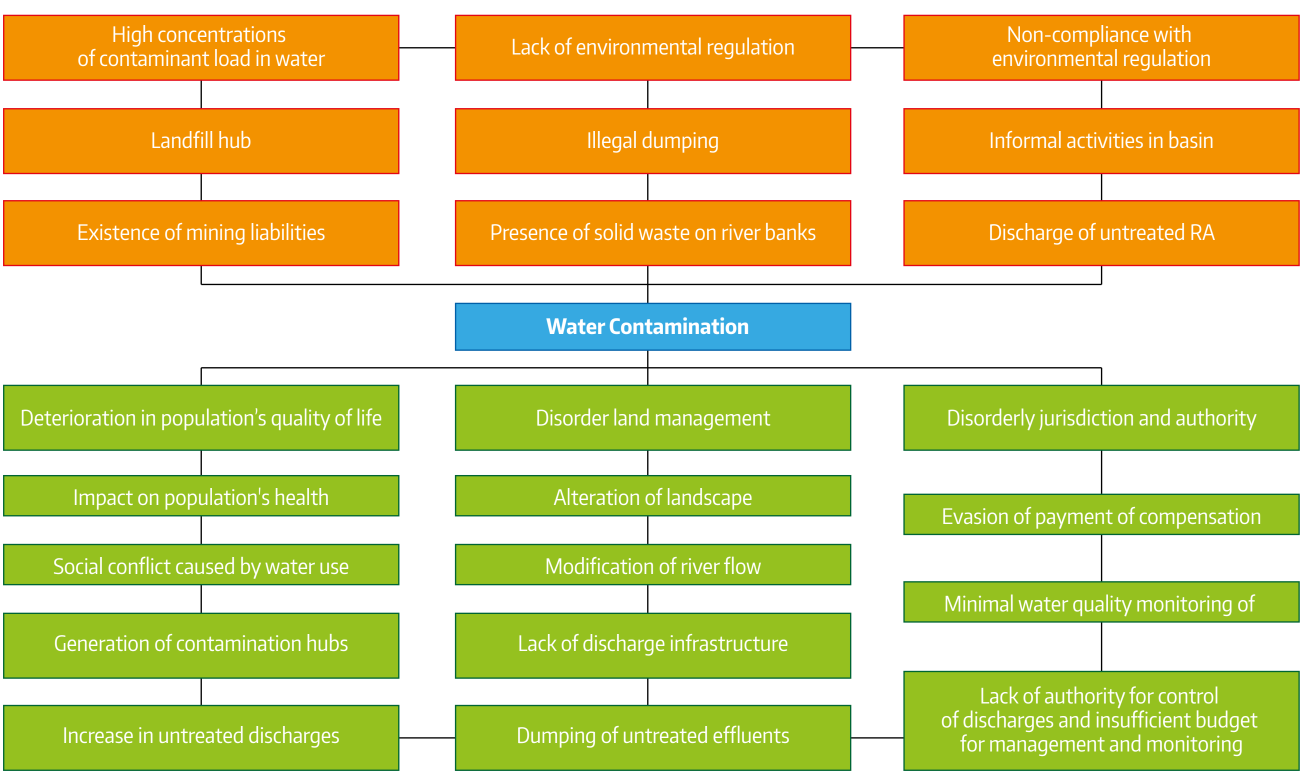
Source : ONERN, 1985: 100; ANA, 2013. Compiled by the authors ly in 2017 (D.S. N°004-2017-MINAM), together with the Maximum Permissible Limits (MPL). However, discharge limits for the manufacturing, agricultural and energy industries have yet to be established. That same year, MINAM created the Agency for Environmental Assessment and Control (OEFA) as a specialized technical body and steering committee for the National System of Environmental Assessment and Control (SINEFA) in Peru.

In 2009, the Law on Water Resources was enacted (Law No. 29338) to replace the General Water Law, designating the National Water Authority (ANA), the governing body of The National Water Resource Management System (SNGRH), as the sole authority. ANA is responsible for the administration of water resources. It grants water use rights, approves authorizations for the dumping and reuse of treated wastewater, conducts water quality monitoring with an annual monitoring plan for basins, authorizes works in natural sources, forms Water Resource Councils and approves their respective Management Plans.

The Law of Water Resources regulates the use and promotes the integrated management of water resources by watershed. The value of water is considered in its economic, environmental and social aspects. The ANA, as the governing body of SNGRH, coordinates the actions of all its members to implement, monitor and evaluate the National Water Resources Plan and its water quality improvement strategy, at the various levels of government. At the institutional level, the Water Resource Quality Management Office of the ANA monitors and produces reports on the quality of surface water circulating in certain stretches of the river.

The Ministry of Housing, Construction and Sanitation (MVCS) is responsible for the National Policy on water, sanitation and wastewater treatment services. It also draws up the investment plan and defines the budget for the sector. The certification of the environmental instrument, a requirement for authorizing the dumping and reuse of treated wastewater, is the responsibility of the General Directorate of Environmental Management of the

Figure 1. Problems of environmental quality in Peru



Source: Ocola, J.J. (2016). Protección del agua - vigilancia y control de vertimientos.

MVCS. In the case of sludge generated in wastewater treatment plants, the Housing sector has enacted Supreme Decree N° 015-2017-MVCS, the regulation for sludge reuse.

The National Superintendence of Sanitation Services (SUNASS) is the supervising body of the Service Provider Company (EPS). It approves the rates and Master Plans of the EPS, and supervises and monitors their compliance, as well as service quality conditions. Since 2017, as a result of the Framework Law for the Management and Provision of Sanitation Services (D.L. N ° 1280), SUNASS has had new functions and competences, not only in the urban area, but also in the rural area, which have gone from "regulating 50 service providing firms, to 28,000 providers, [including] community organizations and municipal management units".

MINAM is responsible for issuing the environmental policy and rules related to the Environmental Quality Standards (EQS) and the Maximum Permissible Limits (MPL) according to the sector or activity. ECAs are a mandatory reference for the design of environmental instruments, plans and activities intended to improve the quality of natural waters. MCVS, together with the Ministries of the productive sectors, are responsible for regulating and approving the environmental instruments, Environmental Impact Studies (EIA) and Programs of Adaptation and Environmental Management of the projects in their environment. The approval of EIAs related to water must also have a favorable opinion from the ANA. In this context, the implementation of MPL and Water-EQS requires establishing a dynamic relationship of coordination between the sectors, the ANA and MINAM.

b. Relations with NGOs, universities and research centers

Since 2011, the ANA has maintained close relations with numerous NGOs for the integration of social projects linked to water management, which various ministries and SUNASS have also done. Several NGOs have been working for over 10 years on water quality management within the framework of integrated water resource management (IWRM). Examples at the regional level include Guamán Poma de Ayala in Cusco, Water for People in Cajamarca, Labor in Arequipa and, at the national level, Soluciones Prácticas, CARE, SPDA, TNC and CONDESAN.

Working closely with NGOs, and often in conjunction with them, are the Church initiatives in various parts of the country, from the Episcopal Commission for Social Action (CEAS) and CARITAS. The Church also has its own experiences involving the water, air and soil quality ("The Mantaro Revives" Project of the Archbishopric of Huancayo), and water quality monitoring (Marianista Project in Otuzco and Sanagoran).

Since 2015, the various repositories of the National Council of Science, Technology and Innovation (CONCYTEC), the National Directory of Researchers and Innovators (DINA), Free Access to Information for Innovation (ALICIA) and the National Register of Researchers in Science and Technology (REGINA), have made it possible to measure the progress made in water sciences, the growing number of master's and doctoral theses, articles and published studies, as well as laboratories (Hydraulics, Fluid Mechanics, Hydrology, Sanitary Engineering, Microbiology, Parasitology, Biotechnology and Water Quality). Likewise, new institutes in water sciences have been created in the past three years, such as the Nexus Institute of the Universidad Nacional San Agustín de Arequipa (food, water, energy and environment), the Center for Water Research and Technology (CITA) of the Universidad de Ingeniería y Tecnología (UTEC), Water Science Institute - ICA, the Universidad Peruana Cayetano Heredia(UPCH) and the Academia Nacional de Ciencias (ANC). A strong interdisciplinary trend and more joint work between academia, firms and the State have been observed. In August 2018, R.J. N ° 237-2018-ANA created the Academic Water Board, comprising representatives of the ANA, 17 national and private[1] universities and the Canadian International Resources and Development Institute (CIRDI).

1. Universidad Peruana Cayetano Heredia-UPCH, Universidad de Lima-ULima, Universidad Nacional Mayor de San Marcos-UNMSM, Pontificia Universidad Católica del Perú-UNALM, Universidad Nacional Agraria La Molina-UNALM, Universidad de Ingeniería y Tecnología-UTEC, Universidad del Pacífico-UP, Universidad Científica del Sur-CIENTIFICA, Universidad Nacional de Ingeniería-UNI, Universidad San Ignacio de Loyola-USIL, Universidad Nacional Pedro Ruiz Gallo-UNPRG, Universidad Nacional del Altiplano-UNAP, Universidad Nacional de San Cristóbal de Huamanga-UNSCH, Universidad Nacional del Centro del Perú-UNCP, Universidad Nacional de Cajamarca-UNC, Universidad Nacional de San Agustín de Arequipa-unas, Universidad Nacional de Trujillo-UNT and Universidad de Piura-UDEP.

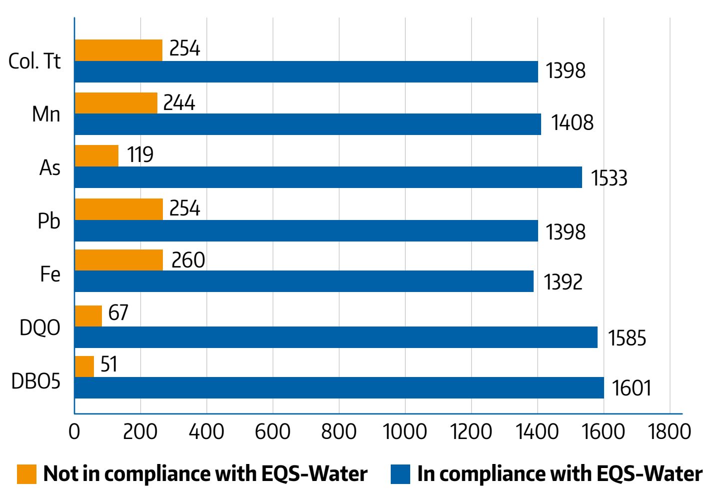
c. Monitoring and data bases

The water quality data are drawn from the monitoring carried out by the ANA in the surface water sources of the basins and sub-basins, as well as the coastal zone (2009 - 2017). Other data are taken from individual studies on the sea, conducted by the Marine Institute of Peru (IMARPE of the Ministry of Production). Other sources are state institutions, such as SUNASS (drinking water quality), OEFA (water quality of surface and groundwater and discharges) and surveillance data from the General Directorate of Environmental Health - DIGESA (2005-2009). The monitoring includes a long list of parameters as part of the surveillance programs of the aforementioned institutions. All results indicate concentrations of the parameters in water at the time of sampling. The parameters characterizing the water of surface bodies are given below:

- Flow (l/s)
- Heat-resistant coliforms
- Conductivity
- Dissolved oxygen (DO)
- pH
- Temperature
- Biochemical Oxygen Demand (DBO5)
- Chemical Oxygen Demand (COD)
- Total phosphorus
- Phosphates
- Ammoniacal Nitrogen
- Nitrites
- Total nitrogen
- Total suspended solids
- Oils and fats
- Metals (list of 26 elements, ICP)
- Total Oil Hydrocarbons (C9-C40)
- Phenols
- Salts (chlorides, sulfates, etc.).

A report on the water quality of ANA, based on the monitoring of 41 basins up to 2015, shows that the parameters exceeding the values of the RCTs-Water were thermotolerant coliforms, BOD5, COD, total phosphorus, ammonia nitrogen, aluminum, iron, manganese, arsenic and lead. These results were found specifically in waterbodies, although not in the entire basin (**Figure 2**). At present, water analyses of the aforementioned institutions are carried out at laboratories accredited by the National Institute of Quality (INACAL). Peru currently has a large amount of data from state institutions.

Figure 2: National monitoring status regarding compliance with Environmental Quality Standards for Water



Source: ANA, 2017. Compiled by the authors *Col. Tt.=Heat-resistant coliforms

3. Main problems impacting water quality

a. Eutrophication

Peru is no stranger to eutrophication. Many of its lentic water bodies have seen an increase in nutrient levels, which initiates this process. Nevertheless, this is still scarcely monitored or studied. In recent years, Lake Titicaca has gone from an oligotrophic to a mesotrophic state, with the Bay of Puno being the most severely affected (Montoya *et al.*, 2015; Komárková *et al.* 2016). This is mainly due to population growth and uncontrolled tourism in the region, which increases the amount of waste discharged into the lake (Fontúrbel *et al.*, 2003, Fontúrbel, 2004). In a study of seven lagoons in the Junín region, Mariano *et al.* (2017) concluded that intensive fish farming is an important factor in the eutrophication process, noting that the Tranca Grande, Cucancocha and Ayhuin lagoons were mesotrophic, while the Habascocha, Tipicocha, Huascacocha and Pomacocha lagoons were eutrophic.

Artificial reservoirs are not unrelated to this problem, with many dams showing signs of eutrophication. According to IMARPE (2008), in the San

Lorenzo dam, areas in the process of eutrophication were found due to the accumulation of waste from the inhabitants of the area, especially the one near the dike. In the Poechos dam, areas in the process of eutrophication were found near the banks. At the same time, reports prepared by the Autonomous Authority of the Chira-Piura Hydrographic Basin indicate the presence of high nitrate values in certain areas, indicating intense eutrophication processes. Matienzo (2014) shows a risk of eutrophication of the waters due to the high concentrations of nutrients in the Jequetepeque River. In a study conducted in October 2014, ANA reported that the Majes-Siguas Special Project dams were eutrophic, in response to which the same Project proposed integral dam management. According to the Participatory Assessment of Water Resource Management of the Chancay-Lambayeque basin (Typsa, ANA and CRHC, 2012), the Tinajones dam shows problems of eutrophication, leading to conflicts over the supply of drinking water to several cities.

In the Peruvian rainforest, lakes and oxbow lakes are also experiencing problems of eutrophication. In this region, it is more common for the process to occur naturally due to the amount of organic matter in the contributing basin, as well as the amounts of sediment transported by rivers. This phenomenon is accelerated by the high temperatures, typical of the region, although it varies according to local hydrology (Riofrío *et al*., 2003).

b. Natural contaminants

The main natural trends in the current hydrological cycle in Peru are oxygen loss and local acidification of coastal marine water in the Pacific Ocean, the continual increase in desertification along the western slope of the Andes, tropical rain with high Andean snowfalls due to the South American summer monsoon and the evapotranspiration of Amazonian forests with possible wind and rain currents of Southwest Atlantic origin. The continuous weathering of the high-Andean mineralized regions produces sulphated acidic waters with a variable metallic load of arsenic, antimony, copper, lead, zinc and, occasionally, mercury. In Peru, the waters of the Caplina-Tacna river basin have naturally high concentrations of arsenic, which is related to the presence of volcanic rocks and thermal springs that emerge in the Western Cordillera (Carlotto, 2014). This pattern is also observed in other stretches of recent volcanism with hydrothermal activity in the Circum Pacific Ring of Fire (Vidal and Cedillo, 1988).

In the oceans, and within the 250 territorial miles, the Humboldt and El Niño currents interact and mix. The annual interaction of these marine currents has a clear paleontological expression in the stratigraphic record of the formations in the Neogene of Sullana and Pisco. These regions have diatomites interspersed with phosphates, both biogenic and sedimented in underwater basins. Phosphates have extensive fauna and flora as evidence of mass mortality events and cycles due to drastic changes in the temperature, pH and salinity conditions of ocean currents. Diatomites register normal events involving a mixture of currents with massive mortality of algae alone. Global knowledge of these natural phenomena at sea shows that they are a consequence of the encounter between marine currents. In coastal ecosystems, there are indications that the mass marine mortality cycle could resume in a few decades, as a consequence of the deoxygenation and eventual acidification of the Pacific Ocean on the coasts of Peru and Ecuador (Alvites, 2016, Fischetti & Christiansen, 2018, Heffermann, 2018).

On the mainland, precipitation weathers, erodes and then transports rocks, sand, clays and soluble salts in variably acidified drainages with an anomalous load of metals when it flows through countless polymetallic mining districts. These regions cover between 5,000 and 25,000 hectares each, are of hydrothermal magmatic origin and are grouped into metallogenic strips of different geological ages, and principally developed during the subvolcanic Cenozoic of the Western Cordillera. In particular, the great arsenic anomaly of certain rivers is known and documented, such as the Chancay-Lambayeque river in Cajamarca (INGEMMET, 2017, Bernex and Korswagen, 2014). Locally, these sulphated waters carry anomalous concentrations of copper, lead, zinc and/or mercury in certain stretches of their watercourses. There is no systematic mapping of the 150 to 200 mining districts and only those currently under exploration or exploitation have meteorological stations and monitor water and effluents (Boltan, 2017, Bernex, 2017). The same is true of most watersheds that do not have sufficient water resource monitoring or management (Bernex and Yakabi, 2016).

Evolution by natural tendencies is complex, poorly documented and requires more hydrogeological, geochemical and geophysical studies. The most advanced recent efforts are in the ANA, the INGEMMET, the Geological Society of Peru, but also in NGOs such as Oxfam and international efforts focused on anthropogenic pollution, such as the Global Alliance on Health and Pollution (GAHP) (Lancet Commissions Report, 2017).

c. Agrochemicals

In Peru, agriculture is the productive activity contributing the largest amount of nitrogen and phosphorus. Despite the fact that over two million hectares are under irrigated agriculture, studies on the impact of fertilizers on water bodies are almost non-existent. There are only periodic evaluations of fertilizer use in the country. However, for a couple of decades or less, the measurement of some of the chemical forms of nutrients in water (NH_4^+, NO_2^-, NO_3^-, total N) has been included in monitoring programs. Nevertheless, owing to the lack of knowledge of their effects they were not given the required attention. The 2012 agricultural census indicates that some 971,200 producers (43.9%) use chemical fertilizers, a 50% increase over 1994. In 2013, a total of 905,798 tons of these products were imported (urea, nitrates, sulphates, phosphates), with 75% being used on the coast, 20% in the mountains and 5% in the rainforest. Likewise, during the past decade, the national supply of fertilizers has increased, with an upward trend that is expected to reach approximately 1,200,000 tons in 2018.

At the same time, approximately 1'370,000 agricultural producers (62%) use some type of organic fertilizer, employing a total of 19,700 tons in 2012. Although there is no evidence of a greater increase, they must be taken into account because of their contribution of nutrients and their actual or potential transfer from agricultural wastewater to natural water bodies. The most commonly used fertilizers available on the market are phosphate compounds, ammonium salts, potassium and magnesium salts, and urea, the latter being the most commonly used ones in 2012, followed by ammonium phosphate and superphosphates (polyphosphates), all with a high content of nitrogen, phosphorus or magnesium and potassium salts (sulphates and chlorides).

The contribution of nutrients and salts from agricultural activity, through wastewater from the activity, affects water resources. On the one hand, they are a potential source of contamination for groundwater which, in some cases, exceed the limits of nitrites and nitrates, making them unfit for human consumption, while on the other, they cause the eutrophication of water bodies, impairing water sources.

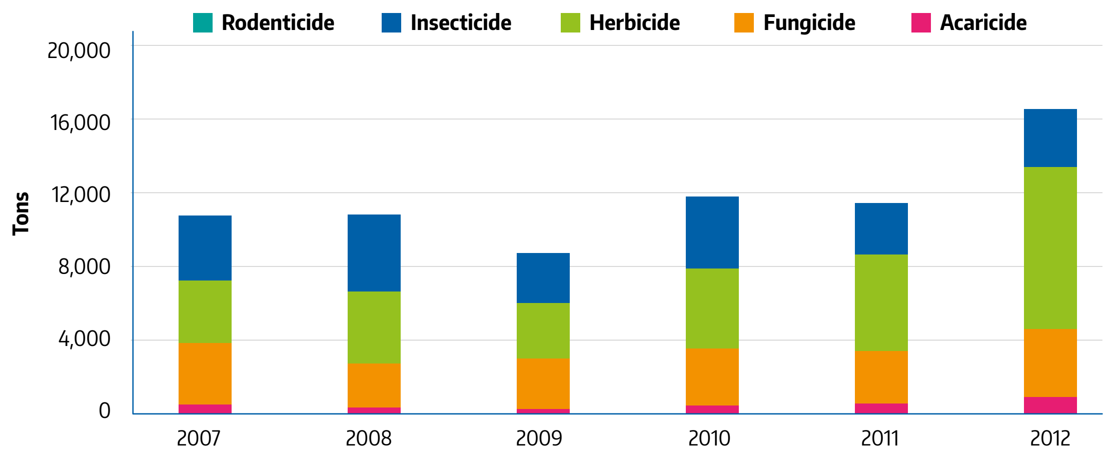
In the case of pesticides, there are no studies or estimates in Peru of the amount of pesticides released into the environment, or studies to determine the compounds and amounts that could be reaching surface or groundwater, much less research on their effects on ecosystems and public health. The only means of estimating this figure, as in the case of fertilizers, is through the data on the amount of pesticides imported (**Figure 3**), although this is also distorted by illegal commercialization, contraband (northern border), street vending in various regions of the country, falsifications and adulterations (north coast, central and southern highlands). in 2012, the national supply of pesticides increased, reaching a value of 16,474 tons (INEI, 2013) of imported products. Although the existence of companies that imported or formulated pesticides was also reported, none of them acknowledged having acquired, imported or commercialized POP pesticides in recent years (CONAM, DIGESA and SENASA, 2006). Although there is no updated information on this point, there is likely to be clandestine use and marketing in addition to the increase and formal use of registered pesticides.

d. Heavy metals

The evaluation of water quality carried out by ANA (2012) considered physical-chemical parameters (pH, electrical conductivity, BOD, and metals such as Lead, Mercury, cadmium, iron, copper), metalloids (arsenic) and microbiological (heat-tolerant coliforms), due to their use as environmental indicators of the impact on natural waterbodies.

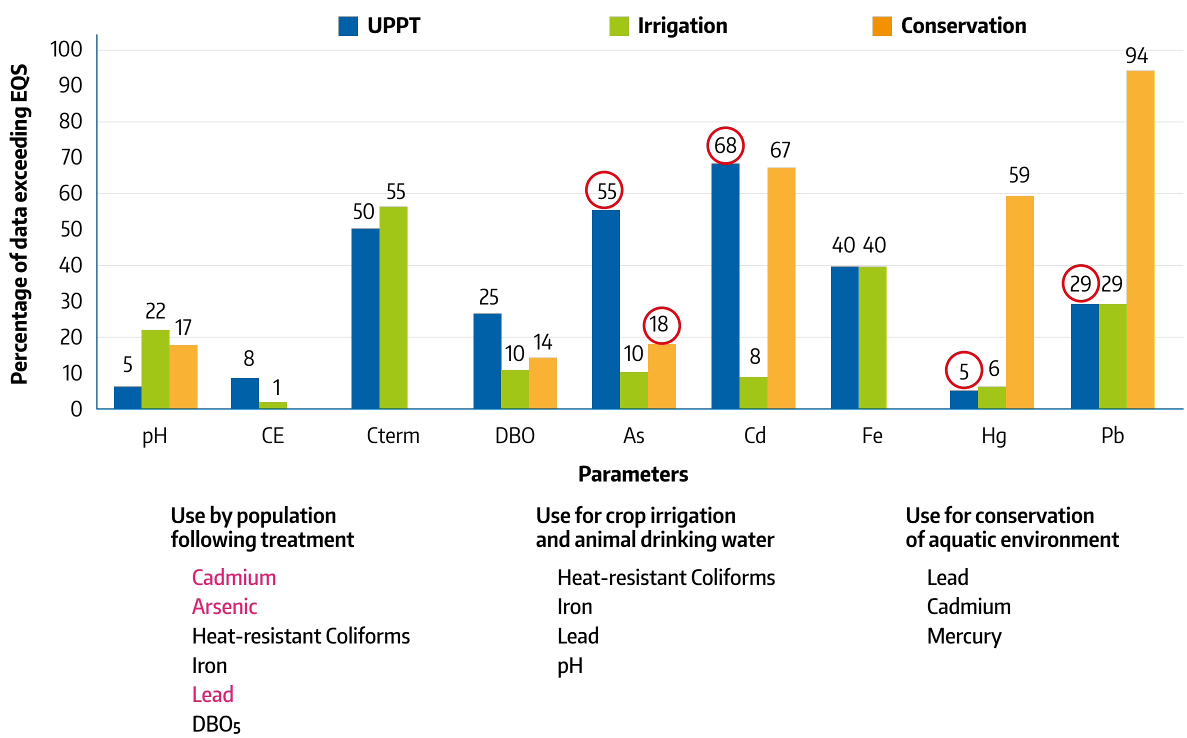
The results obtained on the quality of water resources in the period 2000-2012 show that the heat-tolerant coliform parameters, arsenic, lead and cadmium are affecting the quality of water resources for irrigation (in the three slopes) and population purposes (Amazon and Pacific regions). Likewise, heat-tolerant coliform parameters, BOD_5

Figure 3. Importation of pesticides for agricultural use by type (use), 2007-2012



Source: MINAGRI, 2015 - National Service of Agrarian Health (SENASA).

Figure 4. Waterbodies that exceed environmental quality standards in percentages, by type of use nationwide



Source: Castro de Esparza, 2016.

and lead (Amazon hydrographic region); BOD5, cadmium, arsenic and lead (Pacific region), and pH, arsenic, cadmium, lead and mercury (Titicaca region), have also affected the quality of water resources for the conservation of the aquatic environment. The parameters in question are associated with discharges of wastewater from the population, mining environmental liabilities, informal mining and others related to the natural characteristics of the watersheds (**Figures 4 and 5**).

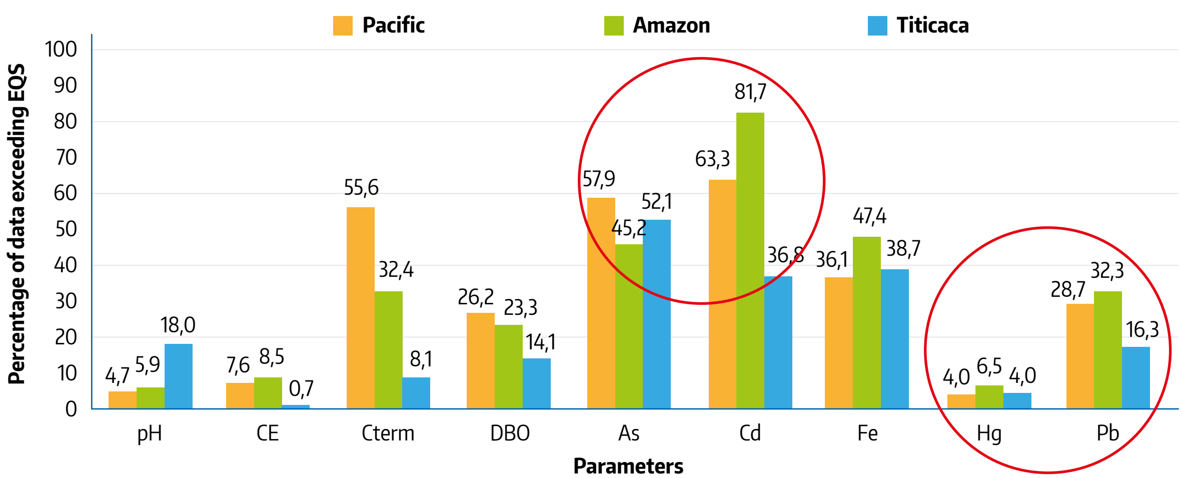
Lead, cadmium, arsenic and mercury are the main elements that create concern for public health. Thus, lead is found in high concentrations in Cerro de Pasco and La Oroya, arsenic in groundwater in Tacna, mercury in Madre de Dios due to informal and illegal mining, and cadmium with wider dissemination due to the use of contaminated fertilizers and the elimination of batteries in the environment. Sánchez *et al*. (2013) reviewed five studies - between 2005 and 2013 - where thirteen elements were analyzed in urine samples from Peruvian communities regarded as exposed and unexposed. Elements such as arsenic, cesium, cobalt, molybdenum and lead were present in almost all the samples of the participants evaluated, confirming exposure. The percentage of people with confirmed exposure to other elements varied between locations. This situation must be analyzed in greater detail, and requires immediate preventive actions to avoid the exposure of populations and prevent poisoning. None of this can be achieved without the participation of the central government, public and private institutions, and the population in general.

e. Deforestation

In Peru, between 75 and 90% of deforestation is associated with slash-and-burn for small-scale agriculture (territories <5 ha) and large-scale agriculture. The first is characteristic of populations that migrate, mainly to the Amazonian regions to expand the agricultural frontier for commercial and subsistence purposes. In the case of the deforestation of the Amazonian forests, in addition to the loss of biodiversity and natural resources, a series of impacts associated with the deterioration of the functions of ecosystems in the availability and quality of water, loss of fertility and erosion, reduction of CO2 fixing, increased vulnerability to climate change and alterations of landscape beauty have been identified. In the Peruvian Amazon, coffee and cacao are the main crops associated with deforestation, as well as livestock activity (GGGI, GDI and SERFOR, 2015).

Deforestation, whose objective is the change of land use for agricultural or livestock purposes, generally results in an increase in the rates of surface runoff, soil erosion with the consequent loss of nutrients (Croke & Hairsine, 2006; Creed *et al*. al.,

Figure 5. Waterbodies for population use that exceed environmental quality standards, in %, by hydrographic region



Pacific H.R.
- Cadmium
- Arsenic
- Heat-resistant Coliforms
- Iron
- Lead
- DBO_5

Amazon H.R.
- Cadmium
- Iron
- Arsenic
- Heat-resistant Coliforms
- Lead
- DBO_5

Titicaca H.R.
- Arsenic
- Iron
- Cadmium

Source: Castro de Esparza, 2016.

2011) and the loss of organic carbon (Wang-Erlandsson *et al*., 2014). Although there are numerical experiments that evaluate and quantify the potential impact of deforestation on water resources in the Amazon (Coe *et al*., 2009), in 2005, the work of FAO and CIFOR (Center for Forest Research) indicated the physical effects of water erosion (turbidity), but without quantifying them systematically.

The number of specific studies oriented towards changes in water quality due to deforestation is limited in Peru. Probably, one of the most important is the study developed by Lindell *et al*., (2010), which evaluates the quality of water in the output of 48 basins in the Andean Amazon transition in northern Peru. This study undertakes a quality assessment, considering natural factors that characterize the hydrochemistry of rivers and deforestation. The most important conclusions are that, between 396 and 1649 m.a.s.l., lithology plays a key role in water chemistry, explaining >70% of the variations in potassium concentrations and a considerable part of manganese, uranium, magnesium and HCO_3, with concentrations increasing exponentially as the altitudinal gradient is reduced. Forest cover varies between 7% and 99% in the basins studied, but the authors do not observe a significant impact of deforestation on the concentrations of the solutions in the river studied. However, these observations should be contrasted with current studies and an effort made to generate information to determine the natural conditions of channels in the southern Peruvian basins, where deforestation may expose mineralized lithologies that will have a greater impact on the amount of water. In general, the impact of deforestation on the quality of water resources in Peru is perceived by the population through parameters such as turbidity. However, studies must be undertaken and in some cases compiled and systematized in order to provide scientific evidence of the actual impact.

f. Salinization

Since the 1970s, there has been no updated information at the national level regarding the issue of salinity. In 1973, ONERN recognized that 306,701 ha were affected by salinization. According to the information compiled by the National Development Institute (INADE), at that time Peru had approximately one million hectares suitable for irrigation on the Peruvian coast, of which about 750,000 hectares were cultivated, nearly half of which had problems of salinity and poor drainage. Brack observed, 25 years later, that about 40% of the irrigated soils of the coast were affected by over-irrigation and that mineral salts (chlorides and sulphates) surface as a result of poor drainage conditions (Brack and Mendiola, 2004). According to Pastor (2010), the salinization of agricultural soils in the coastal areas of Peru is a contaminating process that is on the increase. For this reason, small agriculture has financial limitations for addressing the problem. Moreover, this part of the country is characterized by sandy soils, with the exception of certain fertile valleys, whose source of water comes from rivers in the Pacific basin. Its climate is arid and characterized by low rainfall; Therefore, since water is a scarce resource, the possibility of developing this part of the country will depend on the implementation, administration and management of water resources. ANA recognizes that, "as a result of the excesses of irrigation water used in many of the valleys of the coast, in the lower part of these valleys, this has led to the elevation of the water table and the salinization of major agricultural areas, which represent agricultural environmental liabilities and require remediation actions" (2016).

g. Wastewater

Point sources include industrial and domestic waste, the use of cleaning and beauty products, and food residue that contaminates surface waters. Wastewater is usually expected to be treated at treatment plants, although in Peru, it is often discharged directly into rivers, with no form of treatment. This is compounded by the non-point sources formed by the runoff from agricultural lands (chemical fertilizers) and urban areas and the erosion of deforested lands and forests, which are difficult to control and not usually taken into account. The level of the impact of discharges in their various forms into surface water will depend on the size of the population, the degree of commercial and industrial development, the level of treatment of municipal and industrial wastewater, and the intensity of agriculture.

In 2016, 61% of the national population had sewage systems; the production of wastewater was in the order of 960.5 MMC/year (30 m^3/s) and only

20.62% was treated (198 MMC/year); 4,761 MMC/year were discharged directly into rivers, lakes and coastal marine areas. Between 2010 and July 2016, ANA has identified 4147 polluting sources in the monitored basins; 45% of which corresponded to the hydrographic basins located in the Pacific Slope and 55% to the hydrographic basins in the Titicaca and Amazon slopes. Of the total polluting sources, 90% correspond to domestic wastewater and 10% to industrial wastewater (mining tailings, solid waste dumps, industries, etc.).

From the volume of water use in the country, one can infer that the sectors that generate the greatest volume of wastewater are the sanitation sector, which has incentives for the treatment of its wastewater, followed by the mining, fishing, industrial beer, paper, cement and tannery sectors, all of which have MPL for their discharge into the environment. The hydroelectric and agro-industrial sectors have yet to formulate discharge limits. Firms whose discharge authorizations have been approved total 586, according to ANA. The largest volume of discharge of treated water is from the sanitation sector, but in number, more mining companies comply with this environmental procedure. As for the other sectors, there is an increasing number of firms requesting authorization for their discharges to protect the quality of surface water. The challenge of the country shared by all sectors is to implement efficient treatment systems in accordance with the pollutants they generate, so that they do not damage the quality of our water sources. MPL are economic-environmental instruments that must be complied with and EQS are environmental instruments that must be implemented.

h. Leaching into groundwater and surface water bodies

With respect to water quality in relation to leaching processes, there are limitations such as the lack of existing information on the subject, the disinterest by the regulatory entities in the country, coupled with the lack of methodologies to control the leached material. One of the efforts aimed at addressing this issue analyzes groundwater contamination as a result of the generation of leachates from the decomposition of bodies buried underground in a district south of the city of Lima (cadaverine, putrescine and pathogenic viruses). Although no contamination of the waters in the aquifer has been found, it is striking that the regulations and methodologies to address this issue are still incipient in the country (Espinoza, 2007).

Perhaps the most important activity affecting the quality of water through leaching processes is agriculture. The continuous or excess application of fertilizers acidifies soil, promotes erosion, affects organisms (flora and fauna) and alters the physical-chemical properties of soil. Thus, chemical compounds applied through fertilizers dissolve in the soil solution, are retained by clays and organic matter, and filter through to waterbodies as a result of the porosity of the soil. Salts and acids that reach waterbodies affect their physical-chemical properties. Evidence indicates that certain wells on the Peruvian coast exceed the concentration of nitrates, which must be related to the use of fertilizers or organic matter that is mineralized (Legua *et al*., 2016).

Another critical factor is the impact on water quality of mining activities. Historically, mines in Peru have been abandoned, leaving the area in a similar condition to when they were operating. In other words, tunnels, open pits, tailings dams and tailings have been left outdoors, subject to flooding, erosion, the generation of acid waters and progressive soil destabilization. Accordingly, the country's environmental liabilities are a potential source of toxic substances that can be leached from these facilities, and cause the contamination of the surface and groundwater into which they discharge (Tovar, 2007). Elements that can be infiltrated included arsenic, lead, cadmium, chromium, nickel and cyanide (if used in the leaching process). Although some water quality data are available with these parameters, it is still necessary to improve understanding of this issue and the regulations governing it. A major contribution for the country would be to develop a methodology that considered exposure to the leaching of materials, which can determine the application of weighted ranges to calculate the level of vulnerability of aquifers whose waters are used to supply cities.

i. Emerging pollution

Emerging pollutants are unregulated chemical substances or biological agents, whose presence in the environment is not necessarily new. What is new is the concern over their possible consequences for aquatic ecosystems and human health. Examples of emerging contaminants include drugs, hormones, abused drugs, and personal care and hygiene products, among others (Petrie *et al.*, 2015). These substances are introduced into the environment through residential and industrial wastewater, waste from treatment plants, and effluent from hospitals, agricultural activities and veterinary use.

In particular, the unregulated sale and use of antibiotics for human and animal health, and their possible introduction into aquatic ecosystems, promote the evolution of antibiotic-resistant pathogens and contribute to this global public health problem (WHO, 2014). A recent microbiological study of peri-urban communities in Lima showed that several classes of antibiotics can be detected in treated wastewater, and that hundreds of bacterial resistance genes derived from human excreta and environmental organisms can survive treatment systems and be reintroduced into soils and surface waters through the use of treated effluent (Pehrsson *et al.*, 2016). Similar studies are being conducted in hospitals and communities in other parts of Peru to determine the scope of this problem and its temporal and geographic variation.

There is also growing interest in the study of free-living amoebas as contaminants of aquatic systems. These are eukaryotic microorganisms capable of growing in a wide range of aquatic and terrestrial environments, and include species with high pathogenicity in humans, such as *Acanthamoeba*, mainly the genotype T-4, *Naegleria fowleri*, *Balamuthia mandrillaris*, *Sappinea pedata* and, more recently, *Paravahlkampfia francinae*. (Hoffman & Michel, 2001). All these amoebae can be called "brain eaters", because they cause substantial destruction of the brain mass. In addition to the first three highly pathogenic species, there are *Vermamoeba vermiformes*, *Vanellas* sp. and *Vahlkampfia* sp., all of which are capable of harboring pathogenic bacteria in humans. These free-living amoebas exist in any habitat, but they move faster through waterbodies. In Peru, preliminary studies have shown that cerebral amoeba infections are more common than described in global prevalence studies. Amoebae associated with cases of primary acute meningitis and granulomatous meningoencephalitis have been identified, both of which have lethal consequences. No standard treatment is available, and the immunological processes that predispose humans to acquire the infection and subsequently the disease caused by these free-living amoebas are not known. The main sources of infections were always associated with direct contact with water (Cabello-Vilchez, 2016). These studies suggest that aquatic systems in Peru harbor multiple microorganisms with pathogenic potential and contain a large number of antibiotic resistance genes that can be exchanged with human and animal pathogens. Diagnostic methods with greater sensitivity and new tools based on molecular biology and genomics will provide a better description of these emerging pollutants and their possible effects on health and the environment.

4. Social and economic aspects

a. Human health and water quality

Access to drinking water is fundamental to health, a basic human right and a component of effective health protection policies. Most health problems related to water are due to contamination by microorganisms (bacteria, viruses and protozoa), although there are a considerable number of serious problems resulting from the chemical contamination of drinking water.

The presence of bacteria in water has almost always been studied. *Escherichia coli* (fecal coliform bacteria) has been used as the principal indicator of contamination, which makes it possible to determine the level of water quality to decide whether or not it is suitable for human consumption. However, little or nothing is known or has been studied about the presence of protozoa in this same source. Protozoa are capable of harboring many bacteria and/or bacterial groups, including viral particles such as rotaviruses (which cause diarrhea in newborns). In addition to classic bacteria, there are also environmental mycobacteria capable of causing hospital-acquired diseases, which are usually difficult to identify because other types of bacteria (Gram positive) go through them. Cabello-Vilchez (2016) has identified 1000 CFU/1L of Mycobacteria sp. in drinking water at a hospital in Lima. These data could give an idea of the levels of bacterial contamination that usually go unnoticed in microbiological control guides. Likewise, the presence of free-living amoebas is usually undetected, either because of the small number of microorganisms or simply because these organisms are not sought.

The situation worsens when there are high levels of malnutrition and anemia. INEI (2017) reported that the prevalence of chronic malnutrition, according to the World Health Organization standard, is higher in rural (25.3%) than urban areas (8.2%). It also indicates that the highest rates of malnutrition were reported in children with mothers with no schooling or only with primary education (27.6%) and in children under three (13.6%). A fluctuating decline in the number of children under 5 affected by acute diarrheal diseases can also be observed (**Figure 6**). These variations can be explained by external factors such as droughts, floods and pests, which affect the quality of life in general, including water and generate greater vulnerability in human health.

It is estimated that 54% of the rural population access potable water service through indoor connections and that 21% have sewerage systems, although only 3% of the latter are in good condition. Although the use of sanitary latrines is fairly widespread, most are not used properly. Four out of 10 children under 5 do not have access to clean water, all of whom are from rural families. However, there are many other water-related diseases "caused by the ingestion of water contaminated by human/animal excreta that contain pathogenic microorganisms or water contaminated by chemicals". The latter may be infectious, toxic or indirectly related (Cabezas, 2018) (**Table 2**).

The average annual cost of the effects of the deficiencies in water quality, sanitation and hygiene on environmental health amounts to 3,300 million soles (World Bank, 2013). According to Larsen *et al.*

Figure 6. Children under 5 affected by acute diarrheal diseases

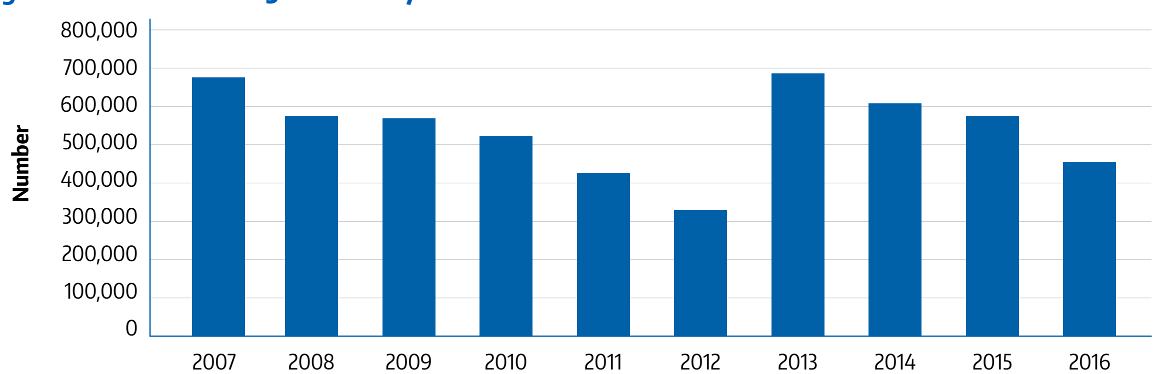
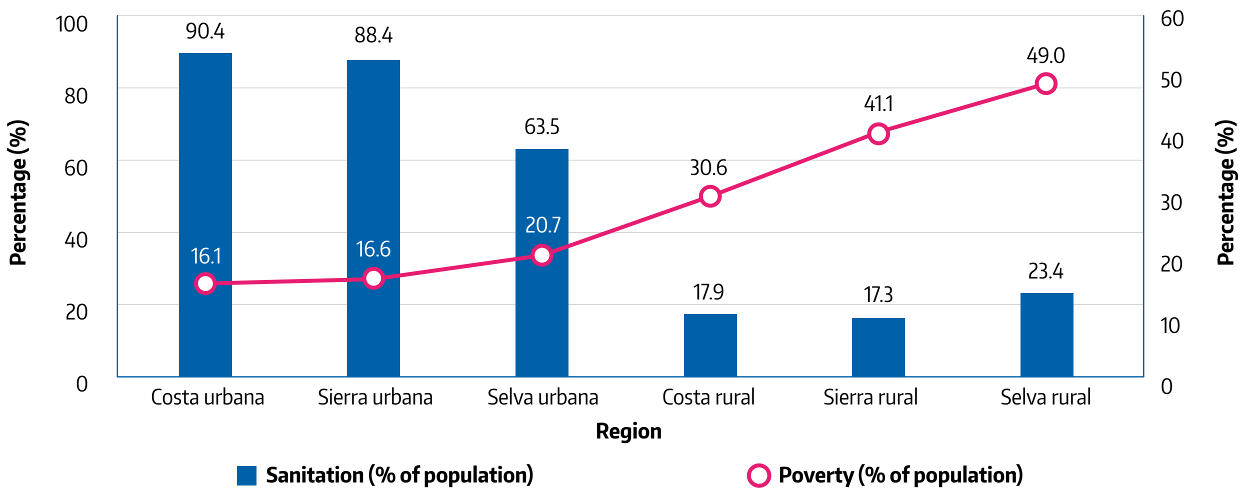


Table 2 Water-related diseases

Type Of Diseases	Explanation	Examples
Water-borne	Fecal contamination	Cholera, typhoid, salmonellosis, *Helicobacter pylori* infection, Hepatitis A and E, poliomyelitis, amoebiasis and enteric organisms
Water-based	Organisms that spend part of their cycle in water	Fasciolosis, paragonimiosis, Schistomiosis, Dracunculiosis
Water-related	Vectors that breed in water	Malaria, dengue, Filariasis, Onchocerciasis, Yellow fever, Arbovirosis (Mayaro, Oropuche, EEV)
Water-washed	Related to poor personal hygiene and contact with contaminated water	Pediculosis, ricketssiosis, scabies, trachoma, conjunctivitis, leptospirosis, free-living amoebas, typhus, diseases transmitted by ticks
Water-dispersed	Organisms that thrive in water and enter through the respiratory tract	Legionella

Source: Cabezas, 2018, modified.

Figure 7. Relationship between access to sanitation and poverty (% of population), 2015



Source: ENAPRES, 2016. Compiled by: Institute of Peruvian Studies.

(2013), the number of annual deaths stands at 1073 and the average number of sick days due to environmental risk factors totals 61,549 (2012). In addition to being a mining country for centuries and have mining waste, Peru has accumulated waste from the significant presence of illegal mining in all the departments in the country, as well as mining operations without social and environmental responsibility, which have a severe impact on human health.

b. Poverty

Globally, Peru has made great progress in reversing the extremely high rates of poverty and extreme poverty that existed until 2001. At that time, the percentage of poor people accounted for 54.8% of the total population, and while the incidence of poverty in cities was 42%, in rural areas of the country, nearly eight out of every 10 inhabitants (78.4%) lived in poverty. In the rural Sierra, 83.4% of the population survived in poverty (INEI, 2002). However, as indicated in **Figure 7**, areas with the greatest poverty have the lowest access to sanitation rates and therefore, the highest rates of Acute Diarrheal Disease (ADD) and hygiene-related diseases.

Likewise, the harsh conditions experienced by towns in rural areas were observed. Only 2.2% of them have access to safe water, while the departments of Tacna, Madre de Dios and Tumbes have the highest levels of safe drinking water. (**Figure 8**).

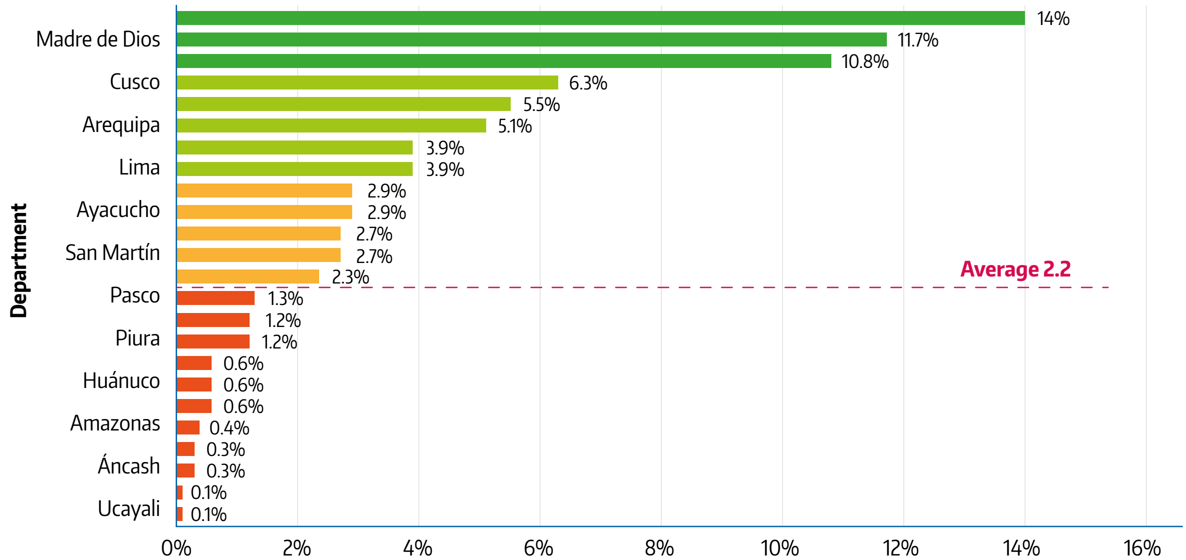
c. Education levels in communities

Peru is among the countries in the Americas that invest least in education, with $20,114 USD per student between the ages of 6 and 15 (2015). This average masks the criticality of the situation of education in rural areas and the importance of existing gaps. Drop-out rates, isolation and widespread poverty combine with multiple shortages of well-trained teachers, materials and infrastructure. The 2017 Education Census of the Ministry of Education (MINEDU) indicates that regular basic education in rural areas comprises over 51,260 institutions, which serve 1,234,449 students (16% of national students) (MINEDU, 2017). It specifies that 42% of total rural enrollment and 80% of rural primary enrollment are in multigrade schools (48% of national Institutes of Education (IE), as a result of the atomization and dispersion of population centers. "However, despite the advance in the expansion of coverage, a considerable population of students -mainly in the Amazon- still lack access to complete basic education and more institutions are required at the secondary and initial levels".

d. Gender

Despite being the second country in South America to have developed its IWRM policy and strategy in 2009, creating normative instruments that reflect the Dublin principles, Peru failed to inte-

Figure 8. Population with access to safe water in the rural sector (%), in 2015



grate the gender dimension into its last Policy, reviewed in 2015. Nowadays, numerous public institutions supported by companies, academies and civil society are helping to fill this gap. In rural areas, 95% of sanitation service providers are chaired by men and 5% by women, according to the diagnostic sheet of the MVCS (SUNASS, 2018). The promotion of the equal inclusion of men and women in decision-making positions within the sanitation sector would help to ensure more equitable conditions in water and sanitation management and access. As noted by Ricalde (2018), "At the level of the JASS, women should play their role as facilitators in the implementation of follow-up and monitoring actions in the performance of tasks related to the promotion of families in healthy housing". However, there are some women who, in addition to participating in 25% of the management positions of the organizations established (committees, boards and associations), attend various health education and hygiene workshops. They also participate in training sessions for boards and other associations and grassroots organizations (the "Glass of Milk" subsidy Program, mothers' clubs, health promoters and parents associations) addressing a wide range of issues (education and community health, habits, water, use of latrines, solid waste), which contributes to improving the quality of life of their homes.

e. City and countryside

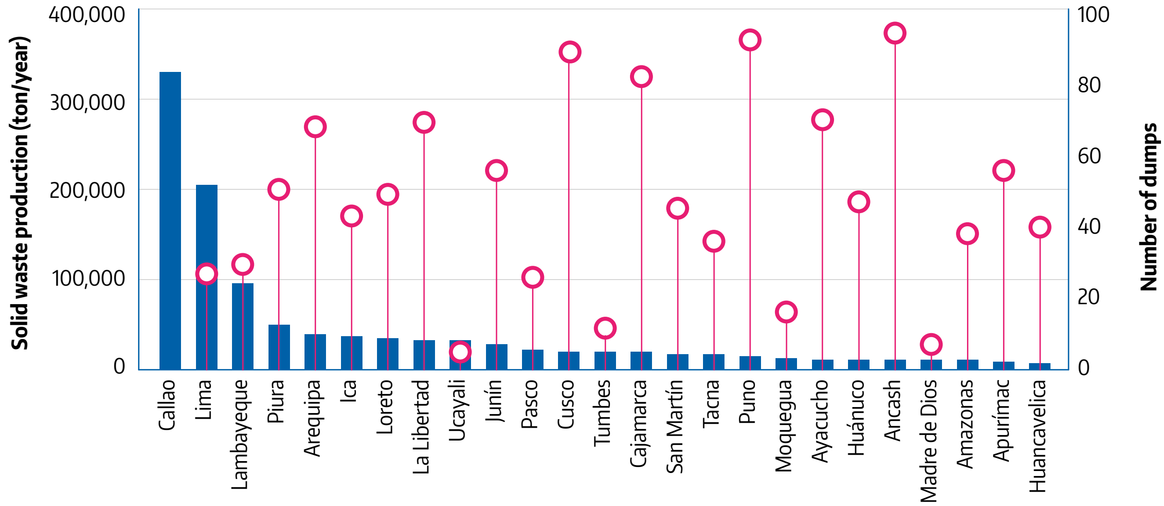
In urban and rural areas, water quality is severely affected by the poor disposal of the solid waste generated, which, during its decomposition, generates by-products in the form of liquid and gases (leachates), which alter the quality of water. Information on the volume of solid waste generated is only available for urban areas, through what was declared by local governments in the Information System for Solid Waste Management (SIGERSOL). In 2015, over 7.5 million tons of solid waste were produced, 64.8% of which was residential, while the rest came from the industrial, commercial and other sectors (SINIA-MINAM). Lima Metropolitana[2] and Callao account for 56.9% of solid waste production (**Figure 9**).

According to D.L. N °1278,[3] the final disposal of solid waste must be carried out in landfills. However, the only departments equipped with this infrastructure are Lima (3), Callao (1), Ancash (2), Cajamarca (1), Junín (2), Loreto (2), Ayacucho (3), Huancavelica (2), Huánuco (2) and Apurímac (3), which receive less than 50% of the solid waste generated annually (MINAM, 2016). The remaining volume has different final destinations: one part is recycled, but an-

2. The value of the solid waste produced by Metropolitan Lima was omitted, since it obscured the other regions.

3. Legal instrument enacting the Law of Integral Solid Waste Management.

Figure 9. Solid Waste Production (ton/year) and number of dumps nationwide (2015)



Source: National System of Environmental Information, Solid Waste-Statistics (Barras: generación de RR.SS. Puntos: número de botaderos). MINAM, 2012. http://sinia.minam.gob.pe/temas/residuos-solidos/estadisticas/#

Table 3. Types of state investment in water and sanitation, 2017

Concept	Percentage
Investment in expanding coverage	80.1%
Investment in rehabilitation	16.2%
Investment in strengthening business and micro-measurement	3.7%
Total	**100%**

Source: D.S. Nº 018-2017-Housing.

other large part is disposed of in open-air dumps, burned or incinerated, or dumped into natural waterbodies, with harmful consequences for the environment and people's health (such as the spread of pathogenic microorganisms, heavy metals, toxic substances and hydrocarbons found in leachates from waste). The presence of organic matter occurs in all productive sectors. Compounds are generated through bacteria and microorganisms, which acidify water, eliminate vital oxygen for aquatic species and make water unsuitable for human consumption, which also creates health problems. Groundwater is also affected by solid waste on the surface, due to the infiltration of leachates through soil. However, water quality is only monitored in a few cases. Water surveillance coverage is much greater at the urban than the rural level, where northern regions and forest departments have less surveillance coverage: of under 30%.

f. Investment in water quality programs

In the 2017-18 report submitted to Peruvian Congress on July 28, 2017, the Peruvian Government recognizes three concepts of investments, presented in **Table 3**. In order to reverse the existing gaps between city and countryside, the Government of Peru approved the National Sanitation Plan (D.S. No. 018-2017-HOUSING) and determined the amount of investment required for narrowing existing gaps.

In recognition of this, the 2017 budget has increased by 72% over the previous year, the largest increase in the past ten years. Several mechanisms have also been created, such as the Safe Water Investment Fund (FIAS) (D.L. No. 1284), designed to finance programs, projects and activities whose purpose is to narrow coverage gaps in water, sewage and wastewater treatment nationwide, as well as to improve the services EPS currently provide. A Financial Study for Water Projects in Peru was undertaken, which analyzed the financial instruments available at the national and local levels, which promote private and public investment for the implementation of water projects (**Figure 10**). The goal is to prioritize investments and develop financial solutions to undertake the most effective projects. MERESE (Law N° 30215, Law of Mechanisms of Compensation for Ecosystem Services), were created, which are financial mechanisms designed to preserve, recover and sustainably use ecosystems that provide ecosystemic services. At present, there are 22 MERESE Water cases in which information is being collected for their design and development.

g. Industry, mining, agriculture and other sectors

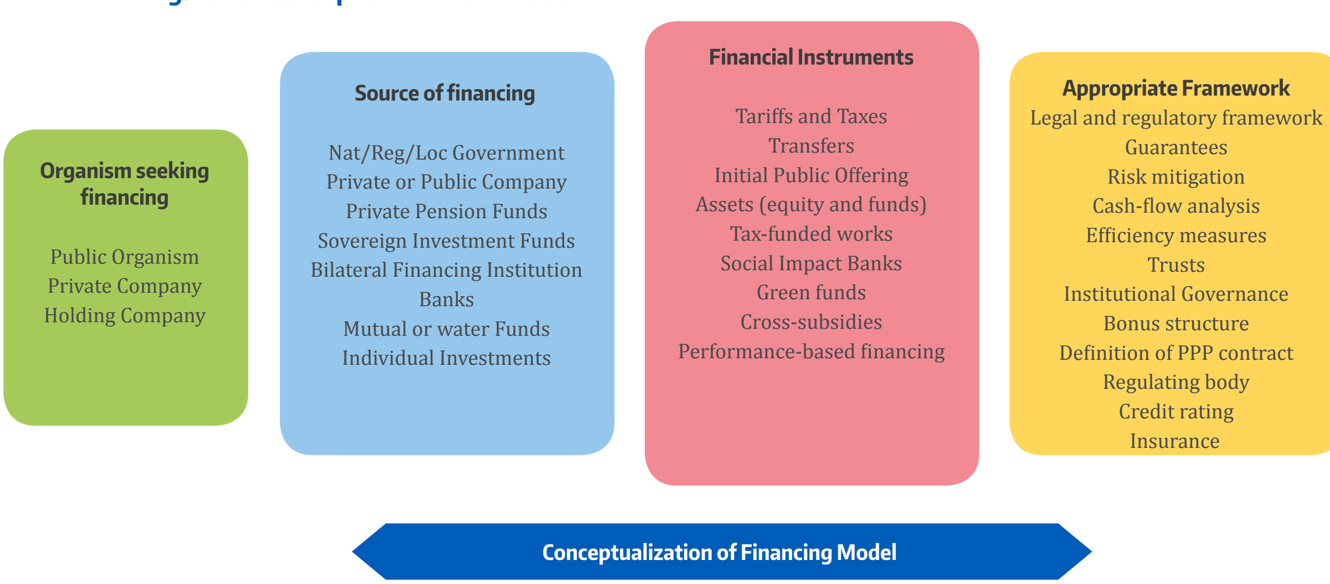
There are significant information gaps regarding the industrial use of water and its management, as well as limited access to existing information. ANA has registered and monitored over 100,000 industrial units nationwide. Average annual discharge of treated industrial wastewater in Peru is 2.81 hm^3/year. According to DAR (2017), approximately five tons of arsenic, 122 tons of barium, 488 petroleum hydrocarbons and just over two tons of lead and hexavalent chromium are discharged into the sea from industrial activities.

A country with a historic mining tradition, Peru now has over 8,000 abandoned mines, including, "all the facilities, effluent, emissions, remains or deposits of waste produced by currently abandoned or inactive mining operations, which constitute a permanent and potential risk to the health of the population, the surrounding ecosystem and property" (**Figure 11**).

Peru is the leading gold producer in Latin America and the sixth largest gold producer in the world, with gold mining creating economic opportunities for the poorest rural areas in the country, such as the Amazon, where 41% of the indigenous population live in extreme poverty. However, informal mining activity takes place, in which mercury is used, posing a threat to the health of people and the environment. The ANA notes that more than 250 mining units operating in processing plants produce wastewater and tailings and clear fell forests. The average discharge of treated wastewater from treated mining waters amounts to 251.72 hm^3/year. However, it should be noted that the mining sector reuses approximately 6,175 hm^3/year of treated wastewater, whereas the sanitation sector reuses 4,074 hm^3/year (DAR, 2017).

In agriculture, more than one million hectares under irrigation produce return waters with agro-

Figure 10. Concept of financial model



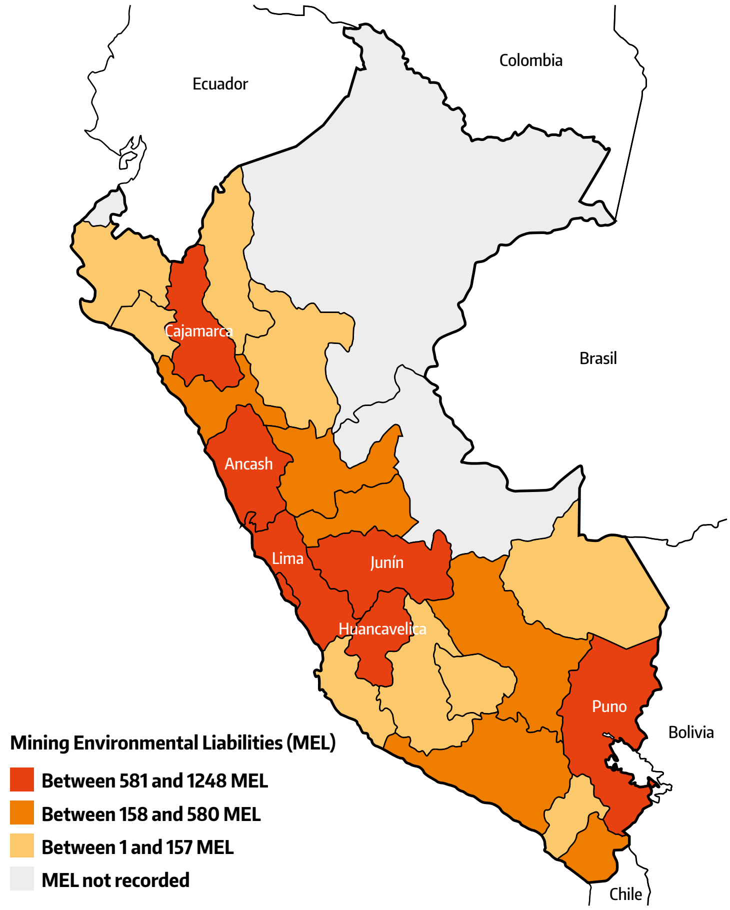
Source: ANA, 2017.

chemical residue, nutrients and high salinity. Average annual discharge of treated agricultural wastewater in Peru totals 1.83 hm^3/year. Average annual reuse of treated wastewater amounts to 6,018 hm^3/year. The agricultural sector benefits most from the practice of reusing treated wastewater. This can be observed in the reuse/discharge relationship, where 42.13 hm^3 correspond to reuse, whereas discharge only amounts to 14.93 hm^3 (DAR, 2017).

h. Environmental conflicts

Environmental contamination problems due to heavy metals have led to socio-environmental conflicts. The exposed population demands a contamination-free environment and one that that does not alter their health status. In August 2017, the ANA Conflict Prevention and Management Unit found that over 50% of water conflicts are related to the type of water quality, followed by cases linked to water quality-quantity. The remaining conflicts are related to the perceptions of actors about the alleged effects on the amount and timeliness of water supplies. In terms of geographical location, the regions of Puno and Apurimac account for over 30% of water conflicts; the regions of Ancash, Cajamarca, Cusco, Ica, Junín and Loreto have a similar percentage, while Arequipa, Huancavelica, Madre de Dios, Moquegua, Tacna and Ucayali have the lowest number of conflicts. Efforts by ANA to achieve transparency and communication permit access to the results of the participatory monitoring of water in rivers, upstream and downstream of mining operations. However, trust is a slow process requiring close contact and mutual understanding.

Figure 11. Record of environmental waste



Source: G.T. Vigilancia Epidemiológica de Riesgos Ambientales Team [They updated the Environmental Mining Waste Inventory, RM N°102-2015-MEM/DM, published in *El Peruano* on March 9 2015].

5. Achieving Sustainable Development Goals (SDG 6)

a. Guarantee the availability and sustainable management of water and sanitation for all

The country is committed to ensuring that each person has access to safe drinking water, regardless of whether they live in the city or the countryside, on the coast, in the mountains or the rainforest, and that water must be properly treated and chlorinated, thus reversing the current low levels.

b. Improving water quality by reducing pollution

Some entities work to protect public health from exposure to water with high levels of heavy metals and arsenic, using the strategy of multiple barriers to reduce the risks associated with the drinking water supply (Castro de Esparza, 2016). Adapted strategies include land use management in the basin (protection of water sources), selection of the best possible source (quality, quantity, continuity), adequate wastewater management, adequate water treatment, well designed and built distribution systems, O&M, and users with good practices and use of systems.

In Arequipa, alternatives are being developed to prevent mercury use in gold mining. One alternative is the direct fusion of gold ore concentrates with borax for mineral recovery (Eppers, 2017). Borax is a substance that poses a low risk to human health, with a low environmental impact, which is easily available and low-cost. Tests have shown that this method is superior to amalgamation and requires less time. Another advantage is that it can be applied with the equipment used by most miners in small-scale mining and artisanal mining, with minor modifications. A group of Peruvian professionals designed and manufactured an equipment prototype to recover gold in which the use of mercury is avoided (Oro ECO-100V and Oro ECO-100H) (Oro Perú, 2010). The device was successfully tested in Madre de Dios, with 95% of the gold present in the black sand being recovered, and without using mercury, far less cyanide. Another example of improving water quality is the Chili River basin where, after the corresponding microbiological diagnoses, the ANA generated an Early Warning System for Harmful Algal Blooms (SAT FAN) in the reservoirs affected.

c. Increasing the efficiency of water use:

Nationwide, although agriculture employs approximately 86% of water availability, efficiency in water use is only 30.35%. Achieving efficiency requires paying attention to three key aspects: (i) water security through storage and control of overexploitation of aquifers; (ii) regulation/control of the water supply in canal systems; and (iii) drainage systems and the technical efficiency of use in systems affected by problems of waterlogging or flooding and salinization of soils (MINAGRI, 2015). For mining companies with environmental and social responsibility, moving towards efficient water management has meant using management criteria and rules for each process (Espinar, 2017).

d. Integrated water resource management at all levels

In order to strengthen IWRM processes, water governance gaps must be reversed, at the level of policies (sectoral fragmentation of functions and responsibilities), accountability (lack of monitoring and evaluation of results), financing (mismatch between financing and the administrative responsibilities of agencies), capacities (specialized and personal technical knowledge), information (dispersal and fragmentation of primary data), objectives (coherence between sectoral and subnational policies) and administration (basins do not coincide with political limits), in accordance with the OECD principles of water governance (Pinto, 2016). The ANA initiated this process with the support of the OECD.

e. Protection and restoration of aquatic ecosystems

Several state institutions (MINAM, MINAGRI, ANA, SUNASS, SEDAPAL) have coordinated and efforts with national and international institutions (CIFOR, CONDESAN, SPDA, Forest Trends), international cooperation (USAID and Canadian cooperation) in the implementation of the Green Infrastructure Project for Water Security. Other cooperation agencies such as SDC, GIZ, and intergovernmental institutions such as GWP South America, WWF, companies and universities are actively working in various parts of the country to restore ecosystems and improve water security levels in all regions. Thus, on the coast, among other ecosystems, it was possible to restore the Ite wetland, an old tailings dump area, which is now home to over 126 resident and migrant bird species; the Huasao and Lucre wetlands in the Cusco mountain range, the wetlands of the Alto Mayo-Tingana sector in the rainforest, and Lake Rimachin in the Pastaza range.

f. Developing international cooperation and capacity building

In the Peru Report for the 8th Brasilia Water World Forum 2018: Sharing Water, ANA highlights the role of international cooperation in the process of modernizing water resource management in Peru (IDB, WB, JICA) and of the creation of eight Water Resource Councils. The Blue Planet Program is also being developed, with the support of Israeli cooperation and UNESCO. This program has a participatory and experiential methodology with nature, to encourage the development of scientific thinking. Another initiative to reverse the gaps in water and sanitation, while strengthening capacities, is the SDCA SABA-PLUS Project, currently being replicated in 14 regions with the participation of regional governments, local governments, communities with water and sanitation boards, and health and education actors, among others. The project facilitated the self-management of services through the development of competencies in the administration, operation and maintenance of systems.

g. Support and strengthen the participation of local communities

All international cooperation projects consider the strengthening of local communities in their operative plans, with a view to achieving interactive participation and being able to assume commitments in water quality and quantity management, as well as in the restoration of ecosystem services. The recognition of and respect for traditional cultural knowledge is therefore extremely important, creating security and trust in communities, which in turn drives participation.

6. Successful experiences in improving water quality and quantity

a. Watershed restoration and protection plans

Since the creation of the ANA and on the basis of a process of greater institutionality, accompanied by dialogues and trans-sectoral works, several successful cross-sectoral experiences of watershed restoration have been undertaken, with the participation of various actors. An example of this is the Educational Intervention Plan for the environmental recovery of the Tingo River micro-basin (2013-2015).[4] As part of the process of increasing citizen participation, actions were undertaken to clean the banks of the Tingo River and raise awareness among residents to keep solid waste separate and not to contaminate the waters of the river. A proposal for "Educational guidelines for the environmental recovery of the Tingo River micro-basin" and "Guidelines for strengthening environmental citizenship in basins" was successfully formulated.

Another example is the "Environmental Education for the prevention and environmental recovery of the Lake Titicaca-Puno basin" program, which is part of the activities of the Multisectorial Commission for the Prevention and Environmental Recovery of the Lake Titicaca Basin.[5]

b. Pilot experiences

The Water, Climate and Development Program GWP South America

The Program is located in the hyperperiphery of Metropolitan Lima in the sub-basin of Santa Eulalia, through which 50% of the water that supplies the capital passes and 70% of electricity is produced, making this sub-basin a valve for the water and energy security of Lima. However, it is severely affected by climate change processes. Phenomena such as droughts and floods impact water availability and affect local agricultural production.

Between 2014 and 2017, the PACyD has strengthened local governance and facilitated the creation of a Specialized Working Group that integrates public and private actors, to participate in the planning of actions for the conservation and recovery of ecosystems that provide water services. It has formulated five projects for the recovery of ecosystem services in the districts of San Pedro de Casta (1), San Juan de Iris (2) and San Pedro de Laraos (2). A research project was also formulated for the recovery of the Huaccha microbasin in Carampoma. These projects will benefit approximately 7,000 people, and are included in the Multiannual Investment Plan of the Water and Sewerage Service for Lima and Callao (SEDAPAL), so their implementation is guaranteed. During the last quarter of 2018, PACyD will implement a project for the construction and recovery of *amunas* in San Pedro de Casta, a pre-Hispanic system for recharging aquifers. This project will be implemented with the participation of the Peasant Community of San Pedro de Casta and will enable the recovery of approximately two kilometers of *amunas*.

In coordination with the National Rural Sanitation Program (PNSR) of the MVCS, the PACyD undertook a diagnosis of the water and sanitation service for population use in the rural population centers (PC) of the sub-basin. The main findings include the fact that the district of Santa Eulalia (in the lower part of the sub-basin) has 13 PCs that lack a water

4. Initiative developed with the participation of specialists from the Ministry of the Environment, the provincial municipality of Pasco and the Universidad Nacional Daniel Alcides Carrión.

5. Initiative developed in partnership with the Regional Government of Puno, the Regional Office of Education of Puno (DRE) and the Local Education Management Unit of Puno (UGEL).

and sanitation system, are supplied by springs and canals, and use blind wells or the open field for the disposal of their excreta. Moreover, 90% of PCs do not have a chlorination system; there is a low appreciation of the water and sanitation service by the population and technical weakness in the provision of the service, by both the Municipality and the JASS. In this respect, the PACyD, in conjunction with the MVCS and the SUNASS, has been coordinating a process for the sensitization of the population and the strengthening of each service provider. Immediately afterwards, interventions will be planned to improve the service (provision and infrastructure), linking natural (water quality, conservation and recovery of ecosystems) with social aspects.

c. Education, training and raising public awareness

Among other successful experiences, ANA has trained "water culture promoters" nationwide to facilitate learning processes at the local level. In this regard, the government has created the Youth for Water Rural and Urban Marginal Water and Sanitation Service (SERUMAS), a program that allows young professionals from various specialties to engage in professional internships, acquire practical knowledge and use them in solidarity to improve the quality of the most vulnerable populations living in rural areas and marginal urban neighborhoods. The National Environmental Education Plan 2017-2022, approved by D.S. Nº 016-2016-MINEDU, guides the environmental education actions undertaken in the community, for which, among other measures, municipalities will be supported through the implementation of education, culture and environmental citizenship programs. It will also promote the organization of community environmental promoters and volunteers. In order to complement this, MINEDU created the "Learning to use drinking water responsibly" Educational Program. For its part, MINAM has developed initiatives to improve education and capacity building, such as the "Clean Beaches" Campaign.

7. Conclusions and Recommendations

Taking stock of the main characteristics associated with water quality in Peru, it should be noted that efforts are recent and, although the results show an increased awareness of the environment, there is a conspicuous absence of a clear policy oriented towards solving the lack of wastewater treatment in the country. These shortcomings are compounded by the limited water governance and gaps in environmental regulations, which would allow greater clarity in the institutional competencies related to water quality monitoring.

A critical point is the weak research capacity and lack of technologies for wastewater treatment. Since pollutants originate from different sources (such as mining and petroleum waste, industrial and population discharge, illegal mining, solid waste), a complex and interdisciplinary approach is required. Thus, the capacity required by the country for water quality management must be supported by human and economic resources capable of answering questions related to causes, effects, treatments and costs. In turn, they must be able to address the problem of emerging pollution associated with climate change (such as fasciolosis and amoebas).

Significant actions worth noting are related to the long-term strategy of the state, which should be oriented to informing the population about the impact of water pollution on health and the environment. This constitutes a significant advance in the paradigm shift towards water resources, where the creation of a water culture will allow the population to actively participate in the recovery and protection of the environment. Likewise, information and the dissemination of knowledge make it possible to work on long-term mechanisms oriented towards payment for ecosystem services, as well as for drinking water service, sewerage and wastewater treatment.

The main recommendations revolve around capacity building to improve quality management, through a strategy and an environmental research plan that will make it possible to implement regional environmental and technological research centers, in order to find appropriate solutions for water treatment or preservation on the basis of local problems. In turn, such plans should establish rigorous studies and protocols to ensure the quality of the information obtained. These centers must obviously be coordinated by expert professionals trained in the necessary issues.

At the coordination level, it is important to establish short-, medium- and long-term goals and targets that align with the government's efforts in education. This will make it possible to achieve results in a coordinated way and establish strategies from broader perspectives for the creation of a water culture oriented towards water conservation.

References

Alvites, D. (2016). *Peruvian coastal upwelling system: productive, naturally sour and breathless.* Tesis de maestría. Universidad Peruana Cayetano Heredia. Lima.

Autoridad Nacional del Agua (ANA), Dirección de Gestión de la Calidad de los Recursos Hídricos (DGCRH) (2012). *Gestión de la Calidad de los Recursos Hídricos en el Perú.* Lima: ANA-DGCRH.

Autoridad Nacional del Agua (ANA) (2013). *Plan Nacional de Recursos Hídricos del Perú.* Lima: ANA. 255 pp.

Autoridad Nacional del Agua (ANA) (2016). *Estrategia Nacional para el Mejoramiento de la Calidad de los Recursos Hídricos.* Lima: ANA. 25 pp.

Autoridad Nacional del Agua (ANA) (2017). *Compendio nacional de estadísticas de recursos hídricos 2016.* Lima: ANA. 224 pp.

Bernex, N., and Korswagen, S. (2014). *Aguas y arsénico natural en el Perú.* 62 pp.

Bernex, N. (2017). Gestión de recursos hídricos, reconstrucción y sostenibilidad. Ponencia presentada en el XII Congreso Nacional y VI Congreso de Geografía de las Américas. *Boletín de la Sociedad Geográfica de Lima.*

Bernex, N. y Yakabi, K. (2016). Agua sin mitos. Lima: ANA-PUCP. 187 pp.

Boltan, R. (2017). Gestión del agua en la gestión minera. Ponencia presentada en el XII Congreso Nacional y VI Congreso de Geografía de las Américas. *Boletín de la Sociedad Geográfica de Lima.*

Brack, A. y Mendiola, C. (2004). *Ecología del Perú.* Lima: Bruño. Segunda Edición, 495pp.

Cabello-Vílchez, A.M. (2016). *Balamuthia mandrillaris* en el Perú, lesiones cutáneas, meningoencefalitis y métodos de cultivo. *Infectio*, 20(2): 107-119. DOI: 10.1016/j.infect.2015.10.006

Cabello-Vílchez, A.M. y Núñez-Ato, R.G. (2018) "Aislamiento y caracterización molecular de micobacterias no tuberculosas en el sistema de distribución de agua en un hospital de Lima (Perú)". *Revista Biosalud,* 17 (2): 7-24. DOI: 10.17151/biosa.2018.17.2.1

Cabezas, C. (2018). Enfermedades infecciosas relacionadas con el agua en el Perú. *Revista Peruana de Medicina Experimental y Salud Pública*, 35(2): 309-316. Retrieved from: https://rpmesp.ins.gob.pe/index.php/rpmesp/article/view/3761

Carlotto, V. (2014). El arsénico y el mercurio en aguas y suelos de las zonas mineralizadas: El caso de Espinar (Cusco). *Aguas y Arsénico Natural en Perú.* Jornada de la Academia Nacional de Ciencias. Lima: Sociedad Geográfica de Lima. pp. 36-51.

Castro de Esparza, M (2016). *Minimización de riesgos para la salud por metales pesados en el agua de consumo humano.* Expo Agua. Lima: OPS-OMS.

Calderón, J. (2004). *El caso del Perú rural.* ITDG.

Coe, M. T. *et al*. (2009). "The influence of historical and potential future deforestation on the stream flow of the Amazon River: Land Surface processes and atmospheric feedbacks". *Journal of Hydrology*, 369(1-2): 165-174. DOI: 10.1016/j.hydrol.2009.02.043.

Consejo Nacional del Ambiente (CONAM), Dirección General de Salud Ambiental (DIGESA) y Servicio Nacional de Sanidad Agraria (SENASA) (2006). *Inventario Nacional de Plaguicidas COP.* 58 pp.

Consorcio Typsa-Tecnoma-Engecorps-Typsa, ANA y Consejo de Recursos Hídricos de la Cuenca Chancay–Lambayeque (CRHC) (2012). *Diagnóstico Participativo de la Gestión de los Recursos Hídricos de la Cuenca Chancay-Lambayeque: memoria divulgativa.* Recuperado de: http://repositorio.ana.gob.pe/handle/ANA/1961

Creed, I.F. *et al*. (2011). Hydrological principles for sustainable management of forested ecosystems. *Hydrological Processes,* 25: 2152–2160. Retrieved from: https://doi.org/10.1002/hyp.8056

Croke, J. & Hairsine, P.B. (2006). Sediment delivery in managed forests: A review. *Environmental Reviews,* 14(1): 59-87. DOI: 10.1139/a05-016

Derecho, Ambiente y Recursos Naturales (DAR) (2017). *Calidad del Agua en el Perú: Retos y aportes para una gestión sostenible en aguas residuales.* 135 pp.

Encuesta Nacional de Procesos Estratégicos (ENAPRES) (2016). *Avances y desafíos del saneamien-*

to rural en el marco de la Gestión Integrada de los Recursos Hídricos del Perú. Elaborado por Venero Farfán, H. Lima: Instituto de Estudios Peruanos.

Eppers, O. (2017). *El uso de bórax para una producción de oro sin mercurio en la minería a pequeña escala.* 11 pp. Retrieved from https://www.researchgate.net/publication/318418780_El_uso_de_borax_para_una_produccion_de_oro_sin_mercurio_en_la_mineria_a_pequena_escala

Espinar, A. (2017). Políticas de Gestión del agua en las operaciones de Buenaventura. En revista *PICSA, CMB,* Agost, 2017.

Espinoza, J. (2007). *Contaminación de aguas subterráneas por lixiviados provenientes de sepulturas bajo suelo en el camposanto "Parques del Paraíso" Lurin – Lima.* Tesis de Maestría en Ciencias Ambientales. Lima: Universidad Nacional Mayor de San Marcos.

Fischetti, M. & Christiansen, J. (2018). "Mass extinction in Earth's Oceans could begin by 2100". *Scientific American,* January issue. Retrieved from: https://www.scientificamerican.com/article/mass-extinction-in-earth-rsquo-s-oceans-could-begin-by-2100/

Fontúrbel, F. (2003). Algunos Criterios Biológicos sobre el proceso de Eutrofización a orillas de seis localidades del Lago Titikaka. *Ecología Aplicada,* 2(1), 75-79. Retrieved from: http://www.scielo.org.pe/scielo.php?script=sci_arttext&pid=S1726-22162003000100011&lng=es&tlng=es

Fontúrbel, F. (2004). Modelo operacional ambiental y aspectos sociales relevantes del proceso de eutrofización localizada en cuatro estaciones experimentales del lago Titicaca. *Publicaciones Integrales,* La Paz.

Global Alliance on Health and Pollution. Online publication. Recuperado de: https://www.pollution.org/

Global Green Growth Institute (GGGI), German Development Institute (GDI) y Servicio Nacional Forestal y de Fauna Silvestre (SERFOR) (2015). *Interpretación de la dinámica de la deforestación en el Perú y lecciones aprendidas para reducirla.* 40 pp. Retrieved from: www.serfor.gob.pe/wp-content/uploads/2016/03/Interpretacion-de-la-dinamica-de-la-deforestacion-en-el-Peru-y-lecciones-aprendidas-para-reducirla-1.pdf

Heffermann, O. (2018). Troubled waters. *Scientific American,* 313, 44-49. DOI: 10.1038/*scientificamerican* 0218-44

Hoffman, R. & Michel, R. (2001). "Distribution of free-living amoebae (FLA) during preparation and supply of drinking water". *International Journal of Hygiene and Environmental Health,* 203(3): 215-219. DOI: 10.1078/S1438-4639(04)70031-0

Instituto Geológico, Minero y Metalúrgico (INGEMMET) (2017). *Estimación del potencial minero metálico en el Perú y su contribución económica al Estado al 2050.* Retrieved from: https://goo.gl/SFL4f3

Instituto del Mar Peruano (IMARPE) (2008). *Monitoreo limnológico pesquero en reservorios de la costa norte del Perú. Informe Anual 2007.* Retrieved from: https://goo.gl/fUpPF9

Instituto Nacional de Estadísticas e Informática (INEI) (2013). *Anuario de Estadísticas Ambientales 2013.* 639 pp. Retrieved from: http://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1140/Libro.pdf

Instituto Nacional de Estadísticas e Informática (INEI) (2017). *Encuesta Demográfica y de Salud Familiar (ENDES) del 2017.*

Instituto Nacional de Estadísticas e Informática (INEI) (2002). *La Pobreza en el Perú en 2001. Una Visión Departamental.* Lima: INEI. 196 pp.

Komárková, J. *et al.* (2016). "Cyanobacterial water bloom of Limnoraphis robusta in the Lago Mayor of Lake Titicaca. Can it develop?". *Hydrobiologia*, 764(1), 249-258. https://doi.org/10.1007/s10750-015-2298-x

Lancet Commissions Report (2017). *The Lancet Commission on pollution and health.* Online publication. Recuperado de: www.lancet.com

Larsen, B. *et al*. (2013). *Economic Assessment of Environmental Degradation in Peru: An update 2012.* Washington DC: World Bank. Unpublished.

Legua, J.A. *et al*. (2016). Evaluación de las Fuentes de Aguas Subterráneas y la Situación Actual de su Almacenamiento y Calidad en el Distrito de Vegueta 2012–2013. *Big Bang Faustiniano,* 5(4): 44-48. Retrieved from: https://goo.gl/TNj1ZE

Lindell, L.; M. Åström & T. Öberg (2010). "Land-use changeversusnatural controls on stream water chemistry in the Subandean Amazon, Peru". *Applied Geochemistry,* 25: 485-495. DOI: 10.1016/j.apgeochem.2009.12.01

Mariano, M. *et al*. (2017). "Contaminación producida por piscicultura intensiva en lagunas andinas de Junín, Perú". *Revista Peruana de Biología,* 17(1), 137-140. Retrieved from: http://www3.redalyc.org/articulo.oa?id=195014936018

Matienzo, R. (2014). *Análisis de la influencia de la represa de Gallito Ciego en la calidad del agua del curso inferior del río Jequetepeque.* Tesis de pregrado. Pontificia Universidad Católica del Perú. Lima.

Ministerio de Agricultura y Riego-MINAGRI (2015). *Análisis de Tendencias que impactan en la Agricultura.* Retrieved from: http://www.minagri.gob.pe/portal/download/pdf/pnapes/actividades/comision/analisis-tendencias.pdf

Ministerio de Ambiente (MINAM) (2016). *Plan Nacional de Gestión Integral de Residuos Sólidos 2016-2024.* 80 pp.

Ministerio de Ambiente (MINAM) (2012). *Cuarto Informe Nacional de Residuos Sólidos Municipales y No Municipales: Gestión 2010-2011.* 379 pp.

Ministerio de Educación (MINEDU) (2017). *Resultados del Censo Educativo 2017.* Retrieved from: https://goo.gl/KdFvPJ

Montoya, H., Komárková, J., & Komárek, J. (2015). Cyanobacterial species, potentially forming water blooms in the Lake Titicaca (Peru). *Arnaldoa*, 21(2), 381-390. Retrieved from: http://journal.upao.edu.pe/Arnaldoa/article/view/169/164

Ocola, J. (2016). Protección del agua – Vigilancia y control de vertimientos – PAVER. Autoridad Nacional del Agua. Retrieved from: https://goo.gl/sZSnbt

Oficina Nacional de Evaluación de Recursos Naturales (ONERN) (1985). *Los recursos naturales en el Perú.* Lima. 326 pp.

Oro Perú (2010, mayo, 7). *ECO-100 equipo para extraer oro sin usar mercurio.* Retrieved from: https://www.preciooro.com/eco-100-equipo-para-extraer-oro-sin-usar-mercurio.html

Pastor, R. (2010). Recuperación de suelos salinos para la instalación de césped deportivo en la playa de Asia, Cañete, Lima. Tesis Mg. Sc. Suelos. Universidad Nacional Agraria La Molina. Lima.

Pehrsson, E.C. *et al*. (2016). Interconnected microbiomes and resistomes in low-income human habitats. *Nature*, 533: 212-216. DOI: 10.1038/nature17672

Petrie, B. *et al*. (2015). "A review on emerging contaminants in wastewaters and the environment: Current knowledge, understudied areas and recommendations for future monitoring". *Water Research*, 72: 3-27. DOI: 10.1016/j.waters.2014.08.053

Pinto, Y. (2016). *La Gobernanza y el Marco Legal para la Gestión de los Recursos Hídricos en el Perú.* Retrieved from: https://goo.gl/U6bzgh

Ricalde, E. (2018). Foro "Participación de las mujeres en la gestión del agua y los servicios de saneamiento en el ámbito urbano y rural. Avances y perspectivas". SUNASS; Cusco.

Riofrío, J. *et al*. (2003). Caracterización limnológica de la laguna de Cashibococha (Ucayali-Perú) durante el año 2001. *Revista Peruana de Biología,* 10(2), 183-194. http://dx.doi.org/10.15381/rpb.v10i2.2501

Sánchez, C. *et al*. (2013). *Exposición ambiental a múltiples metales pesados en poblaciones del Perú.*

Super Intendencia Nacional de Servicios de Saneamiento (SUNASS) (2018). *SUNASS visibiliza participación de las mujeres en la gestión del agua y saneamiento.* Noticias. Retrieved from: https://goo.gl/31qYhk

Tovar, J. (2007). *Las aguas subterráneas y la minería en el Perú.* Sociedad Geológica del Perú.

Vidal, C.E. y Cedillo, E. (1988). Los yacimientos de enargita-alunita en el Perú. Trabajo presentado en el VI Congreso Peruano de Geología. *Boletín de la Sociedad Peruana de Geología,* vol. 78, 109-120.

Wang-Erlandsson, L. *et al*. (2014). Contrasting roles of interception and transpiration in the hydrological cycle–Part 1: Temporal characteristics over land. *Earth System Dynamics,* 5(2): 441-469. DOI: 10.5194/esd-5-441-2014

World Health Organization (WHO). *Antimicrobial resistance: global report on surveillance 2014.* Retrieved from: https://goo.gl/K6XaCL

Normative References

Decreto Ley N° 17752, Ley General de Aguas. 24 de julio 1969.

Decreto Supremo N° 261-69-AP, Reglamento de los Títulos I, II y III del Decreto Ley N° 17752. 13 de diciembre de 1969.

Decreto Supremo N° 007-83-SA, Modifica el Reglamento del Decreto Ley N° 17752. 11 de marzo de 1983.

Decreto Legislativo N° 613, Código del Medio Ambiente de los Recursos Naturales. 8 de setiembre de 1990.

Ley N° 28611, Ley General del Ambiente. 13 de octubre de 2005.

Decreto Supremo N° 002-2008-MINAM, Aprueban los Estándares Nacionales de Calidad Ambiental para Agua. 30 de julio de 2008.

Ley N° 29338, Ley de Recursos Hídricos. 30 de marzo de 2009.

Ley Nº 30215, Ley de Mecanismos de Retribución por Servicios Ecosistémicos. 28 de junio de 2014.

Decreto Supremo Nº 016-2016-MINEDU, Aprueba el Plan Nacional de Educación Ambiental 2017-2022. 9 de diciembre de 2016.

Decreto Legislativo N° 1278, Ley de Gestión Integral de Residuos Sólidos. 22 de diciembre de 2016.

Decreto Legislativo N° 1280, Ley Marco de la Gestión y Prestación de los Servicios de Saneamiento. 28 de diciembre de 2016.

Decreto Legislativo Nº 1284, Creación del Fondo de Inversión Agua Segura. 28 de diciembre de 2016.

Decreto Supremo N° 004-2017-MINAM, Aprueban Estándares de Calidad Ambiental (ECA) para Agua y establecen Disposiciones Complementarias. 7 de junio de 2017.

Decreto Supremo N° 015-2017-VIVIENDA, Aprueba el Reglamento para el Reaprovechamiento de los Lodos generados en las Plantas de Tratamiento de Aguas Residuales. 21 de junio de 2017.

Decreto Supremo N° 018-2017-VIVIENDA, Aprueba el Plan Nacional de Saneamiento 2017–2021. 23 de junio de 2017.

Resolución Jefatural N° 237-2018-ANA, Conformación de la Mesa Académica del Agua. 14 de agosto de 2018.

United States of America

Physics and economics provide principles for evaluating the efficacy of water quality policies. Analyses of current water quality legislation indicates that, while effective in some ways, they have significant physical and economic deficiencies. Managing water quality poses many problems but the most important are: 1) toxic contaminants; 2) non-point source contaminants; 3) managing salinity; 4) monitoring; and 5) governance. The **U.S.** is an example of the "Water Paradox in Developed Nations."

Aerial view of the Hoover Dam, located on the course of the Colorado River, United States of America © iStock

Water Quality and its Management in the United States of America

Henry Vaux, Jr.

Introduction

Water quality in the United States is said to be sufficiently good to support most uses to which water is commonly put. Indeed, instances of water borne disease are rare, water of suitable quality is available for industry and agriculture and most waters are suitable for recreational purposes. Yet, in a country as geographically vast and varied as the United States, there are a multitude of water quality problems. Some arise anew as a consequence of economic and population growth. Others are problems that may have been effectively managed historically but are no longer well managed because the physical and biological causes have outgrown the policy and institutional arrangements that were designed to address them. Still others are long-term problems that have proven to be intractable historically. The pace of technical change and economic growth coupled with the stagnation or decline of the institutions and resources available for managing water quality mean that future levels and patterns of water quality may be seriously jeopardized.

The history of water quality in the United States is somewhat mixed. European explorers and early European arrivals to the moist eastern and middle western lands found almost unlimited supplies of pristine natural surface waters. As the population and economy grew in the ensuing years, waterways came to be used as receptors for both industrial and domestic waste. This led at first to localized instances of significant water pollution. Over time the extent and severity of the localized instances grew until few regions of the country were entirely free of both areas of persistent contamination and more frequent acute but temporary episodes of pollution. Early action to address water pollution was itself localized and regionalized. Early federal legislation that appeared in 1948 assigned responsibility for managing water quality to the states (33 U.S.C. 1251-1376. P.L. 80-854). This turned out to be an ineffective strategy.

With the management of water quality in the hands of the states the levels of standards and the stringency of regulations tended to become bargaining tools, part of an effort to an effort to attract new industrial and other economic development. When states competed for economic development by offering standards and water quality regulations that were weaker and less effective than those offered by competing states, the results were almost always weaker standards and regulations in many or all states. Water quality in the aggregate thus continued to decline over time. In the late 1960s, the continued deterioration in the quality of

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the nation's waters began to draw increasing public attention. One widely publicized incident dramatically underscored the deleterious state of the nation's waters by mid-20th century. The Cuyahoga River, which flows through Cleveland, Ohio and discharges into Lake Erie, had become little more than an open sewer filled largely with industrial wastes. The river itself caught fire periodically and the prolonged efforts to extinguish it received national publicity. This incident, coupled with reports of similar disastrous levels of contamination in other waterways and the fact that swimming and other water contact sports were frequently banned to protect public health, set the stage for enactment of the Clean Water Act of 1972 and the Safe Drinking Water Act of 1974 which remain to this day the pillars of water quality management in the United States. These Acts will be described and evaluated in more detail later in this chapter as they continue to provide the legislative and legal basis for managing water quality. Much of the contemporary assessment of water quality in the U.S. begins with these two Acts.

The remainder of this chapter is in four sections. The first of these derives and discuss some principles of water quality management based upon the Law of Conservation of Energy and Matter. In an ideal world water quality management schemes would be consistent with these principles. In the second section the legal framework governing water quality in the United States is discussed. The discussion includes a detailed description and evaluation of the current national laws governing water quality including those identified in this introductory section. In the third section, water quality problems that need to be address in contemporary time frames are identified and analyzed. A fourth and final section contains some concluding comments and recommendations for actions.

Managing water quality: some underelying theory

The principle of materials balance, which is derived from the Law of Conservation of Energy and Matter, embodies a number of useful lessons that should be heeded if the management of water quality is to be optimal in an economic sense. The schematic in **Figure 1** illustrates the principle as it follows from the Law of Conservation and Energy and Matter. That law holds that matter and energy are always conserved. So too with the resources and materiel that flow through production and consumption systems. Beginning at the left of the diagram are the raw resources and materials that are used in production. The production process transforms those resources and materials into a) useful goods and services and b) the residuals of the production process, WR_p. These residuals typically do not have any value and left unregulated are discharged to one or more of the environmental waste sinks - land, air or water. The useful goods and services are purchased by consumers and in the processes of consumption undergo a further transformation, the consumptive transformation, in which the trash or garbage that results from consumption, the residuals of the consumptive processes, WR_c, are also discharged to the environment. For purposes of explication it is assumed in the diagram and the underlying symbolism that regulations do not exist. However, lessons about regulations, their stringency and how they can be applied do emerge from this analysis.

One major result, called the Principle of Materials Balance, holds that the weight of the resources that enter the production process, W_{res}, is approximately equal to the weight of the residuals from productive transformation, WR_p, plus the weight of the residuals of consumptive transformation, WR_c, (Ayers, Kneese and d'Arge, 2015). That is:

1) $W_{res} = WR_p + WR_c$

Where
W_{res} = the weight of the resources and material that enter production processes
WR_p = the weight of the residuals of production
WR_c = the weight of the residuals of consumption

Several important corollaries follow from this principle:

- **Corollary 1:** There are only two ways to reduce the weight (quantity) discharged to the environment: a) reduce the weight of the resources and materials that are put through the productive and consumptive transformation – called throughput; or b) capture the residuals from the productive and consumptive transformations and recycle them through the system as resources. This is what recycling is all about.

- **Corollary 2:** The more stringent the standard for one sink the laxer the ambient quality of the other sinks. In other words, the land, air and water sinks are interrelated – not independent—and it is simply not feasible to control the quality of all three sinks very tightly thru the simple expedient of promulgating standards. It is also important to recognize that that different sinks have different capacities to dilute or transform different kinds of wastes. These capacities vary from place to place.

There is a second important principle from economics that should be considered in the fashioning of water quality control policies and standards. This principle holds that, in most cases, it is inefficient to eliminate pollution totally. This is illustrated in **Figure 2** where the optimal point –the optimal mount of pollution abatement is found where the marginal costs of control and the marginal benefits of control intersect (are equal). Stated differently, in most instances, some amount of pollution will be economically optimal. The rationale is that at some point the incremental costs of treating or controlling additional quantities of pollutants will exceed the incremental benefits that would be conferred if the unit of pollution in question is controlled. In most cases optimal pollution or optimal control of pollution will be at the point where the costs of an additional unit of treatment just equal the benefits (or damages averted) as a consequence of treatment. Among the several exceptions to this principle are cases where the pollutant in question is so virulent that it will cause enormous damages in terms of human health and loss of life. Another example arises in instances where the costs of cleaning up or attenuating a pollutant are themselves huge, perhaps bordering on being infinitely large (Baumol and Oates, 1993).

These principles provide useful guidance in devising effective and efficient pollution control strategies. They also provide useful criteria against which to evaluate existing pollution control. It is clear that water quality management should be part of integrated pollution control strategies that explicitly acknowledge the interrelatedness of the three sinks, land, air and water. In the next section, the major national laws and policies governing the management of water quality will be identified and discussed. In that discussion it will emerge that one of the shortcomings of pollution control policy in the United States is that it is sink specific and pro-

Figure 1. Schematic of the Principle of Material Material Balance

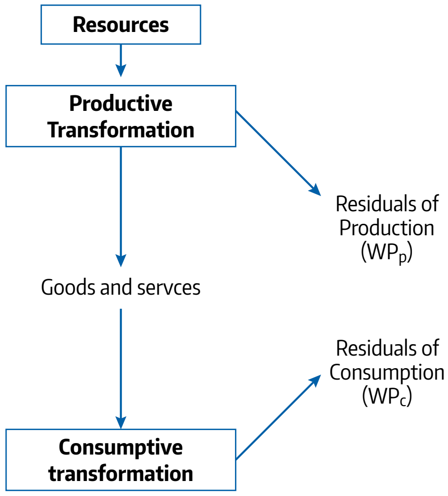
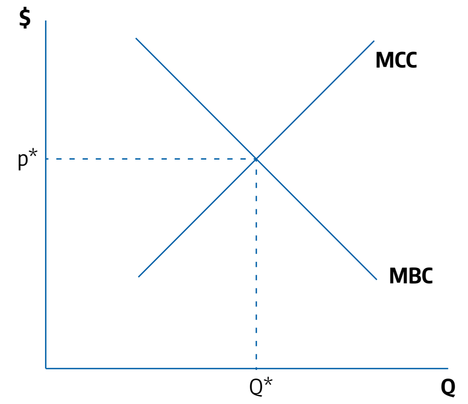


Figure 2. Incremental costs and benefits of pollution control



Where:

MCC= marginal costs of pollution control in USD$
MBC = Marginal benefits from pollution control un USD$
Q* = Optimal quantity of pollution control
P* = Incremental price of optimal control

vides little or no acknowledgement of the interrelatedness of waste sinks. Simultaneously, it is also clear that these policies were not designed to be consistent with principles of economic efficiency. However, it is true that the data required to assess efficient strategies may not always be available or are expensive to obtain.

Water quality laws and policies

There are two major federal laws and associated polities that govern water quality and its management in the United States. They are: 1) the Clean Water Act of 1972 and 2) the Safe Drinking Water Act of 1974. A third law, the Toxic Substances Control Act of 1976, aimed at controlling toxic substances generally is also germaine but is not related to water pollution exclusively. Rather, toxic substances in water or susceptible to being in water are treated directly under the terms of the Safe Drinking Water Act, amended. Below the details of these laws are described and evaluated. However, at the outset, it should be noted that while these laws and policies are the most important and most visible there are numerous other federal laws, parts of which are directed at improving and maintaining water quality. In addition, the States and Territories also have their own laws and policies which are consistent with the major federal laws but modify and strengthen them in a variety of ways. Under the Constitution of the United States the laws and policies of states and territories cannot be devised and/or enforced to weaken or modify the intent of federal legislation. The state laws and policies as well as the minor federal laws and policies are too numerous to be considered further here. However, they are important to the extent that in some instances they strengthen one or more aspects of federal legislation and, in other instances, they serve to adapt the features of the federal law to some unique circumstances which are found frequently in a country as vast and variable as the United States.

Clean Water Act of 1972 (Public Law 92-500; 86 Stat 816). The Clean Water Act of 1972, technically called the Federal Water Pollution Control Act, lays out the fundamental bases for modern water pollution control in the United States. The Act focuses on the quality of water in the surface waters of the country. It does not address problems of ground water pollution. The Act also focuses on point sources which are generally defined as discharges to a waterways that emanate from an identifiable point such as a sewer outfall, a discharge pipe or confined discharge from an industry, including discharges of heated waters that exceed the ambient temperature of the receiving water body (See **Box 1)**. The Act also addresses non-point source discharges which, because they are defuse, complicate the problems of regulation. However, actions and policies to address non-point source discharges are not emphasized to the extent that policies focused on point source discharges are.

The Clean Water Act was passed by Congress and signed into law in 1972. It has been as amended several times since then, most notably in 1977, 1981, 1987 and 2014 (For a complete overview see: Bearden et. al.2010). The law is complex and although it is now more than 40 years old parts of it remain controversial and the subject of continuing debate. As noted above, an earlier version of this Act, passed in 1948, assigned responsibility for establishing and enforcing water quality standards to the States. This proved unworkable and the 1972 Act vested the authority to promulgate water quality standards with the federal government. The principal objective of the Act was to make all of the nation's surface waters fishable and swimmable by 1983. The Act was based on the proposition that discharges into any waterway in the U.S. were to be illegal. However, the Act provided that dischargers could obtain discharge permits after meeting certain conditions specified by the law and by the regulator, who was identified as the U.S. Environmental Protection Agency. The permits were subsumed under the general heading of the National Pollution Discharge Elimination System (NPDES). Today, all point sources dischargers in the U.S. hold a permit which itself is part of an effective enforcement system. Those who discharge without a permit are subject to significant fines. The Clean Water Act has two main parts. The first encompasses a set of regulatory requirements aimed at industrial and municipal dischargers. The second authorizes federal financial aid to municipalities and other public

Box 1. Important concepts in waste water treatment and management

Levels of Treatment

Primary Treatment. Primary treatment is the basic level of treatment. It involves the removal of solids and floating material from waste water.

Secondary Treatment. Secondary treatment entails the removal of suspended compounds and colloids, usually through natural biological processes that entail the biochemical oxidation to convert suspensions and colloids to constituent chemicals. Such treatments are usually accomplished in aerobic environments utilizing microorganisms that are found in adjacent and nearby streams. Together with primary treatment they remove a significant majority of the Biological Oxygen Demand (BOD) found in the feed wastewater.

Tertiary Treatment. Tertiary treatment involves the removal of specific compounds beyond those that are usually removed by secondary treatment. Nitrogen and phosphorous are the primary examples but there are many others and the level of tertiary treatment required will depend upon the specific composition of the waste water in question. The methods of tertiary treatment may be biological, chemical and/or physical. Tertiary treatment is sometime called "Advanced Waste Water Treatment".

Types of Standards

Different types of standards are typically employed in specifying the goals and objectives of wastewater treatment systems specifically or broad regional and national water quality goals. There are several different types standards. They are discussed below:

Ambient Standards. Ambient standards specify the desired physical, chemical and biological characteristics of receiving media, water in the present case, which collectively form the goals of water quality management actions and policies. The specification of an ambient standard is simply the statement of an objective or a set of objective. The standard itself is not fulfilling. It must be attained by other means such as the specification and enforcement of discharge standards, pollution fines or other pricing mechanisms both individualy and collectively.

Discharge Standards. Discharge standards express the biological, chemical, physical (and in some cases, quantitative) standards that must characterize waters that are discharged to a surface waterway or other receiving body. The stipulation and enforcement of discharge standards is one way of achieving ambient standards. It should be noted that discharge standards are effective with point source pollutants where there is a point where the discharge in question can be monitored. They are usually ineffective in controlling non-point source pollution because of the difficulty in identifying where the standard is to be applied and enforced.

Technology Based Standards. Technology based standards specify the types of technology and related operational considerations necessary to achieve the ambient standard. They are usually based on cost and effectiveness considerations. They achieve pollution management by specifying what must be done to waste streams rather than by the impact of the waste streams on the environment.

Input Standards. Input standards specify the quantity and quality of certain inputs that may be applied in specific production processes in order to affect the quality and quantity of the residuals, both productive and consumptive that are subsequently generated. output. Stated differently, they specify the quality and quantity of the inputs to the production process in order to impact the quality and quantity of the residuals. They have been proposed as an effective means of dealing with non-point source pollutants but they have rarely been used in the United States and do not have a substantial record of effectiveness. They will usually be quite costly to enforce.

Technologies

Best Available Technology (BAT). The most effective waste treatment technology, including processes, without regard to cost or affordability.

Best Practicable Technology (BPT). The most effective waste treatment technology, including processes, subject to constraints on costs and affordability. The constraints are established by the regulator.

entities to assist in the construction of wastewater treatment plants that meet the required standards for discharge.

The regulatory process begins with the establishment of surface water quality standards. The responsibility for promulgating the standards rests with the States though all standards are subject to Federal approval. For states that fail to establish standards or are unable to establish standards that merit federal approval, the federal government itself is authorized to establish the standards. The federal review responsibility is exercised by the Environmental Protection Agency (EPA). The standards themselves express the maximum concentrations of biodegradable wastes, heat and pH that are permitted in the waterways of the state in question. These ambient standards are to be achieved by a set of technology standards.

For industry, the initial requirement was to employ the Best Practicable Technology (BPT) to treat the waste stream. The Act called for the advancement to Best Available Technology (BAT) by 1989 to improve the level of treatment. The Act required further that ambient standards specify the maximum allowable concentration of pollutants needed to permit the stream to be used for which ever use the standard called for. These maximum allowable concentrations serve as checks to ensure that the ambient standards are, indeed, met. They require the States to establish the Total Maximum Daily Load (TMDL) of pollutants that must be met if the achievement of the ambient standard is to be assured. When the appropriate (BPT) technology does not achieve the TMDL additional treatment may be required. The specification of TMDLs is thus a part of the planning for pollution control and also part of the enforcement process.

For regional and municipal wastewater treatment systems the treatment technology is required to be that which achieves at least full secondary treatment of the waste stream. Again, where the use of secondary treatment is insufficient to achieve the TMDLs for the body of water in question additional treatment may be required. In 1972, at the time the Act was passed, the funding needs for constructing treatment facilities to provide full secondary treatment were well beyond the capacity of most regions and municipalities financially. Accordingly, the Congress included in the legislation provisions authorizing the federal government to participate in the financing of facility construction in the amount of 75% of the capital cost. The remainder of the cost was to be borne by states and localities as were the operation and maintenance costs. The ceiling on the federal contribution to capital costs was reduced to 55% by the Municipal Wastewater Treatment Construction Grants Amendments of 1981 (P.L. 97-117). One of the early problems with the grants program was the lack of training programs for facility operators and the consequent inadequate pool of trained operators. This problem proved vexatious in the early years of the program although, with time, it was overcome.

As noted above the basin Clean Water Act of 1972 has been amended and clarified four times. since its original passage. The first two pieces of amending legislation, the Clean Water Act of 1977 (P.L. 95-217) and the Municipal Wastewater Treatment Construction Grant Amendments of 1981 (P.L. 97-117) were intended to adapt and expand parts of the original legislation to specific local and regional circumstances and to situations that had not been anticipated in the original legislation. The provisions of both of these acts are many, detailed and complex. Treatment of all of them them is beyond the scope of this paper. The significant exceptions were the creation of program focused on toxic wastes in the 1977 Act and the reduction of the ceiling on the federal cost share from the 75% to 55% mandated by the 1981 Act.

A third piece of amending legislation, the **Water Quality Act of 1987** (P.L. 100-4), was notable in a number of respects. Perhaps first and foremost it provided specific programmatic authorizations to address non-point source pollution. This contrasts with the 1972 Act and the 1977 Amendments that had focused almost exclusively on point sources. The 1987 Act authorized the states to devise and implement programs aimed at managing non-point source pollution. Within this authorization they were encouraged to develop programs aimed at the protection of ground water. Such protection programs were potentially significant since it is almost always true that it is cheaper to prevent ground water pollution in the first place rather than cleaning it up after it has occurred. The Act also made available grants covering up to 60% of the development and implementation costs of non-point source control programs. Although the nation has continued to struggle with the management of non-point sources, the promulgation of implementation of Best Management Practices (BMPs) has served as a significant start. As noted a later in this chapter management of non-point sources remains a significant problem for the nation.

The 1987 Act authorized other important adjustments in the national clean water program. First, it targeted specific water pollution problems and authorized new programs and strengthened programs for dealing with them. Among these were pollution control strategies targeted at specified toxic discharges that had previously been identified as problematical. Second, it changed the fundamental nature of the federal/state relationship that had prevailed since the authorization of the 1972 Act. This was accomplished by phasing out of the wastewater treatment construction grants program and replacing it with State Water Pollution Control Revolving Funds. Under this arrangement the federal government provided an initial grant to capitalize the revolving fund and the states added 20% to that amount. Eligible projects then received low interest loans from the revolving fund and these loans were repaid into the fund where the money became available to support other projects. The other important feature of the revolving fund arrangement was that a variety of water quality projects were eligible to receive funding loan – not just the construction of waste water treatment plants as had previously been the case. Among the eligible projects identified in the Act were: a) construction of municipal wastewater treatment facilities; b) projects of control non-point pollution sources; c) construction of decentralized wastewater treatment systems; d) creation of green infrastructure projects; and e) projects to enhance and protect estuarine waters. In addition, the Act devolved to the states partial responsibility (subject to Federal oversight) for the management of the national (NPEDS) permit program. (Leibsman and Laws, 1987).

The third major feature of the 1987 Act was the strengthening of the general enforcement mechanisms both Federal and State programs by increasing fines and even imprisonment, where called for. Fourth and finally, it made provision whereby local areas that faced special circumstances could seek redress or relief from some of the more stringent provisions of the various pieces of the water pollution control legislation (Liebsman and Laws, 1987). Taken as a whole the 1987 legislation illustrated how the original Act of 1972 could be modified and strengthened in response to emerging circumstances and to experience with programs that had performed at levels less than anticipated.

The Clean Water Act of 1972, as amended in 1977, 1981 and 1987 and in numerous other pieces of legislation wherein minor changes were enacted, was to some extent flawed from the beginning. The Act focused on a single sink –water– fails to incorporate the principle from the materials balance that emphasizes the interrelatedness of all sinks. This significant omission had been repeated earlier with both the Clean Air Act of 1970 (42 U.S.C. 7401 et seq. P.L. 84-159) and the Solid Waste Disposal Act of 1954 (P.L. 89-272) and its successor the Resource Conservation and Recovery Act of 1976 (P.L. 94-580) all of which focused on single waste receiving sinks. There was little or no recognition or acknowledgement that these sinks were interrelated. Thus even today the single sink focus of U.S. pollution control strategies means that there are instances and regions where one or more of the sinks is overutilized and one or more of the other two are underutilized. The failure to pursue broadly integrated strategies of residuals management remains one of the major shortcomings of environmental management in the U.S. today. This means that water quality will rarely be managed optimally because the costs of pollution control are rarely considered ad compared with the benefits of control.

The is an additional flaw in the underpinnings of the Act and this revolves around the proposition that efficient waste disposal practices should seek to balance the costs and benefits of residuals management such that at the equilibrium point the costs of the last additional unit of treatment or regulation (control)should just be equal to the benefits achieved from the last unit of control. This means that there is some optimal level of pollution and only in rare instance will it be economical to clean up all pollution (Dolbear, 1967). The problems of measuring and monetizing the costs and benefits are difficult to be sure and the costs of obtaining that information must be counted as costs of control. However, the 1972 Act specified an ultimate goal of zero discharges nationally and established a deadline for the achievement of that goal. In this way, the Act failed to acknowledge that the some of the costs of clean-up would not generate sufficient benefits to make those costs worth bearing. The fact is that the zero discharge goal has never been achieved and probably never will be achieved. At best the specification of such goals create false sets of expectations.

In spite of these fundamental flaws it is hard to argue with the proposition that the Act has served the country well. The nation's waters are now demonstrably cleaner than they were in 1972. This has occurred despite the significant population and economic growth in the last 40 years, the increases in the throughput of materials in the economy and changes in both the quantity and quality of residuals. Yet more than 40 years after it was first enacted the Act remains controversial. On the one hand, there are groups that argue that the Act does not go far enough, that it is only infrequently updated and that there are important classes of pollutants that are either under regulated or not regulated at all (e.g. Adler, Landeman and Cameron. 1993). On the other hand are groups, that feel that the Act represents unwarranted government intrusion on industries, businesses and public institutions. The fact that there are countervailing dissatisfactions probably attests to the political wisdom of those who fashioned it in the first place.

Safe Drinking Water Act of 1974 (P.L. 93-523) Shortly after the mid-twentieth century the United States began to experience significant outbreaks of waterborne illness in a number of urban communities. These outbreaks belied the commonly held believe that virtually all drinking water supplies in the country were safe. The government responded with the National Community Water Supply Study to examine the safety of drinking water supplies nation-wide (Bureau of Water Hygiene, 1970). The study found that there were substantial deficiencies in the quality of drinking water nationally and also documented concerns about the capacity of drinking water treatment systems to deliver purified water suitable for drinking (Bureau of Water Hygiene, 1970). The needs for and the antecedents of the Safe Drinking Water Act of 1974, as amended, are found in the National Community Water Supply Study. The Safe Drinking Water Act (P.L. 93-523) was incorporated into the Public Health Service Act as Title XIV. It is important to note at the outset that there is a clear distinction between the Clean Water Act, as amended, which focuses on the pollution and quality of the nation's surface waters, and the Safe Drinking Water Act, as amended, which focuses on the quality of the nation's drinking water supplies.

The Safe Drinking Water Act of 1974 established three authorizations that are crucial to maintaining healthful drinking water. First, it empowered the Environmental Protection Agency to identify and set standards for contaminants in drinking water including those with the potential to appear in drinking water. Second, it required the Environmental Protection Agency to establish and enforce regulations to ensure that contaminants remain absent from drinking water. Third, it authorizes the States the assume responsibility for oversight and enforcement of standards and regulations once they have been approved. The Environmental Protection Agency is required to maintain a contaminant candidate list and to update that list every five years. The Agency is also required to evaluate at least five contaminants on this list every five years and make a determination as to whether to proceed with regulation or not (Tiemann, 2017).

A contaminant is selected as a candidate for standard setting and regulation if it meets three critical criteria.

- Contaminant may have adverse health effects.
- Contaminant occurs or has a likelihood of occurrence at levels and frequencies that constitute a public health concern.
- Regulation offers an opportunity for health risk reduction.

Once a contaminant has been selected for regulation the Agency must establish a Maximum Contaminant Level Goal (MCLG) which is at the level where there are no anticipated adverse effects plus some margin of scarcity. The standard is then set as a Maximum Contaminant Level (MCL) which is as close to the goal as is feasible. The Agency then must then propose a rule and, after time for comment, issue a national drinking water regulation that is enforceable. The standards are generally set utilizing the best scientific information available and are to be applied with treatment echnologies that are understood to be feasible (Tiemann, 2017). In cases where small systems (serving less than

10,000 consumers) can show financial hardship there are provisions that allow for relief though not for microbial contaminants.

In addition, to standards and regulations the Safe Drinking Water Act addresses several specific problems. One of these is lead which was used extensively in older pipes and can appear in the water transported in these pipes. The Act authorizes the regulation of the use of lead in plumbing by requiring that plumbing be lead-free. The Act itself defines "lead-free" as no more than 0.2%. Subsequent amendments to the Act have tightened this definition still further. Concern about lead is especially pronounced because body-burdens are cumulative. A variety of other programs have been authorized to provide financial assistance to small communities and school districts who find that existing lead problems are beyond their financial capacity to rectify.

Drinking water supplies derived from ground water also acquire special attention in the Safe Drinking Water Act. Data on ground water use for drinking water supplies are apt to be confusing. The data show that the vast majority of public water supply systems (91%) employ ground water. Yet 68% of the drinking water consumers in the U.S. are served by systems that employ surface water. This apparent contradiction is explain by the fact that most metropolitan areas, where the majority of people reside, are supplied with surface water while the small systems that predominate in rural areas are supplied by ground water (Environmental Protection Agency, 2010). Ground water that supplies drinking water is thus subject to stringent regulations under the terms of the Act including identical standards and regulations regarding contaminants. The Act provides specific and elaborate protections from underground injections that might imperil the quality of ground waters used as drinking supplies. Additionally, aquifers that are the sole source of drinking water receive special protection and are eligible for federal funding to support ground water quality in waters that are sole source and to support state ground water quality protection programs (Tiemann, 2017).

In terms of the locus of authority, the Act authorizes the states to assume primary responsibility for the management and enforcement of the standards and regulations. There is some significant context here. The U.S. Congress has always been extremely reluctant to involve the federal government in any activity having to do with the management of ground water. The lone exception is ground water that falls within the jurisdiction of two or more states. Such ground water is called interstate ground water. The circumstances that led to the passage of the Safe Drinking Water Act had illustrated clearly that regulation of drinking water could be devolved upon the States without any restriction at all. Thus, the provision of the Act that allows the States to assume primacy for standards and regulations is consistent with the federal reluctance to become involved in ground water management and in the management of some local surface waters.

The Act specifies certain conditions which must obtain if a State is to qualify for primacy in the management of drinking water quality. First, it must set water quality standards that are as least as high as those promulgated by the federal government. It must develop effective procedures for enforcement, including a system of fines sufficient to deter citizens from violating the standards and regulations. And, it must maintain inventories, monitor and accomplish routine inspections. Finally, States must plan for the provision of safe drinking water supplies in the event of emergencies. Virtually all of the U.S. States and Territories have fulfilled the conditions for primacy and do, in fact, exercise primacy. The exceptions are the State of Wyoming, the District of Colombia and several native American tribes which are autonomously governed as a consequence of Treaties or legislation (Tiemann, 2017).

There are numerous amendments to the Safe Drinking Water Act. The Amendments of 1986 (P.L. 99-339) were wide ranging and focused on the speed with which EPA regulated contaminants; the establishment of strong requirements for disinfection and infiltration of public water supplies; the creation of well head protection programs (supported by demonstration projects): strengthening EPA's enforcement authorities. Additional amendments in 1988 (P.L. 100-572) and in 1996 (P.L. 104-182) attempted to add regulatory flexibility, target resources to the greatest health risks and increase the emphasis on the prevention of pollution. The Amendments of 2002 (P.L. 107-188) focused on the maintenance of security of public water supplies efforts to plan for and respond to bioterrorism aimed at public water supplies (Bearden, et. al., 2010).

The Safe Drinking Water Act of 1974 has served the nation well in protecting drinking water quality. Since its passage and implementation there have been few outbreaks of water-borne illness and plentiful supplies of healthful water have been available in most locales throughout the nation. Some 91 contaminants including chemical, biological and radiological contaminants are regulated. There are, however, signs that the quality of drinking water may not be as well protected in the future as it has been in the past. This is particularly the case because of the profusion and widespread distribution of toxic chemicals that are susceptible of appearing in drinking water supplies. In addition, much of the infrastructure that supports the gathering, transport and treatment of drinking water supplies is in need of renewal and maintenance. Unless this task is addressed aggressively the threats to drinking water quality are likely to grow quite rapidly (Venkataraman, 2013). The future challenges that the U.S. must address in fashioning the water quality management policies of the future are identified and discussed in the next section.

Water Quality Management in the U.S.: Future Challenges

Despite flaws –both basic and situational– the laws that promulgate the fundamental strategies and policies for managing water quality in the U.S. have served the nation reasonably well. This is true for both the qualitative condition of surface and some ground waters and also the quality of drinking water supplies nationwide. However, a number of potentially severe water quality problems loom. They will require both resources and political will if they are to be addressed effectively. Although these problems are numerous there are five that appear to be especially challenging. Three of these are problems of pollution that have been well known for many decades but have proved particularly vexatious and resistant to effective solutions. They are – toxic contaminants, non-point source contaminants and salinization of water and land. Two others concern the ability of the nation to respond to water quality management problems by devising appropriate regimes of governance and appropriate responses to public pollution management challenges. In this section each of these problems is discussed in turn.

Toxic Contaminants (Chemicals)

Toxic chemicals which can enter or are susceptible of entering drinking water supplies are regulated under the terms of the Safe Drinking Water Act of 1974 as amended. The Act provides for establishment of enforceable regulations, where indicated, and also stipulates the processes through which additional contaminates can be added to the list. New contaminants with the potential to be toxic appear in the environment every day. They come from industry, agriculture, pharmaceutical chemicals, mining and natural gas extraction. The Safe Drinking Water Act requires that potential contaminants be listed on a Contaminant Candidate List and requires further that research be undertaken for the purpose of deciding whether a contaminant should be regulated and at what levels. The legislation also requires that a decision to regulate or not be made on at least five contaminants in each five year period. Venkataraman (2013) provides evidence that shows that the number of contaminants being added to the Contaminant Candidate List is growing faster than the capacity of the EPA to evaluate them. The crux of the problem is that existing programs that identify and evaluate new contaminants are inadequate scaled and funded.

Moreover, this problem is being exacerbated by the current federal administration which has reduced and will continue to reduce the funding available to support both the research and the scientific assessments needed to evaluate potential contaminants. This means that even as the number of potential contaminants grows the capacity to evaluate them for possible regulation is shrinking. It appears only logical that under such circumstances the likelihood of a significant contaminant escaping regulation before it has done real damage whether to humans or the environment. In spite of these facts, Venkataraman (2013) reports the results of a number of polls that show sharp declines in public awareness to the fact that the threats to the healthfulness of water supplies are largely hidden from view.

Cranor (2017) has documented at some length the general difficulties faced by the government in trying to regulate toxics. He posits two crucial questions which underlie virtually all decisions about when and how to regulate.

- When in the life of the chemical should it be evaluated to determine whether it has deleterious health effects?
- What kind and how much scientific evidence should be required to protect public health?

He goes on to show that the vast majority of chemicals that are introduced into markets are not evaluated prior to such introduction. While a strong case can be made for requiring evaluation of chemicals prior to release to markets the default practice is to release them and assume that there will be no deleterious effects. With respect to the quality and quantity of science needed to evaluate new chemicals, Cranor documents many instances in which industry (and others) have insisted that regulation must be based on science that is sufficient to yield unambiguous results. Frequently, it is not feasible to develop such conclusions either economically or scientifically. The effect then is a failure to evaluate potential contaminants on the basis of their risk potential and simply assume that the lack of science about possible impacts means that those impacts will be benign. This sort of phenomenon has led to the enunciation of the "precautionary principle" in which decisions about the need for regulation must be premised on the notion that little information or insufficient information should be grounds for banning or severely limiting the proposal to proceed to develop or release to market (Cranor, 2017).

The problem of proliferation in the number of new chemicals developed for release each year coupled with inadequate regulation and a system of incentives that induces producers to resist regulation bodes ill for the future of water quality generally and drinking water in particular. There are no obvious, workable solutions to this problem because of the lack of resources to develop them. It is difficult to avoid the conclusion that the nation must await some catastrophic event that could have been avoided by proper regulation before developing reasonable regimes of regulation based on available science to protect the health and welfare of the public.

Non-Point Source Contaminants

The record of the last half century suggests that the nation has done a reasonable and effective job of cleaning up its surface waters and maintaining relatively good water qualities thereafter. The explanation for this success lies largely with the fact that management and regulatory policies have been largely focused on point sources of pollution. Similar success has not been achieved in the regulation and management of non-point source contaminants even though the importance of non-point source pollutants has been acknowledged in the Clean Water Act. The Act authorized several programs focused at managing non-point sources but there is general agreement that they have not been very successful. This is attributed to the fact that only a small fraction of the federal funds appropriated for pollution control were aimed at non-point sources and because of the inherent technical difficulties of regulating non-point source contaminants.

Non-point source pollutants are characterized by the fact that their sources are diffuse. They include sediments, nutrients, chemicals and contaminants and pathogens. They tend to be carried by storm water flows, snowmelt and other hydrologic phenomena that move dissolved or suspended solids across the landscape surface or percolate to ground water. In this latter case gravity and soil structure play important roles in mobilizing the pollutants (Puckett, 1995). The diffuse nature of these pollutants makes the regulation of them extremely difficult. In fact, they are almost impossible to regulate directly and hence must be regulated indirectly by controlling or regulating the activities that generate them. This tends to be a very expensive proposition and the expense is even greater when the costs of necessary monitoring are also counted. The consequences of unregulated non-point source pollution include sedimentation of waterways; human caused nutrient enrichment (usually from phosphorous or nitrogen) of lakes and streams (eutrophication); biological and chemical contamination of water supplies; and, ground water contamination. Thus, for example, the highly visible problem of eutrophication or artificial enrichment of waterways with nutrients is primarily due to non-point sources that are not effectively regulated (Puckett, 1995).

There are a variety of strategies and techniques for regulating non-point source pollution that have been developed over the last 50 years. Today, these are frequently subsumed under the heading of "Integrated Watershed Management". This concept incorporates the proposition that the management of water and related land resources should be carried out on a watershed basis since watersheds are the basic hydrological units. The concept also embodies the proposition that Best Management Practices (BMPs) should be employed if erosion, application of chemicals (fertilizers and pesticides) and the unwanted transport of sediments, nutrients and other contaminants are to be kept to an absolute minimum (Mostaghimi, Brannon, Dillaha and Bruggeman, 2001).

Techniques that can be employed to in integrated watershed management which would minimize non-point source discharges to places outside the watershed include:

- Conservation tillage to reduce erosion and sediment flows.
- Contour farming and strip cropping.
- Buffer zones, especially adjacent to waterways.
- Use of cover crops and appropriate crop rotation
- Precision farming for nutrient and pest management.
- Rotational grazing.
- Sediment detention structures and constructed wetlands where necessary.

The appropriate mix of these techniques varies from place to place and depends upon local conditions and activities. The variability of hydrologic and other environmental conditions across watersheds nationally means that centralized, command and control regulation –as might be employed at the federal level– is not especially practicable. Moreover, the current difficulty with utilizing the array of Best Management Practices stems from the fact that they must be employed on a largely voluntary basis. These means that it is unlikely that expensive steps will be undertaken at all and it creates a problem within the watershed where agricultural, industrial and other operators who are otherwise independent must act cooperatively (Mostaghimi, Brannon, Dillaha and Bruggeman, 2001).

There are a variety of ways in which residents of a watershed might organize to manage non-point sources. These include the formation of special districts, which function as local units of governments; the establishment of cooperatives that establish regulatory regimes through processes of self-governance; as well as informal collective arrangements. Point\non-point source trading whereby relief from specified point sources regulations can be granted in exchange for control of non-point source pollution has also been proposed (Ribaudo and Gottleib, 2010). It is probably true that states and even the federal government could mandate such arrangements but this is quite unlikely in the absence of subsidies which are likely to be very expensive in the aggregate. There are instances in which watershed residents have organized voluntarily to work collectively for the control of non-point source pollution but these are few in number and it is unlikely that strictly voluntary organization could solve the problem on a national –or even perhaps– regional scales.

The picture that emerges is one that suggests that non-point source pollution is not susceptible of being controlled at a national or state level easily or inexpensively. Best Management Practices and technology standards can be mandated but that does not guarantee that they will be effective. One reason why the effort to control point source emissions has been much more effective than companion efforts to addressed to non-point source emissions is the assymetric level of federal investment in control efforts. It is estimated that 90% of the federal funds appropriated for water quality management since 1972 have been used to address point source pollution problems. The remaining 10% were focuses on non-point source problems. This underscores both the need for balanced government financial support. The fact that most programs of non-point source control will have to be devised and implemented locally or regionally will complicate any national effort to deal with these problems further. Finding ways to design and implement programs to manage non-point source pollutants effective will likely remain a serious problem in the U.S. for the foreseeable future.

Problems of Salinity in Agriculture and Elsewhere

All naturally occurring waters contain dissolved mineral salts. So long as those salts are in low concentrations they do not create qualitative problems for all but a few uses of water. Waters with "significant" concentrations of salts (defined as greater than 5000 parts per million) are considered to be of impaired quality for most uses. Good quality water is defined as having saline concentrations of below 600 ppm. Activities like irrigated agriculture in which water is subjected to a phase change from a liquid to a gas concentrate salts. Thus, as water is evaporated or transpired the salts remain in the root zone and accumulate unless they are manageged. Above some threshold level, which differs by crop, salinity concentrations result in reductions of yield and in relatively higher concentrations constrain productivity altogether. Salinity can also be introduced into crop root zones by high water tables or by natural soil salinity, which can be dissolved in irrigation water (Gratton, 2002).

Irrigated acreage in the U.S. totals about 22.26 million hectares. Of this, it is estimated that perhaps 30% is subject to salinization. This is significant for production because about 45% of crop production is accounted for by the 28% of hectares that are irrigated (U.S. Department of Agriculture, 2014). The common method of combatting salinity is to apply water in addition to what the crop demands for the purpose leaching salts from the root zone. This increment of water is called the leaching fraction and the quantity of it depends upon the salt concentration of the water and the crop in question. Where water tables are high and/or the leaching fraction is not readily drained it is necessary to provide drainage facilities to remove the water from the root zone via gravity flow. This is commonly done by installing subsurface drainage tiles to remove the water from the root zone. The drainage water is normally quite salty and presents a major disposal problem. Ocean disposal and evaporation ponds are frequently used for this purpose but are not without their own set of problems (Orlob, 1991). Thus, where irrigated agriculture is practiced, water and soil salinity threatens agriculture productivity and can pose a related threat from saline drainage waters which may be a necessary outcome of management efforts to protect soil and water productivity (Pitman and Lauchli, 2002).

The salinization of agricultural lands is a problem that goes back thousands of years. The Sumerian civilization, the great Mesopotemian and the Hohokam of Americas are among the civilizations thought to have been destroyed by the salination of their agricultural lands and subsequent loss of their food supply. The management of salinity and its contribution to the deterioration of water quality will continue to be a problem into the indefinite future. Now, however, salinity is poised to become a water quality problem for cities located in the arid and semi-arid portions of the U.S. The city of Phoenix, Arizona is the prime example. Phoenix is the 5th largest city in the U.S. in terms of population. It is located in an arid region with an average annual precipitation of 200 mm. Its water supply is made up of a significant quantity of water imported from remote locations. Much of that water is quite salty. The estimated quantities of salt imported to the Phoenix area each year are 2.2 X 108 kg. while the amount exported is only 2.2 X 105 kg. This is not a sustainable situation. (U.S. Bureau of Reclamation, 2015).

The current most visible symptom of increasing urban salinization is found in the increasing salinity content of the wastewater streams reaching the wastewater treatment plants. The concentrations that might be expected from the import of salt have been magnified by the fact that water softeners are widely used in the Phoenix Area. The softeners work by employing an exchange column which exchange hardening elements (zeolites) for sodium ions. The water softening then contributes addition mineral salts to the waste stream. The severity of the problem becomes clear when it is recognized that virtually all of the treated wastewater in the Phoenix area is recycled. It is used for landscape irrigation (golf courses and public landscaping) and ground water recharge. Desalting these waste streams will be relatively expensive even though desalting costs tend to be sensitive to the salinity of the feedwater (National Research Council, 2008). The point is that one way or another the increased costs of a relatively expensive and scarce water supplies are only likely to get more expensive with time. Reducing salt inputs an be achieved by reducing water use (in an already water stressed area) and regulating implements such as softeners that contribute to the problem (U.S. Bureau of Reclamation, 2015). With time, salinity will become a pervasive problem that will impact most consumptive uses of water. Thought and research are only now beginning to be applied to this problem as it effects urban areas located in arid and semi-arid environs.

Monitoring

The successful management of water quality (and water quantities) depends upon the generation of appropriate data on the trends and state of water quality. Effective enforcement of standards and regulations is dependent upon monitoring. Other things equal, the more sophisticated the water quality management system, the more data on water quality is needed for both system design and system operation. There is simply no substitute for good water quality and water quantity data. It is a basic and essential piece of the water management puzzle. Modern methods of monitoring rely on sophisticated technology and are often costly to acquire and maintain. Monitoring will almost always be a publicly supported activity since the benefits are widespread. Yet, importance of gathering and managing data is not widely appreciated by the public. Indeed, it is very difficult to generate the political support needed to garner adequate funding to support essential monitoring activities.

This has been especially true in the United States over the last two or three decades where, for example, the number of stream gauging stations has been significantly reduced as a consequence of budget stringencies. The continuing pressures on water quality from economic and population growth are occurring at a time when the resources and will needed to monitor the qualitative consequences of these pressures on the nation's waters have become inadequate. There is no evidence that this trend of increasing inadequacy is likely to be reversed in either the near or more distant future. Yet, there will be a need for new and improved techniques and protocols for water quality monitoring in the future if sharp declines in water quality are to be avoided. Developing and maintaining the water quality monitoring systems needed for the future will be on of the nation's major water quality challenges.

Problems with Infrastructure[1]

The United States has very serious problems with infrastructure of all sorts. This is attributable to many years of deferred maintenance and a lack of political will to get on with the tasks of renewing infrastructure from basic transportation facilities to water provision and sanitation facilities. Infrastructure for both water supply and sanitation is aging. Moreover, aging facilities are being required to serve larger populations and to a higher level of quality then was true in previous years. In 2013 the American Society of Civil Engineers (2013) concluded that aging drinking water systems face a deficit of $USD 11 Billion to replace and renew facilities and comply with current and future water regulations. The report concluded also that the costs of treating and delivering drinking water are in excess of the funds available to sustain drinking water systems. The concern extends to both facilities which can be federally underwritten as well as to local utilities which continue to have operating deficits. Finally, the report made note of the fact that elected politicians seem currently unwilling to provide the funds needed to sustain and renew both drinking water and sanitation. This, in turn, places the protection of public health and the delivery of public services in future jeopardy.

The picture with respect to quality is very much the same. Many of the wastewater treatment facilities subsidized with federal dollars under the Clean Water Act are now approaching 50 years in age and investment in renewal and rehabilitation will be badly needed in the near future. The prospects for needed funding and renewal appear dim. Part of the problem lies with the fact that the public appears to be unaware of the threats posed by the aging of critical drinking water and waste water treatment facilities. Venktaraman (2013) reports the results of a number of polls that show sharp declines in pubic concerns about the quality and availability of water supplies. He attributes the lack of awareness to the fact that threat to the availability and healthful of water supplies are largely hidden from view. Perhaps, more importantly, he notes that the price of water supplies and wastewater treatment services in the U.S. are very small, averaging just 0.3% of disposable income. This means that consumers only cover a small portion of what is required to deliver safe water supplies and provide sanitation services.

The urban water supply and sanitation situation in the United States provides a good example of the "Water Paradox in Developed Nations" (Venktaraman, 2013). The quantity and quality of water supply and sanitation services is now very much in jeopardy despite the fact that they were once the

1. Parts of this discussion draw heavily on Vaux, 2015

envy of the world. Public apathy and an apparent unwillingness of users to pay a significant portion of the capital and operating costs of such systems threatens the future adequacy and quality of water supplies and water quality generally. Overcoming this apathy will require both education and development of the political will to attend to these critical infrastructure issues.

Governance

The history of water quality and the management of water quality in the United States illustrates how effective management requires the intervention and supervision by the federal government. The setting and enforcing of water pollution standards becomes an object of competition when left to the states. States have an incentive to set standards low and/or lower them in an effort to attract new business or attract business from other states that may have more stringent standards. The result is either no standard or some lowest common standard that allows for unacceptable levels of pollution. Similarly, federal responsibility and oversight is required to protect and safeguard the quality of drinking water. Only the federal government has the resources needed to support the science upon which safe drinking water standards can be based. And, only the federal government is in a position to ensure that a common set of drinking water standards is established and enforced nation-wide. This is not to say, that the federal government cannot devolve standard-setting and enforcement to the States wherein the federal government retains oversight and supervisory policies to ensure that the states carry out mandates such as those contained in the Safe Drinking Water Act of 1974 as amended. Despite the primacy accorded to the federal government by modern water quality and safe drinking water laws there are concerns that must be addressed if past successes will be a prelude to the future.

It has been said more than once that a camel is a horse constructed by a committee. Participatory democracy is messy and depends upon the willingness of the participants to find workable compromises. Thus, for example, the processes that led to the pollution management strategies that were adopted in the 1970s led to an overarching approach which treated waste receiving sinks individually. Hence, the country has failed to manage its waste streams in an integrated fashion that acknowledged not only all three sinks – land, air and water – but also the interactions between them. Even where the laws of physics govern and there is no dispute about the accuracy and veracity of the relevant science some departure from the prescriptions of that science had to be accepted as a price of getting any effective pollution control programs at all. But what of the case where the science is uncertain?

The inherent uncertainty of much science has been used in a strategic sense to block regulatory actions (Cranor, 2017). This is frequently accomplished by the targets of regulation and rule-making who insist that no regulations should be established unless there is complete certainty about the science. Such strategies often rely upon the employment of "experts" willing to testify that there are valid scientific disagreements that should be settled first. Another such strategy, frequently employed by environmentalists holds that the "precautionary principle" should be applied in all instances where an activity might result in some environmental damage. The "precautionary principle" holds that where the science is inadequate to support some activity or an action permit might be sought the presumption should be that virtually complete scientific certainty should obtain before the activity in question is permitted or allowed.

All things equal, policies should be based upon the best available science. However, strategies designed to obfuscate or falsely contest the credibility of existing science may tend to discredit available science which is solid and sound. Focusing on the certainty or lack of certainty of the available science is frequently disruptive and also frequently distracts from the objectives of the policy-making effort in question. The democratic government of the type that currently prevails in the United States appears to invite this kind of squabbling over science for the purpose of disrupting the policy process rather than trying to ensure that appropriate policies are enacted, based on the best available science and directed toward the most urgent goals where water pollution or other kinds of environmental contamination are concerned. In the next several years thorough reviews of water quality management will be necessary as a part of a long overdue need to update those policies in response to contemporary circumstances. Those reviews should account for available science and set the stage for the use of sound science in fashion of water quality management policies for the future.

There is a second critical problem with governance that plagues the country today. The senior political leadership eschews science. Thus, for example, climate change is dismissed as a hoax perpetrated by the Chinese for the purpose of damaging the economy. Senior officials appointed to lead the top environmental agencies have expressed an intent to roll back many environmental regulations and generally encourage further development of hydrocarbons and other mineral deposits on public lands that have been historically reserved for environmental and recreational purposes. Although most of the regulations issued pursuant to the Clean Water Act as amended and the Safe Drinking Water Act as amended have not been rolled back some regulations and procedures related to the management of toxic waste have been relaxed (Cranor, 2018). It would not be surprising if other actions were forthcoming that would further weaken water quality regulations including those related to the governance of drinking water quality.

The problems related to the regulation of water quality and drinking water safety at the national level are problems that are likely to persist in the absence of new and innovative water quality legislation. The problems with current political leadership at the national level are problems that directly threaten environmental quality (including water quality), public health and safety and a host of other programs that enhance public welfare. All of these programs have traditionally been under the purview of the national government. The prospects for solution of the problems created by anti-scientific policies and policies related to the provision of environmental quality and the services provided by it are clouded further by apparent public apathy. Venktaraman (2013) reports the results of a number of public opinion surveys that reveal pervasive public apathy to issue related to water quality and sanitation. Whether these disturbing trends in environmental quality and the making of policies for the governance of environmental quality can be reversed likely depends upon whether levels of public concern can be aroused to the point where these current trends can be reversed through electoral processes.

Conclusions

From its beginnings as a country the U.S. had ample supplies of good quality water. Over time water quality declined as population and economic growth generated wastes, some of which were disposed of either accidently or by design in water bodies. In the 19th and early 20th centuries a number of strategies were adopted in an effort to attenuate the decline in water quality and provide the means of improving it. These included the construction of more storage to dilute pollution and a federal law vesting the responsibility for managing and improving water quality with the states. Neither of these strategies proved workable. At the mid-20th century two laws were adopted that proved to be reasonably effective. The Clean Water Act of 1972 addressed the state of the nation's surface waters and provided means for improving and regulating their quality. The Safe Drinking Water Act of 1974 was adopted in response in an increase in waterborne disease. Both of these Acts, as amended, proved reasonably successful in meeting their stated objectives.

Despite these apparent successes there are flaws in each act that need to be corrected. Additionally, economic and population growth has continued with the result that today both Acts need updating if they are to be as successful in the future as they have been in the past. The Principle of Materials Balance which is based upon the Law of Conservation of Energy and Matter leads to a derivative conclusion that it is important to manage waste in an integrated fashion. That is, that the three waste sinks –land, air and water– should be considered together and the interrelationships between them should be acknowledged by modern water pollution control strategies. The Clean Water Act of 1972 is sink specific as is the Air Pollution Control Act. Future water pollution management strategies should treat water as one of three sinks that need to be managed holistically and with explicit attention to the relationships between the sinks. The Clean Water Act also authorized a very large wastewater treatment program which was significantly subsidized with federal funds. The program has been highly successful but the facilities are nearing the end of their designed lives and will need to be replaced. There is no evidence yet that the federal government is prepared to address these challenges.

The Safe Drinking Water Act if 1974 requires careful regulation of toxic contaminants to prevent them from appearing in drinking water in specified concentrations. New contaminants appear every day from industry, agriculture and pharmaceutical production. The measures for identifying and evaluating new contaminants provided for in the 1974 Act are inadequate to meet the demands of today. There are several possibilities for rectifying this problem. Substantial new resources can be made available to increase the number of contaminants that are evaluated and subsequently regulated each year. Alternatively, policies can be adopted to control contaminants prior to the time they are released to market. Current practice calls for identification of dangerous contaminants only after they have been released and may already have done damage to the environment and public health. In addition, aging water supply and sanitation facilities threaten the quality of drinking water and a major national program to rebuild and upgrade infrastructure should include these facilities.

There are also a number of specific water quality problems that must be addressed in a timely fashion if the nation is to enjoy the benefits of high quality ambient waters and healthful drinking water supplies. These are dealt with in the final section.

Recommendations

Contaminants

Contaminants are now pervasive in the environment and new contaminants are released every day. Existing institutions are not equipped to deal with the problem at its current scale. Solutions to the problem will require both substantially augmented resources to support contaminant identification and evaluation and tougher regulations. Regulations that require careful and independent third party evaluation of chemicals before they are released will ultimately have to be adopted if widespread "public poisoning' is to be averted.

Non-Point Source Pollutants

Earlier legislation has been fairly effective in cleaning up and regulating significant amount of point source contamination. Today, much of the pollution in surface waters and ground waters comes from non-point sources. Control of these pollutants will require more attention from all levels of government federal, state and local than they have received in the past. It appears that some adaptation of integrated watershed management holds the most promising prospects for managing this problem. An intergovernmental institutional arrangement that might be successful would take advantage of the resources available to the federal government and provide those to states who would be required to establish and oversee the creation and operation of local, watershed based, districts which would be required to develop and implement integrated watershed management programs aimed specifically at controlling non-point source pollution. The federal government would provide the resources and oversight while the states would provide additional oversight and enforcement of the requirement that such districts be effective and sustainable.

Salinity – Agricultural and Urban

In the long-run salinity –be it agricultural or urban– destroys the productivity of the land and increases the costs of urban water supplies and sanitation. So, long as the import of salt to a basin exceeds the export salinity will become an increasing severe problem. Managing saline drain waters will be crucial where agricultural lands are afflicted with highly saline water supplies and high water tables. Lands with exceptionally high saline inputs and drainage problems will ultimately be forced out of production. It may be beneficial to retire such lands early and manage the residual salt balances in effective ways. Urban salinity promises to increase the cost of water supply and sanitation as the problems of salt disposal become increasingly severe. It is not a stretch to imagine circumstances in which the costs of controlling urban salinity lead to outmigration. Desalinization is quite expensive though the costs are sensitive to salt concentration of feedwaters and the use of desalinization technology may buy considerable time for urban areas.

Infrastructure

United States has a severe infrastructure renewal problem caused by public apathy and general neglect. Water supply and sanitation infrastructure is no exception to the general problem. It is difficult to see how this problem can be overcome without massive infusions of money from national, state and local tax bases as well as from rate payers. What is needed most at the moment is a large scale and effective education program designed to alert the public to the seriousness of the problem; the consequences of doing nothing; and the costs of addressing it. It is true that decentralized water supply systems and more use of recycled water may help. The long deferred nature of the renewal problem together with the fact that many local purveyors do not now have reserve funds or a means of getting them from existing rates suggests that the problem cannot be solved short of increases in rates and taxes.

Governance

The current posture of the political leadership in the environmental institutions of the federal government focuses on eliminating science as a basis in policy-making and abandoning many of the current regulations. These circumstances threaten real harm in the form of unregulated toxics and the relaxation of regulations intended to protect and advance public health and safety as well as the general welfare. There are two remedies and both are needed. First, through the electoral process pick senior leaders who will rely on science and scientific evidence. Second, invest in education at all levels and cultivate a populace that is largely aware of the need for science as well as reasonable regulations to protect the environment, public health and the general welfare.

References

Adler, Robert W., J.C. Landeman and D.M. Cameron. 1993. The Clean Water Act: 20 Years Later (Washington, DC: The Island Press). pp. 320.

American Society of Civil Engineers. 2013. Report Card for America's Infrastructure (2013). http:// http:// www.infrastructurereportcard.org/

Andreen, William L. 2003. Water Quality Today – Has the Clean Water Act Been A Success? Alabama Law Review. Vol. 537

Ayers, Robert U., Allen V. Kneese and Ralph C. d'Arge. 2015. Economics and the Environment: A Materials Balance Approach (New York, NY: Routledge). pp.121.

Baumol, William J. and Wallace E. Oates. 1993. Economics, Environmental Policy and the Quality of Life. Engelwood Cliffs, NJ: Prentice Hall, Inc.) pp. 377.

Bearden, David M., Claudia Copeland, Linda Luther, James E. McCarthy, Linda-Jo Schierow and Mary Tiemann. 2010. Environmental Laws: Summaries of Major Statutes Administered by the Environmental Protection Agency (Washington, DC: Congressional Research Service) Report # 7-5700. pp.22-30.

Bureau of Water Hygiene. 1970. Community Water Supply Study – Analysis of National Survey Findings. Washington,D.C.

Copeland, Claudia. 2016b. Clean Water Act: A Summary of the Law. Congressional Research Service. CRS Report RL 30030. Washington, DC

Copeland, Claudia. 2016a. Water Quality issues in the 114th Congress: An Overview. Congressional Research Service. Report 7-5700. Pp. 1-17. Washington, DC.

Cranor, Carl F. 2017. Tragic Failures: How and Why We Are Harmed by Toxic Chemicals (New York, NY: Oxford University Press). pp. 252.

Cranor, Carl F. 2018. Personal Communication. 1-8-18.

Dolbear, F. Trenery, J. 1967. On the Theory of Optimum Externality. American Economic Review. Vol. 57. pp. 90-103.

Douglas, Thomas J. 1976. Safe Drinking Water Act of 1974 – History and Critique. Boston College Environmental Affairs Law Review. Vol. 5. Issue 3. Article 5. pp. 1-44.

Environmental Protection Agency. 2010. Factoids: Drinking Water and Ground Water Statistics for 2009. Available at: https://nepis.epa.gov/Excel/zyPGF.cgi/P100N2VG.PDF?Dockey=P100N2VG.PDF

Gratton, Stephen R. 2002. Irrigation Water Salinity and Crop Production. (Oakland, CA: University of California Division of Agriculture and Natural Resources). Publication 8806. pp. 1 – 8.

Lawrence R. and Elliott P. Laws. 1987. The Water Quality Act of 1987: A Major Step in Assuring the Quality of the Nation's Waters. Environmental Law Reporter. 17ELR 10311.

Mostaghimi, Saied, Kevin Brannon, Theo A. Dillaha and Adriana Bruggeman. 2001. Best Management Practices for Nonpoint Source Pollution Control: Selection and Assessment in Ritter, William and Adel Shirmohmammadi, eds. Agriculture and Nonpoint Source Pollution: Watershed Management and Hydrology (Washington, DC: Lewis Publishers) pp. 257-304.

National Research Council. 2004. Confronting the Nation's Water Problems: The Role of Research (Washington, DC: The National Academies Press). http://doi.org/10.17226/11031.

National Research Council. 2008. Desalination: A National Perspective (Washington, DC: National Academies Press) pp. 298.

Orlob, Gerald T. 1991. San Joaquin Salt Balance: Future Problems and Possible Solutions in Ariel Dinar and David Zilberman, eds. The Economics and Management of Water and Drainage in Agriculture (Boston, MA: Kluser Academic Publishers) pp. 143 -167.

Pitman, Michael G. and Andre Lauchli. 2002. Global Impact of Salinity and Agricultural Ecosystems. In Andre Lauchli, Andre and Ulrich Luttge, eds. Salinity: Environmental -Plants-Molecules (Springer, Dordecht) pp. 3-20.

Puckett, Larry J. 1995. Identifying Major Sources of Nutrient Water Pollution. Environmental Science and Technology, Vol. 29, No. 9. pp. 408A - 414A.

Ribaudo, Marc O. and Jessica Gottleib. 2010. Point-NonPoint Trading – Can It Work? Journal of the American Water Resources Association. Vol. 47. No. 1. pp. 5-14.

Tiemann, Mary. 2017. Safe Drinking Water Act (SDWA): A Summary of the Act and Its Basic Requirements. Congressional Research Service. Report 7-5700. Washington, D.C. pp. 1 – 27.

U.S. Bureau of Relcamation. 2015. Central Arizona Salinity Study, Technical Appendix O. pp. 1-12. usbr.gov/lc/phoenix/programs/cass/cass/html

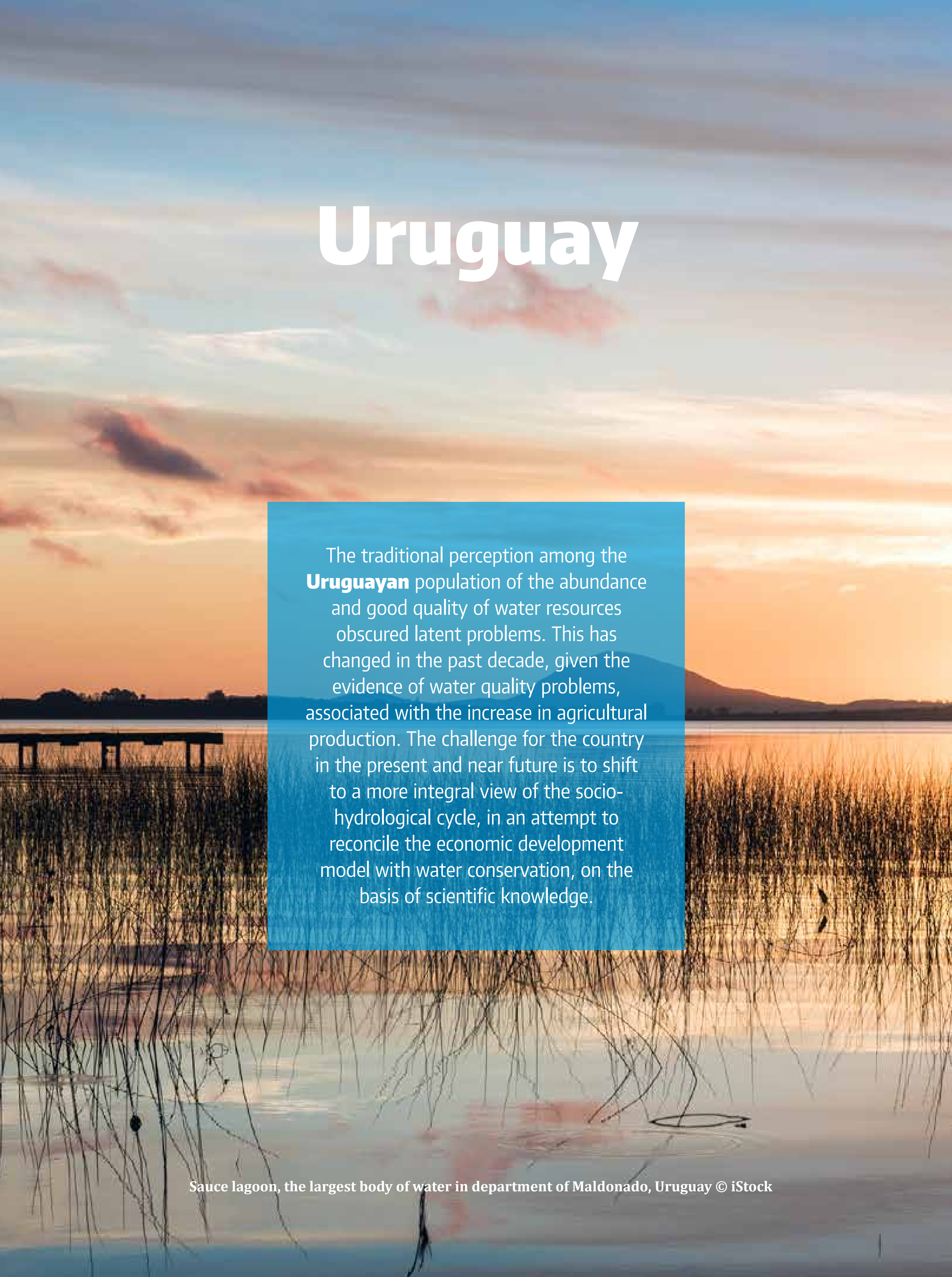
U.S. Department of Agriculture. 2014. 2013 Farm and Ranch Irrigation Survey. U.S. Census of Agriculture Washington, DC: U.S. Department of Agriculture).

Vaux, Jr., Henry. 2015. An Overview of Urban Water Management and Problems in the U.S.A. in IANAS, Urban Water: Challenges in the Americas. A Perspective from the Academies of Sciences. (Mexico City, Mexico: InterAmerican Network of Academies of Science). pp. 504-523.

Venktaraman, Bhawani. 2013. Access to Safe Water: A Paradox in Developed Nations. Environment. Vol. 55, No. 4. July/August. pp. 24-34

Uruguay

The traditional perception among the **Uruguayan** population of the abundance and good quality of water resources obscured latent problems. This has changed in the past decade, given the evidence of water quality problems, associated with the increase in agricultural production. The challenge for the country in the present and near future is to shift to a more integral view of the socio-hydrological cycle, in an attempt to reconcile the economic development model with water conservation, on the basis of scientific knowledge.



Sauce lagoon, the largest body of water in department of Maldonado, Uruguay © iStock

Water Quality in Uruguay: Current status and challenges

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Abstract

In Uruguay, the effects of increased production and agricultural productivity have begun to be noticed in the quality of water resources, modifying the traditional social perception. The great challenge is to reconcile the economic development model with water resource conservation, mainly through the implementation of proper regulations, based on scientific development and technical innovation.

1. Introduction

Most of the country lies within the basin of the Uruguay River which, together with the Paraná and Paraguay rivers, comprise Río de la Plata. Surface water courses drain into six major watersheds: the River Negro (68400 km^2), the River Uruguay (45300 km^2), the River Santa Lucía (13400 km^2), Río de la Plata (12100 km^2), the Atlantic Ocean (9300 km^2) and Lagoon Merin (27800 km^2) (**Figure 1**). Most of these basins have soils with low infiltration rates which, combined with a high intensity of precipitation, lead to high surface runoff, whose annual average indicates a good availability of water resources in relation to the number of inhabitants (18900 m^3 per capita).

Soil and climate features make Uruguay a particularly suitable territory for agriculture and livestock farming. With a GDP of over $52,000 million USD and a per capita income of

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US $15230, it is currently considered a high-income country (World Bank, 2018). Between 2003 and 2016, GDP experienced average annual growth of 4.5%, with the agroindustrial sector being the main source of wealth generation, accounting for 78% of total exports.

Although cattle products have historically been the main export item, the burgeoning development of agriculture -which has experienced a significant increase in both area and intensity- has led to a increase in soil productivity and in recent years has displaced livestock as the main income generator for the country. In 2017, agroindustrial sales exceeded US $9 billion, the main products being grains (especially soybean), beef, and forestry and dairy products (Uruguay XXI, 2016). It is therefore primarily an agricultural country and an exporter of agricultural goods.

Since the beginning of this century, the temperate region of South America has seen an increase in the rate of land use change (FAO, 2009). According to data from the Directorate of Agricultural Statistics (MGAP-DIEA, 2003, 2015), in Uruguay, the area of rainfed crops increased more than fourfold between 2000 and 2015. This increase was largely due to the cultivation of soybean, which increased elevenfold during the period (**Table 1**). Forestry expanded even more, increasing its occupied territory during the same period more than 30 times, while dairy activity intensified, in the latter case with a significant decrease in the proportion of small and medium producers (**Table 1**).

These changes also resulted in a threefold increase in the importation of nitrogen and phosphorus fertilizers (**Table 1, Figure 2**), while the amount of pesticides rose by 20%, with herbicides registering the highest growth in imports (30%).

Figure 1. Map of Uruguay, highlighting the dense main water network and the principal river basins

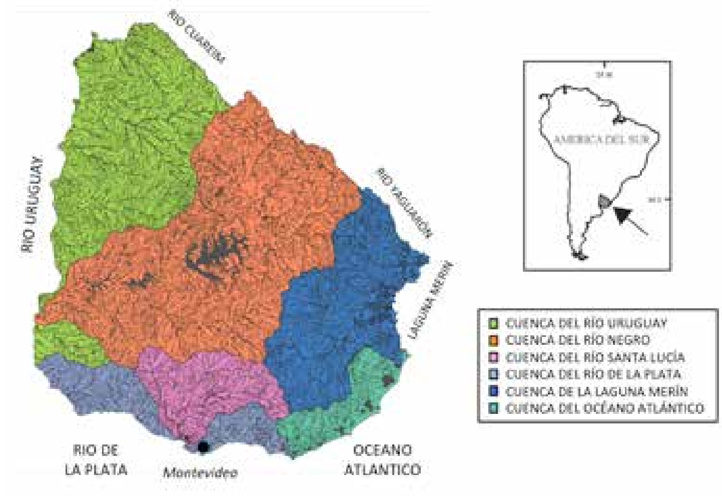
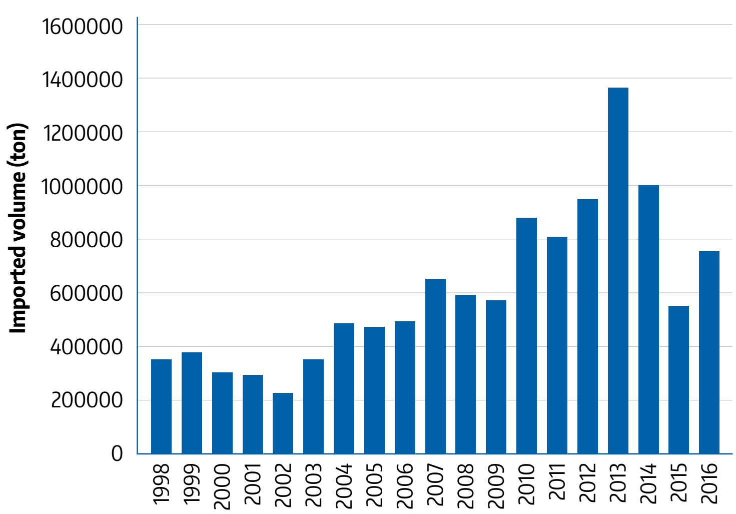


Figure 2. Evolution of fertilizer imports in Uruguay between 1998 and 2016



Source: MGAP-DGSSAA data.

Table 1. Evolution of agricultural and forestry area, industrialized milk and importation of nitrogen and phosphorus fertilizers in Uruguay between 2001 and 2015 (DIEA, 2003, 2015)

Type	Sugar harvest 2000-2001	Sugar harvest 2014-2015
Rainfed crops (ha)	341000	1500000
Soybean (ha)	12000	1334000
Forestry (ha)	58000	1800000
Industrialized milk (thousands of liters)	1047	2927
Fertilizer imports (ton)	300000	800000

Source: DIEA, 2003; 2015.

With an approximate population of 3,400,000 inhabitants (INE, 2015), according to Tabaré Aguerre (minister of agriculture between 2010 and 2017), Uruguay is able to feed approximately 30 million people and one of the objectives of government policies is to boost this productive capacity by 30% (Presidencia, 2014).

Since the outset, the country has been linked to livestock, and pastures are its emblem. Since the country is predominantly flat, it has been used almost entirely for agricultural purposes since colonial times. Private property has been the main form of ownership, government lands are scarce and conservation work is carried out in less than 1% of the country (MVOTMA, 2016a). Accordingly, pristine ecosystems, understood as those existing in the same condition as they had prior to European colonization, are practically nonexistent. With a population density of approximately 19 inhabitants/km^2 and 95% of the population residing in urban centers, the country has a very small population in rural areas (INE, 2015). The general perception is that Uruguay is characterized by large expanses of natural countryside, where nature dominates. However, this conception has been formed on the basis of a heavily urban and European culture, which has tended to ignore First Nations and pre-colonial natural environments. In fact, several species of animals have become extinct during the occupation of the territory, while many others are endangered, mainly due to the loss of habitats (Soutullo *et al*., 2013).

In short, although the country has limited industrial development and its economy is predominantly agricultural, its territory and ecosystems have undergone more changes than the population realizes.

In general terms, water resources meet the needs of users, the first priority being the supply of drinking water to populations. However, in a country where nearly 95% of the land is under some type of productive use, a large number of water courses are expected to have higher concentrations of nutrients than the population might expect or admit while some of them are likely to have problems of eutrophication (Kruk *et al*., 2013; OAN, 2017). In recent years, national conflicts have begun to emerge between productive activities and the sustainability of water, mainly for recreational uses and for supplying the population, due to the deterioration of its quality (**Figure 3**).

Figure 3. Ramírez beach (Río de la Plata) on the coasts of Montevideo, where an accumulation of cyanobacteria can be seen in the foreground

Photo: Luis Aubriot.

2. Current water quality issues in Uruguay

This section will address key issues concerning water quality in Uruguay. It begins by exploring the case of eutrophication in the main water bodies in Uruguay and their reservoirs, and includes a specific example on the subject in Cisne lagoon. It then analyzes the presence of heavy metals in sediment, specifically in the coastal area of Montevideo, describing a specific case of organic pollutants in that area. This is followed by the identification of the effects of agrochemicals on aquatic biota, particularly fish, and a case study on the presence of pesticides in fish at a RAMSAR site in the Uruguay River. Lastly, enteric viruses in various aquatic matrices are explored. These specific issues, despite being crucial and topical, do not cover all the water quality problems in Uruguay, but they do represent some of the main challenges the country must face now or in the short term.

Table 2. Characteristics of the main rivers in Uruguay

River	TP	TN	Basin area	Flow	Large dams (n)
Santa Lucía	200 (<10 – 1060) n=298	920 (105 – 3000) n=160	13413	116	2
Negro	114 (62.8 – 913) n=88	725 (350 – 6000) n=94	70714	930	71
Uruguay	50 (11 – 887) n=473	990 (90 – 3300)	440000	4622	66

The median and range (minimum - maximum) of the concentration of total phosphorus (TP) and total nitrogen (TN), the drainage basin area, main channel flow (historical average) and number of large dams (volume> 3x106m^3) are shown).

2.1 Water quality and trophic status of rivers and reservoirs in Uruguay

The increase in agricultural, forestry and dairy activities is recognized as one of the main causes of eutrophication and deterioration of the water quality of rivers, reservoirs and coastal areas around the world (Smith, 1999, Moss 2010). In Uruguay, several studies indicate that this process is occurring rapidly, causing serious health problems in inland (Oyhantçabal and Narbondo, 2014) and aquatic ecosystems, as well as in their use for fishing activities, recreation and drinking water supply (Rodríguez-Gallego *et al*., 2017; Arocena *et al*. 2013; Pacheco *et al*., 2012; Chalar *et al*., 2011).

These impacts are in addition to those generated by traditional livestock. Studies evaluating the integral ecological quality of streams in the Santa Lucía river basins (Arocena *et al*., 2008), Negro superior and Tacuarembó show widespread alterations in the natural cover of riparian zones and the channels, due to the action of cattle, which causes a physical impact (trampling and herbivory) and provides organic matter (excrement). Moreover, dairy production (with a high concentration of livestock) and agriculture in areas adjacent to streams contribute to the eutrophication of water bodies.

One of the main consequences of eutrophication is the appearance of potentially toxic cyanobacteria blooms. These events are recorded in various bodies of lentic and lotic water in the main basins in the country (Ferrari *et al*., 2011, Bonilla, 2009). Many of these blooms, with high levels of microcystins (toxins), can have harmful effects on human health, either through direct contact in recreational activities or as a result of drinking contaminated drinking water. Microcystins (hepatotoxins) are the most frequent toxins in the world, as is also the case in Uruguay, although blooms with neurotoxins have also been reported in various water bodies in the country (Bonilla *et al*., 2015). Toxins can also affect the health of animals that drink from water sources with cyanobacteria. There have been reports of cattle deaths in the Negro River basin, probably associated with the intake of high concentrations of toxins (Font, 2016).

A synoptic analysis is provided here on the current state of eutrophication of the main lotic ecosystems in the country: the Santa Lucia, Negro and Uruguay rivers (**Figure 1**). These three rivers receive anthropic impacts of various types and their waters are used for multiple purposes (potabilization, electric power generation, fishing, irrigation, transport, recreation and industrial activities). According to the total nutrient concentrations (Table 2), all three systems are classified as eutrophic and hypereutrophic.

Santa Lucia river

This river is located in the south of Uruguay and is the country's main source of drinking water, supplying 60% of the population. The water supply flow is regulated by three reservoirs. The use of water resources for drinking water conflicts with the type of land use of the basin, its urbanization and industrialization, which has caused several environmental problems and severe symptoms of eutrophication. Cities in the basin do not have sanitation or else it is incomplete and lacks tertiary treatment of effluents (except for the cities of Florida and Canelones). Moreover, 23 of the 54 operating industries (slaughterhouse, dairy, textiles, beverages), began to use complete liquid effluent treatment in 2016. Land uses comprise livestock (71.3%), including the dairy farms and milking parlors that cover more than 25% of the surface of the basin, followed by agriculture (16.2%) and forestry (4.2%), with 7.2% of native forest, wetlands, water bodies and rocky soils (Achkar *et al.*, 2012). One of the most notorious symptoms of environmental deterioration was the appearance in March 2013 of cyanobacterial blooms (*Dolichospermum* sp.). with high production of geosmin, giving the water an unpleasant taste and smell.

The river has experienced progressive eutrophication since the last decade, reaching record levels of total phosphorus (TP) in 2011 (median and range: 510 and 183-1060 µg PT l^{-1}, respectively) with a tendency to stabilize at high intermediate values (218-358 µg PT l^{-1}, minimum and maximum in 2015). The Canelón Grande Stream discharges one kilometer upstream of the water treatment plant of the OSE. This stream has hypereutrophic conditions caused mainly by specific contributions (slaughterhouse industry, human settlements without sanitation, animal husbandry) and intensive agriculture, while their TP contributions can account for more than 50% of the river's load, mainly during low water periods.

Negro River

The available information on the water quality of this region focuses largely on three large dams located in the main channel (Rincón del Bonete, Baygorria and Palmar), and its largest direct tributaries (Chalar *et al.*, 2014). The contributions of nutrients by these tributaries, dendritic morphometry and the greater residence times of the water in summer determine the eutrophic nature of these reservoirs, in keeping with traditional models of eutrophication (Salas and Martino, 1991). Studies show that since 2000, there has been an increase in the occurrence of cyanobacterial blooms. As in the Uruguay River (Chalar, 2002), during the summer months, cyanobacteria in the Negro River are intensified by a set of synchronic factors: temperature increase, high bio-availability of phosphorus, relative limitation of nitrogen, increase in residence time, increase in transparency and stability of water column. Cyanobacteria blooms have been recorded in open waters in the three reservoirs. dominated by *Microcystis* spp. and sometimes co-dominated by *Dolichospermun* spp. (González-Piana *et al.*, 2011).

Uruguay River

The Uruguay River is one of the main tributaries of the Río de la Plata basin. Potentially toxic cyano-

Box 1. Eutrophication of the Cisne Lagoon

The small Cisne lagoon, located in the south of Uruguay (department of Canelones), receives waters from a basin with an area of no more than 50 km^2. It has been used to supply drinking water to a large sector of the Costa de Oro (Canelones) since 1970. The system is under heavy environmental stress due to the intensification of land use. Consequently, the average concentration of total phosphorus in the lagoon water increased from approximately 100 to 700 µg PT l^{-1} in less than 25 years. These high levels of nutrients create significant environmental and health risks, jeopardizing the continuity of the drinking water supply.

The aforementioned environmental situation, coupled with an intense socio-political conflict caused by pesticide use in the basin, established the basis for the Cisne Lagoon Basin Commission to be formed by the end of 2014. This area has made it possible to advance the adoption of precautionary measures, productive reconversion and the expansion of monitoring. The 2016 and 2017 monitoring campaigns have yielded promising results in the sense of a change in the upward trend in phosphorus levels. In any case, it is not yet possible to conclude that the process has been reversed. In addition, it should be noted that the levels were still many times higher than what is desirable for a source of water for human consumption (ca. 500 µg PT l^{-1} in the summer of 2017).

The case of the Cisne lagoon basin is undoubtedly paradigmatic and typical in terms of the relationships between the intensification of land use and consequences on water quality. At the same time, strategies for handling the problem are rare at the national level, particularly because of the small territorial scale and the agro-productive/agroecological reconversion approach promoted by local authorities in the basin. Is it possible to permanently reverse the process of environmental degradation in the Cisne lagoon basin and achieve a sustainable local development model? What would be the alternative source of drinking water for the Costa de Oro if the Cisne Lagoon underwent an abrupt change of status?

Box 2. Origin, sources and distribution of organic pollutants on the coast of Montevideo

Sediment in Montevideo Bay shows evidence of chronic organic contamination, with high concentrations of aromatic hydrocarbons (AH) and aromatic polycyclic hydrocarbons (PAH) (SAHs = 15.7 - 327 µg g^{-1}; SPAHs = 196 - 65501 ng g^{-1}) (**Figure 4**). These hydrocarbons are derived from fresh and degraded petroleum, as indicated by the pristane/phytane ratio>>1 (Colombo *et al.*, 1989) and the high concentration of the unresolved complex mixture (UCM), respectively, and also from petroleum combustion, as indicated by the predominance of high molecular weight PAHs with 4-6 aromatic rings (Commendatore *et al.*, 2012). The main sources of these compounds are oil transport and refinement, port activities and vehicle emissions (Venturini *et al.*, 2015). Together with a significant anthropogenic contribution of hydrocarbons there is, as indicated by the perylene/SPAHs>10 ratio (Venkatesan, 1988), a natural contribution of hydrocarbons derived from higher inland plants, which would be associated with the continental contribution of the Rio de Silver (Venturini *et al.*, 2015). In addition, high concentrations of wastewater pollution indicating compounds, both of fecal origin (S Steroids = 2.28 - 34.8 µg g^{-1}, coprostanol = 0.05 - 21.2 µg g^{-1}) and derived from domestic and industrial detergents have been registered in this area. (SLABs = 76.3 - 7779 ng g^{-1}) (**Figure 4**). This is associated with the inadequate treatment of this type of effluent or even the absence of treatment. By contrast, sediment from the coastal area near Montevideo has moderate to low levels of organic pollution, compared with other coastal cities in the region and the world (Venturini *et al.*, 2015 and references included therein).

bacterial blooms have been detected along the river, mainly of the filamentous genus *Dolichospermum* (Kruk *et al.*, 2015, Ferrari *et al.*, 2011), regulated largely by hydrological conditions. Blooms are inversely associated with rainfall and river flow, since the concentration of nutrients is high (O'Farrell and Izaguirre, 2014). In 1978, the Salto Grande reservoir (780 km^2) was built on this river to generate electricity and supply drinking water. Various studies suggest that the reservoir is eutrophic (Conde *et al.*, 1993) and that it has frequent types of toxic cyanobacteria blooms such as *Microcystis* and *Dolichospermum* (Kruk *et al.*, 2015). The TP load in the headwaters of the reservoir is proportional to the river flow and related to the intensive agricultural activity undertaken in its basin and soil erosion (Chalar, 2006).

Prospects

The increase in the scope and intensity of agricultural and livestock activities, coupled with the predictions of climate change for the region, suggest a scenario with eutrophication and deterioration of the water quality of aquatic systems in Uruguay. Recent studies have shown that a majority of aquatic ecosystems, both lentic and lotic, have total phosphorus values that exceed the current standard allowed by legislation for all types of water (limit: 25 µg PT l^{-1} (Decree 253/79). The high levels of nutrients in the water coupled with the forecasts of temperature increase and extreme weather events (heavy rains and prolonged droughts) (Van Vliet *et al.*, 2013; IPCC, 2007) will directly affect the hydrology of water bodies and their status. The increase in rainfall could create a greater contribution of nutrients to water due to runoff and the washing of agricultural soils, increasing the load of nutrients in water, while drought conditions could lead to a decrease in the flow of rivers and reservoirs, increasing the residence times of water and contributing to the appearance of algal blooms. In this context, all relevant measures aimed at reducing the nutrient load in rivers and reservoirs should be urgently adopted in order to reverse the current trend of increasing eutrophication and water quality loss.

2.2 Heavy metals in the sediments of the coastal area of Montevideo

Anthropogenic activities developed in coastal areas cause serious pollution of surface waters and sediments, and the coastal area of Montevideo is no exception to this global pattern (Muniz *et al.*, 2015, 2011). In Uruguay, most of the recent development of sediment metals has taken place in the coastal zone of Montevideo, including the last sections of the most important tributary channels of this coastal portion. The main antecedents of metals in the surface sediments at the bottom of the Río de la

Plata estuary show consistently high levels in the innermost zone of Montevideo Bay and the Port, decreasing towards the adjacent coastal zone. Despite a significant decrease in a time scale of 10-15 years, Hutton *et al*. (2015) recently reported still high values of Cr, Pb, Cu and Zn in the port area and close to the mouths of the Miguelete and Pantanoso streams, which are in the ranges of being able to cause adverse effects on biota (PEL; **Table 3**), and compromise water quality.

Another recent study conducted in the Arroyo Carrasco basin (Mello, 2011) highlights the high level of Cr contamination in the system. In the innermost portion of the Bay of Montevideo, geochronological studies have shown the anthropic impact of metals derived from industrial and port activities during most of the 20th century. The latest studies on the spatial distribution of heavy metals in the coastal area of Montevideo show interesting changes over time: most metals have decreased their concentrations in the innermost region of Montevideo Bay and port area, notably Cr and Pb, but there have also been significant decreases in Zn and even Ag (Muniz *et al*., 2015; -Rodríguez *et al*., 2010).

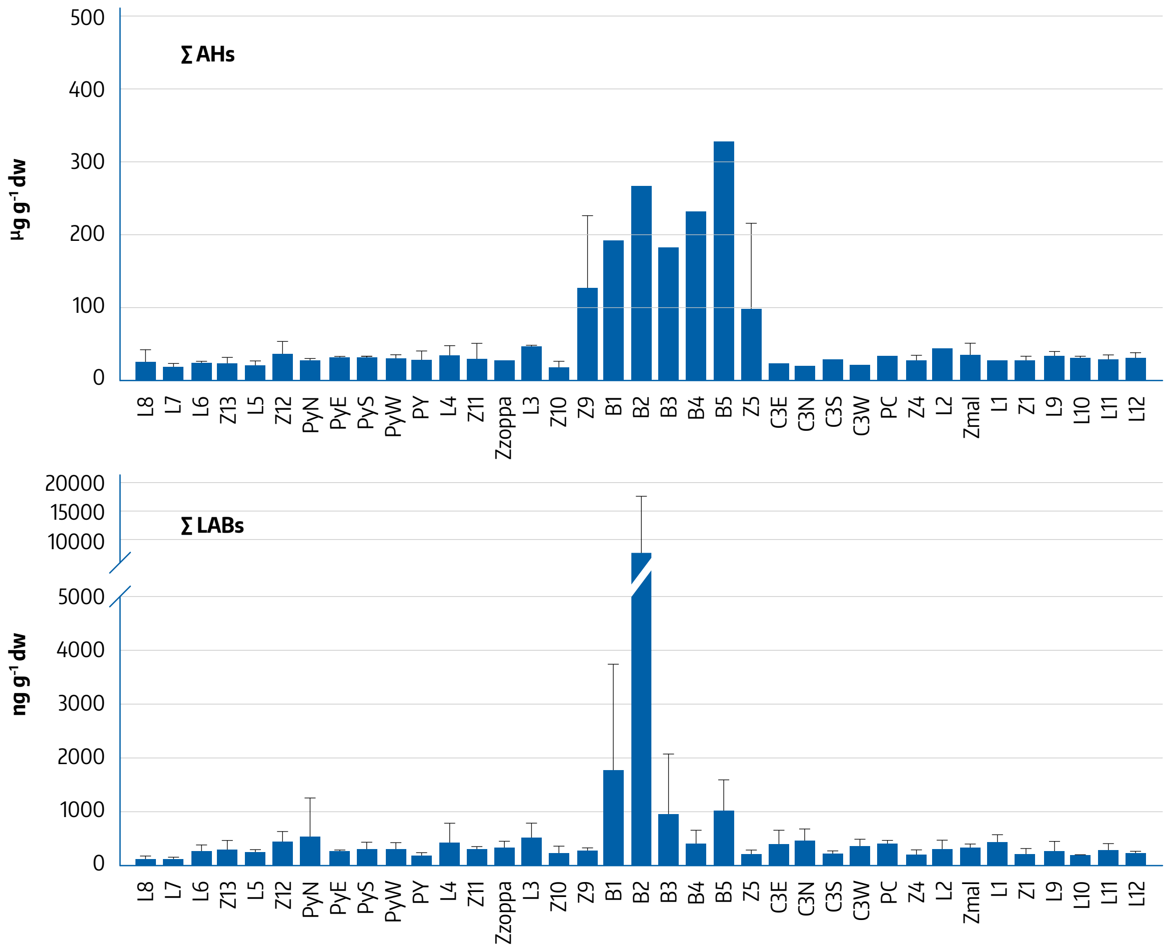
Table 3. Maximum, minimum and average values of several metals studied along the coast of Montevideo*

		BI	BE	ZE	ZO
	As				
Min		5.7	5.9	6.0	3.6
Max		8.1	6.3	7.4	7.9
Average		6.7	6.1	6.7	6.3
TEL	7.24				
PEL	41.6				
	Cd				
Min		0.6	0.4	0.4	0.5
Max		1.4	0.5	0.6	0.7
Average		1.1	0.48	0.5	0.6
TEL	0..8				
PEL	4.21				
	Cr				
Min		28.7	22.4	20.4	29.3
Max		217.1	41.6	32.1	30.8
Average		163.2	32.3	28.3	27.9
TEL	52.3				
PEL	160				
	Zn				
Min		160.8	73.1	58.7	83.8
Max		390	89.8	93.1	128.1
Average		380.2	82.4	83.1	82.7
TEL	124				
PEL	271				

		BI	BE	ZE	ZO
	Cu				
Min		28.5	28.2	25.1	32.4
Max		120.5	37.8	36.6	36.6
Average		99.4	33.6	32.4	32.4
TEL	18.7				
PEL	108				
	Ni				
Min		14.3	13.5	12.6	11.4
Max		20.4	16.4	19.8	19.8
Average		17.4	15.1	17.5	17.4
TEL	15.9				
PEL	42.8				
	Pb				
Min		47.1	19.8	17.6	16.8
Max		139.2	23.5	21.2	40.8
Average		117.2	21.5	17.6	22.5
TEL	30.2				
PEL	112				

* TEL and PEL values are also presented for each metal (TEL: threshold effect level, which means the concentration below which there is no biological risk of any kind; PEL: (probable effect level, i.e. the concentration above which there will probably be some biological risk, affecting the aquatic biota. Between TEL and PEL it is understood that there may occasionally be an effect on aquatic biota). The values correspond to seasonal studies conducted in 2010 and 2013. Internal bay=IB; External bay= EB; East Zone= EZ; West Zone= WZ. Concentration values are all given in mg kg^{-1} of dry sediment.

Figure 4. Concentration of total aliphatic hydrocarbons (ΣAHs; above) and total linear alkylbenze (ΣLABs; below) in the sediment in Montevideo Bay



Note: (L8-Z9: Montevideo West, B1-B5: Montevideo Bay, Z5-L12: Montevideo East).

The prohibition of the use of fuels with Pb, the decrease in the activity of tanneries, the shift from traditional to digital photography and greater control and improvement of the effluent discharge system into the Miguelete and Pantanoso streams are some of the explanations for this remarkable decrease. At the same time, the adjacent coastal area is now relatively homogeneous from the point of view of the concentration of metal elements, with a marked increase in the western portion of Montevideo (Muniz *et al*., 2011), which 15 years ago was the most unspoiled coastal portion of the Department (Muniz *et al*., 2004). In this respect, it is worth noting the recent emergence of untreated effluents derived from irregular urban settlements in this area of the coastal strip of Montevideo (Muniz *et al*., 2011, IMM, 2009). Nevertheless, for several of the metals studied, sediment concentrations are below the threshold level (TEL, **Table 3**, suggesting that they will not cause adverse effects on biota.

2.3 Effects of agrochemicals on aquatic biota

Although the change in the productive matrix in Uruguay has been established and projections indicate that the intensification of land use will continue, there is little scientific evidence at the national level on the potential effects of exposure to pesticides in aquatic biota.

Most of the available studies use fish as an experimental model. These include field and laboratory studies on effects at different levels of organization (from molecular to changes in population and community attributes), associated with certain agricultural items. In this respect, field studies undertaken on basins located in Melilla (Montevideo), a rural area with intense horticultural and fruit activity, showed alterations in the metabolism of the heme group in fish. Samples of *Astyanax aff. fasciatus*, collected in a sector of Cañada del Dragón where deciduous fruit trees are grown, showed a significant accumulation of protoporphyrin, coproporphyrin and uroporphyrin (Carrasco-Letelier *et al*., 2006) (**Table 4**). In the Arroyo Juncal basin, a pattern of differential accumulation of specific porphyrins was observed in fish with different habits, regarding both their food and position in the water column. There was a significantly higher accumulation in species associated with sediment (*Corydoras paleatus*) compared to those found in the water column (*Jennynsia multidentata, Gymnogeophagus meridionalis* and *Cheirodon interruptus*) (Matteo, 2008) (**Figure 5 a-c**). At the same time, in field and laboratory studies with specimens of *A. aff. fasciatus* collected in Melilla, alteration of cerebral acetylcholinesterase activity has been detected due to exposure to a mixture of organophosphorus pesticides and carbamates, used in the production of deciduous fruit trees (Pistone *et al*., 2012). In this regard, studies under controlled conditions of exposure to methyl azinphos (48 h) showed signs of intoxication in A. aff. fasciatus at concentrations of between 1 and 4 mg l^{-1} (reduced locomotor activity and feeding, increased respiratory rate, spiral or erratic swimming, among others). At the same time, this study estimated that the LC50 (48 h) for this species is 2.31 mg l^{-1} (**Table 4**).

In other parts of the country, such as the basins of the Uruguay River and the Arroyo Colorado, endocrine effects were observed in fish (Rivas *et al*., 2014; Vidal, 2007). In the first case, immature specimens of *Cyprinus carpio* exposed under controlled conditions to sediments from areas under the influence of forestry production (Paysandú Dept.) and agriculture (New Berlin, Dept. of Río Negro, mainly soybean crops) showed significantly higher levels

Table 4. Variation of metabolism of heme group in Astyanax aff. fasciatus of the Cañada del Dragón*

Río	Zone A	Zone B	p-value
Liver mass (g)	53.63 ± 23.20 (7)	94.79 ± 38.62 (10)	NS
Coproporphyrin *	239.18 ± 49.93 (7)	188.53 ± 29.87 (10)	0.034
Uroporphyrin *	257.33 ± 57.32 (7)	196.22 ± 28.91 (10)	0.018
Protoporphyrin *	634.72 ± 122.64 (7)	476.27 ± 74.72 (10)	0.010

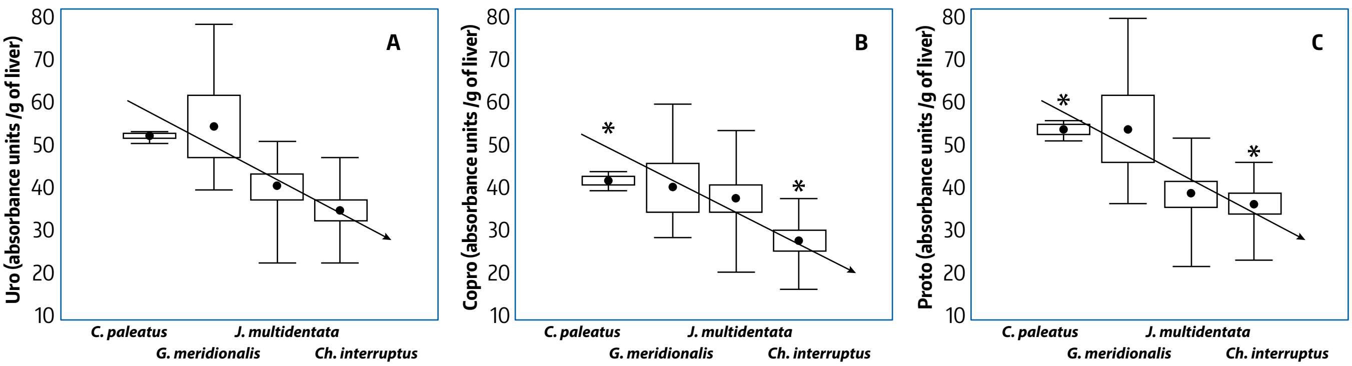
* Values are expressed as a mean ± DS (number of samples). * nmol g^{-1} of liver tissue. NS: not significant. Zone A: Land use intensive fruit growing. Zone B Land use grasslands and wetlands.

Table 5. Cerebral acetylcholinesterase activity in groups of Astyanax aff. fasciatus exposed under controlled conditions to increasing concentrations of methyl azinphos (organophosphorus pesticide) for 48 hours*

Methyl azinphos (mg l^{-1})	Specific AChe activity (nmol min^{-1} mg^{-1} protein)	Inhibition (% Control)
Control	60.38 ± 5.53 (19)	0a
0.01	44.49 ± 3.68 (20)	26b
0.10	27.07 ± 5.06 (20)	55c
1.00	9.45 ± 2.63 (19)	84d
2.00	9.02 ± 2.10 (20)	85d
4.00	8.28 ± 1.45 (19)	87d

* Los valores son expresados como media ± DS (número de muestras). Letras distintas indican diferencias significativas entre grupos (Test de Tuckey p < 0.05).

Figure 5. Patterns of accumulation of specific porphyrins in fish in the Cañada del Dragón: a) Uroporphyrin, b) Protoporphyrin and c) Coproporphyrin

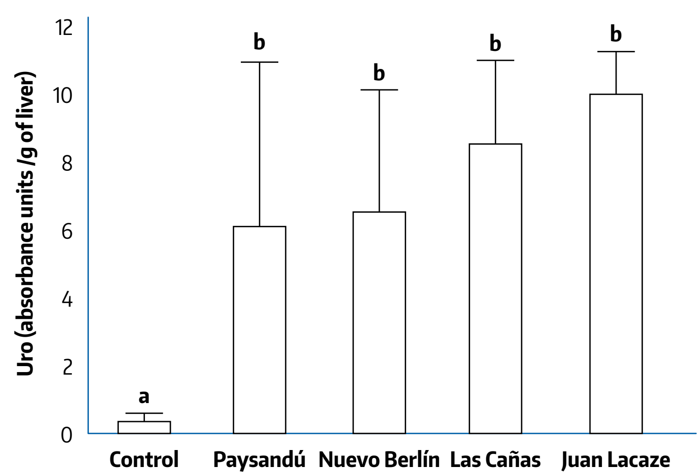


of vitellogenin than the control group (**Figure 6**). In Arroyo Colorado, an effect was observed at the population level, involving a process of masculinization in females of *Cnesterodon decemmaculatus*, which reaches an incidence rate of almost 15% in areas under the influence of agricultural activity.

At the assembly level, changes (specific composition, biomass, diversity, density and size structure) have been registered in basins where the main use of soil is for rice production in rotation with pastures. The assemblies of sites influenced by rice cultivation are highly unstable (change in the composition and dominance of species) and the most significant effect occurs after the drainage of farms, when assembly is dominated by species classified as tolerant. At the same time, a cumulative effect is observed (in successive harvests, changes are greater) and, therefore, the changes recorded could be associated with land use, with greater effects being observed in the eastern rice area than in the north of the country (Eguren *et al*., 2013).

Ernst *et al*. (2018) detected the presence of agricultural and forestry pesticide residue in the muscle of fish for human consumption from localities on the Uruguay and Negro rivers (the main activity is continuous agriculture in three of them and pastures and afforestation in one of them). A total of 15 fungicides, 10 insecticides and five herbicides were detected, 28 of which are authorized for use in rainfed crops (mainly barley, sorghum, soybeans and wheat), with fungicides being the most frequently recorded. Although the presence of pesticides was detected in 96% of the 149 samples analyzed

Figure 6. Levels of plasma vitellogenin in immature specimens of "common carp" exposed to sediment in the Uruguay River *



*Vertical bars indicate a confidence interval of 95% while the letters show statistically significant differences.

(with an average of 4 and a maximum of 21 compounds per sample), in most cases, levels were below the quantification limit (11-85 μg kg- one). The compound that recorded the maximum value was chlorpyrifos (194 μg kg^{-1}) in a sample of *Prochilodus lineatus* (detritivore and migratory species). In quantifiable cases, the concentrations registered do not exceed the maximum values for human consumption. In relation to land uses, the authors note that the average number of pesticides per specimen was significantly lower in the locality where the dominant land use is pasture and forestation (San Gregorio de Polanco, Río Negro basin). Moreover, the amount and composition of pesticides was significantly different when comparing the agricultural areas with the livestock area.

2.4 Presence of enteric viruses in various aquatic matrices

In South America, the study of enteric viruses in various environmental water matrices (study area concerning environmental virology) has been extensively developed in Brazil and Argentina. Regarding Uruguay, until the beginning of this decade (2010) there were no published studies reporting the presence and frequency of these viruses in Uruguayan waters.

One of the first studies conducted examined the presence and genetic diversity of Rotavirus (RV), Norovirus (NoV) and human Astrovirus (HAstV) in wastewater that is directly discharged (untreated) into the Uruguay River, one of the main water courses in the country, used for recreation, drinking water for human consumption and navigation. Fortnightly samples were taken during a one-year period in four cities on the Uruguayan Northwest coast (Bella Unión, Salto, Paysandú and Fray Bentos). The aforementioned viruses were studied because they represent the main viral agents responsible for acute gastroenteritis in children under five. The results of these studies demonstrated the presence of a high percentage (80%) of detection of these enteric viruses, revealing the extent to which they had spread, with high viral loads, from this wastewater to the Uruguay River. NoV was the virus most frequently detected, with 51% of the samples analyzed showing positive, followed by RV with

Box 3. Presence of pesticides for agricultural-forestry use in fish in the Esteros de Farrapos National Park and islands in the Uruguay River

The intensification of soy and forestry use in the basin of the Esteros de Farrapos National Park and Islas del Río Uruguay Ramsar site (basin 19 in Figure 1) and extensive pesticide use creates a risk of soil, water and biota contamination in the area and among the local population, as well as impacts on other local productions. In response to the concern of local residents over the environmental quality of the area, the Vida Silvestre Uruguay NGO undertook a participatory research experience to evaluate pesticide concentrations in various environmental matrices of the protected area and its watershed, including commercially important fish.

Fish species with different feeding habits (piscivorous, omnivorous and iliophage) were chosen to represent different levels of the aquatic food web. The fish were collected in 2010 by the fishermen of Nuevo Berlín in their everyday work. Table 6 summarizes the main results found. Endosulfan was found at all levels of the trophic network, including species that feed directly on the sediment (Shad), omnivorous species (Boga and Yellow catfish), and a mainly piscivorous species (Wolf fish); likewise, it was found in both purely migratory (Bogue, Shad) and resident species (Wolf fish and Yellow catfish). Given that the importation, production and use of Endosulfan have been banned in Uruguay since 2011, these results highlight the importance of repeating these studies to evaluate the efficiency of the measures taken. DDT and DDE, one of their degradation products, were also recorded in the wolf fish caught. DDE was found in five of the six specimens analyzed, with lower levels than those found of DDT. The detection of these compounds may be due to the high persistence of these substances, although there is also the possibility that they have continued to be used illegally despite the bans imposed in Argentina in 1990 and in Uruguay in 2005.

Finally, it is worth noting that the analysis of shad individuals in the wake of a massive mortality event within the study site found Endosulfan in concentrations 52 times higher than those recorded in the live fish collected in the river. By way of reference, the Admissible Daily Intake value recommended by the World Health Organization (WHO) for Endosulfan is 0.006 mg kg^{-1} of body weight, while for DDT, the Tolerable Daily Intake is 0.002 mg kg^{-1} body weight.

These preliminary results suggest the usefulness and efficiency of evaluating pesticides in fish as a biomonitoring tool, and raise the need to advance the evaluation of the biological and ecological effects of chronic exposure to persistent pollutants and the risks these compounds may pose for biota and public health.

Table 6. Results of presence of pesticides for agricultural-forestry use in fish in the Esteros de Farrapos National Park and islands in the Uruguay River

Species	Pesticide	Positive cases	Concentration range (mg kg^{-1})
Hoplias malabaricus	Total endosulfan	5/6	0.009 - 0.052
Hoplias malabaricus	DDT	3/6	< 0.0001
Prochilodus lineatus	Total endosulfan	3/3	0.020 - 0.023
Leporinus obtusidens	Total endosulfan	1/3	0.011
Pimelodus maculatus	Total endosulfan	3/3	0.011 - 0.038
Prochilodus lineatus*	Total endosulfan	3/3	0.418 - 1.81

49% and HAstV with 45%. At the same time, when each city was analyzed separately, these enteric viruses were present with very similar frequencies (50-51%), with the viral detection frequency being slightly lower in the city of Bella Unión (40%). This city is the only one of the four analyzed with a wastewater treatment plant with a stabilization pond system.

As expected, since they are excreted in high concentrations in the fecal material of infected individuals, these enteric viruses were present in high concentrations in wastewater. The viral concentrations or loads detected in these samples ranged from 4x103 cg l^{-1} (genomic copies per liter) to 4x107 cg l^{-1}. Considering each virus, a slightly higher concentration of RV than of NoV and HAstV was observed. RV and HAstV were detected with a higher frequency in the colder months of the year, reflecting a probable high circulation of these viruses in these populations in the winter months. Through the genetic study of these viruses, it was observed that the three enteric viruses studied showed a high genetic diversity (Victoria *et al.*, 2016, 2014, Lizasoáin *et al.*, 2015, Tort *et al.*, 2015). Likewise, the NoV studied in wastewater from landfills located on the east coast of the city of Montevideo for a period of six months were detected in 33% of the samples and in high concentrations (Alberti, 2012).

Although the various processes used in wastewater treatment plants (WWTP) do not completely eliminate the viruses from treated effluents, high removal rates of up to 6 log10 have been reported in various processes (Zhang *et al.*, 2016). In Uruguay, despite the large number of cities with WWTP, 32% of departmental capitals still do not have a WWTP, including Montevideo. In view of these data, a study was conducted in which the presence of enteric viruses was evaluated at a WWTP with tertiary treatment and subsequent disinfection with UV light. By way of a summary, from the results obtained, it was observed that the four enteric viruses studied (RV, NoV, HAstV and human adenovirus, HAdV) showed a decline in both the percentage of positivity and the viral concentration throughout the process, showing that this combination of processes is effective in reducing the impact of enteric viruses on treated effluents released into environmental water bodies (A. Lizasoáin, pers. comm.).

Due to the presence of high concentrations of enteric viruses in untreated wastewater, and lower concentrations in WWTP effluents, as well as the absence of WWTP in several major cities in Uruguay, these viruses have been studied in several recreational bodies of water used for different purposes by the Uruguayan population. In recreational waters in various places in the city of Barros Blancos (southern region of the country), enteric viruses RV, NoV and Picobirnavirus were detected in 90% of the samples analyzed, showing a wide territorial distribution with the presence of both human and bovine viruses, revealing the high risk of infection of the inhabitants of that city (Gillman, 2016). At the same time, preliminary results of a study being conducted on surface water samples from two major rivers, the Uruguay River and the Santa Lucia River (which supplies water to a large part of the city of Montevideo) indicate that these rivers have moderate pollution by HAdV and bovine Poliomavirus, once again showing fecal contamination that is not only anthropogenic but also due to the presence of cattle on the coasts of these water courses (V. Bortagaray, pers. comm.).

In Uruguay, groundwater is frequently used for both human consumption in rural and suburban areas and agricultural activities. One study detected and quantified RV, NoV and HAdV in waters from semi-emergent wells in the Department of Salto. The results show contamination of these wells by RV in 32% of the samples analyzed, showing the viral contamination of the Salto aquifer and its vulnerability to the infiltration of wastewater through soil (P. Gamazo, pers. comm.).

In conclusion, we can say that wastewater contributes a high load of enteric viruses to the receiving bodies, which are often rivers used for various human activities such as recreation and water intake for consumption. However, it has been observed, in both Uruguay and other countries, that these WWTPs have the capacity to remove a significant number of viruses in their final effluents (Zhang *et al*., 2016). Although viral contamination is not high in rivers, the continuous contribution of wastewater (mainly untreated) to these bodies negatively impacts the water quality of the various water resources in Uruguay.

3. Social Issues

This chapter on the social and economic aspects in relation to water quality begins with the expression of this relationship at the citizen level, based on the denunciations that the National Institution of Human Rights collected in 2017. Since then, in order to present information that partially explains this collective awareness, aspects of risk perception and everyday strategies for generating confidence in water for human consumption, the relationship between structural poverty and vulnerability among the inhabitants of small, scattered rural local communities and between the inhabitants of irregular urban settlements have been highlighted. Finally, a sectoral economic analysis is conducted of which account for most of the contamination of surface and ground water courses, industries and agriculture, as well as the most severely affected sectors: tourism and artisanal fishing.

3.1 Human rights and water quality

The National Institution for Human Rights and the Ombudsman's Office (INDDHH), created in 2008, is committed to the defense, promotion and protection of the human rights recognized in the Constitution of the Republic and International Law. It is an autonomous state body operating within the scope of the Legislative Branch. Several experiences in water pollution problems or other drinking water issues have been recorded by means of two mechanisms: a) complaints filed regarding alleged human rights violations related to the subject, and b) concerns raised by members of social organizations and/or government agencies during activities organized by the INDDHH.

The main complaints received in 2017 by the INDDHH related to water quality, which are still under investigation, concern the following problems:

- Lack of drinking water in Rural Schools in the Department of Paysandú. It was reported that in two rural schools in the Department of Paysandú, on the west coast of Uruguay, tap water, supplied by emerging wells, is not potable, meaning that bottled water for drinking and cooking must be purchased. The complainants stated that the contamination of these water wells was due to the use of agrochemicals in the adjoining plots of land, where there are soybean crops, in addition to the problematic geological structure of the groundwater used due to the geochemical characteristics of the aquifer from which it is extracted, in addition to the suspension of the service offered by the state provider of potable water, State Sanitary Works Board (OSE), in its program for small towns and rural schools (see 3.3).
- There is a lack of treatment of waste generated in the process of purifying water from the Santa Lucía River, in the Aguas Corrientes plant (Department of Canelones). A complaint was filed for alleged damage to the locality of Aguas Corrientes and its residents, due to the lack of treatment of the sludge generated by the water purification process carried out in the plant of the OSE public company, waste from which is discharged directly into the Santa Lucia river, downstream of the water intake. The complainants stated that the river bed and the native forest have been damaged, affecting the recreational and economic activities of the population, and mentioned the difficulty of accessing public information.

- Contamination of drinking water sources due to use of agrochemicals. In 2016, a complaint was filed regarding the contamination of drinking water sources due to the use of agrochemicals in the Cisne Lagoon basin, in the Department of Canelones. Although the Municipality of Canelones made progress in preventive and control aspects, there was concern about the effective collection of fines imposed on those who violated the regulations. This prompted a request for information about data for the whole country to the Ministry of Livestock, Agriculture and Fisheries (MGAP), which replied that, due to the breach of the regulations related to the protection of water sources, between 2013 and 2016, ten resolutions involving economic sanctions were established for companies and/or individuals, on which the collection of said fines had not been effective in 2016.

At the same time, there have been a series of problems related to water quality in the country, reported by spokespersons of various social organizations and collected during the National Assemblies of Human Rights and in the most recent discussion on "Water, Society and Human Rights," organized by the institution in April 2017. The following concerns were highlighted: lack of health indicators enabling one to link problems in the health of the population with environmental causes and/or linked to water quality; lack of effective management authority for water issues, diffuse responsibilities and inter-institutional coordination, mainly involving the National Water Board (DINAGUA) and the National Environment Directorate (DINAMA) of the Ministry of Housing, Territorial Planning and the Environment (MVOTMA), MGAP and the Ministry of Public Health (MSP); concern over the impact on water resources of large productive projects, such as a new cellulose processing plant on the Negro river; restrictions on institutionalized social participation in the Basin Commissions due to their functioning, advisory functions and their low number in relation to existing hydrographic basins, as well as to the lack of participation of citizens in water management and protection plans, particularly the Action Plan for the protection of environmental quality and the availability of drinking water sources-Santa Lucía River Hydrographic Basin (hereinafter referred to as the Santa Lucia River Action Plan, MVOTMA, 2015) and the National Water Plan (MVOTMA , 2017); and criticism of the reform of the Law of Irrigation with Agrarian Destiny, approved by the Uruguayan Parliament in 2017.

3.2 Representations, beliefs and perception in an agro-city on the Uruguayan coast

Several of the issues linking human rights and water quality for human consumption are mentioned in a recent anthropological doctoral research project (CIESAS, Mexico) undertaken by Evia (2018). The research addresses the problem of occupational and environmental exposure to agricultural pesticides in a medium-sized city and its sphere of influence in the Uruguayan agricultural coastline. The research methodology combines qualitative and quantitative social research techniques, with a predominance of ethnographic observation in domestic and productive spaces (Hammersley and Atkinson, 2014, Emerson *et al.*, 2011). A survey conducted between April and May 2017 in two census segments that include urban and suburban land found that concern for "water and contaminated water courses" ranked fourth among "environmental problems".

Ethnographic observation found that water "contamination" was a common emerging concern among various social groups and that there is a shared perception that the quality of the water distributed by OSE is not always reliable. This is mainly expressed in terms of concern over the "contamination" of the water or the fact that "OSE water cannot be drunk". The sensory elements that are most significant for the population and used at the domestic level to assess water quality are: 1) a strong smell and taste or a smell and taste of chlorine, and 2) water color and turbidity ("the water comes out white"). An inquiry into what are presumed to be the causes of this "contamination" revealed four main causes: the water may contain traces of "products used in the field" (a term that encompasses both agricultural pesticides and fertilizers); "they add a lot of chlorine" to the water; water in the zone has a high concentration of "nitrites" and "nitrates", and/or the city does not have a wastewater treatment plant, as a result of which the collector pipe pours this waste directly into the same river as the water intake for the potabilizing plant just a few meters away. The first two causes listed are described as recent processes ("in recent years", "this used not to happen before"), while the other two are processes that have existed for longer. Neither the official water quality monitoring studies nor their results (for example, DINAMA, 2016) seem to be known or used as information sources by the general public.

On the basis of the analysis of the qualitative material, a first major division has been identified between a) water for food consumption, and b) water for domestic hygiene (floor cleaning, laundry, bathroom). Within water for food consumption, it was found that a distinction is made between water "for drinking", water that is boiled (for mate or other types of infusions) and water used for cooking. The strictest criteria for "purity" and restrictions on the type of source to use apply to "drinking water". The aforementioned survey shows that with respect to the source of water used for drinking, it was found that: 51% buy bottled water, 26.5% use the public network (OSE), 15.7% use well water and 5.9% combine water from the OSE network with the purchase of bottled water, while the main source of water used to prepare food and/or cook it is network water (OSE), with 79.4%, followed by 16.7% that use water from wells/water cisterns, 2% combine water from the OSE network and wells and 1% buy bottled water for cooking. There is a widespread belief that bottled water (sometimes referred to as "mineral water") is water with better quality, a better taste and "healthier", because it does not have "products" attributed to the water network. Another practice that was found, complementary to the purchase of bottled water, is the use of domestic water filters. Filtered water can be used both for direct drinking and for infusions and/or cooking. Finally, it was found that it is a common practice to seek and fetch water from "semi-upwelling" wells that are considered "purer" than water from the network because the water comes out "clean" because the wells are "deep," although it is unusual to have water potability analyses. Access to these wells depends on neighborly relations and mutual assistance. The purchase of bottled water, as well as access to water from semi-upwelling wells, can be interpreted as preventive health practices adopted at the level of domestic groups as part of the self-care strategies developed by domestic groups (Menéndez, 2009; Haro , 2000) due to the distrust in the quality of water provided by the network.

3.3 Drinking water in rural Uruguay

The Program for the Supply of Drinking Water to Small Towns and Rural Schools in the rural interior of the country was a management program comprising projects that involved technical, social, commercial and administrative aspects within the framework of the tasks carried out by OSE, a state company which has a monopoly on the supply of drinking water services throughout the country. Uruguay was the first country in the world to declare access to drinking water and sanitation a fundamental human right, as a result of which it created this Program.

The target population to be supplied was approximately 300 rural schools, which translates into 4000 homes and 6850 students, constituting the most vulnerable population from the socioeconomic and health point of view. This population was previously supplied by unsafe sources: Untreated rainwater, underground sources (artesian wells, pipes, etc.) and/or fetching from surface sources.

A major challenge has not only been to provide safe water production infrastructures, but also to ensure the sustainability of this service over time. Eighty-five per cent of the solutions involved drilling while the remainder entailed extensions of existing water networks. OSE systems have doubled to date and an additional effort is required to operate and maintain these systems located in remote villages. From the outset, ensuring the participation of rural communities was crucial to contributing to the sustainability of the Program. To this end, schoolchildren and rural teachers were trained by the OSE to perform basic quality controls related to the bacteriological acceptability of water and contribute to the care of water and related facilities.

The program began in September 2010 and ended in June 2016 with an investment of $12.2 million USD, half of which was donated by the Spanish government. In early 2018, all the systems had been incorporated into the system for water quality monitoring undertaken by OSE laboratories for all the drinking water systems in the country.

3.4 Poverty and urban waters

The last census, conducted in 2011, shows that in Uruguay there are 589 irregular settlements at the urban level inhabited by 165,271 people (78% in Montevideo) (INE, 2015). The link between the inhabitants of irregular settlements and natural water courses is significant for the productive and reproductive activities that produce a negative impact on them, reinforcing the conditions of vulnerability and health risks of women, children and young people (Batthyany, 2009). In these areas, the inhabitants have unemployment rates that are higher than the national average while the vast majority of their population have income levels below the poverty line, with an unemployment rate in women nearly double that of men (29% women and 16.9% men) (MIDES, 2016). The demographic structure shows an inverse relationship to the national one with a greater proportion of childhood and youth than of older adults, high fertility rates in adolescents from households with over two unmet basic needs (six times higher than those in this same group in households where basic needs are met) (MVOTMA, 2013).

Irregular settlements in Uruguay have similar characteristics of total or partial absence of sanitation solutions, non-existent or dilapidated drainage systems, a lack of public lighting, public spaces, green areas and urban facilities, and poor environmental quality due to the existence of rubbish dumps, proximity to water courses and the presence of flood zones. The proportion of homes that can be flooded is 13.4%, compared to 3.9% of the national average, and only 24% of homes are connected to the sanitation network (INE, 2015).

The basins of the Miguelete, Pantanoso and Carrasco streams in the capital city of Montevideo have poor water quality and irregular settlements on their banks, inhabited by a total of 115,763 people. These streams receive domestic and industrial wastewater, with seasonal variations (MVOTMA, 2009). Despite some state control, there are still endemic problems such as informal waste dumping, discharges of untreated urban sewage and industrial effluents with nutrient loads (MVOTMA, 2017). Informal waste dumping is directly linked to the activity of waste collection and classification, which is significant in irregular settlements. According to a recent study on the Characterization of the Population of Garbage Collectors in Montevideo (IMM, 2012), this group of people (estimated at 20 612, according to the 2008 census) have higher poverty indicators than neighboring groups, even within the same settlement, and are in a situation of greater vulnerability and risk regarding various types of health situations.

Social practices of populations in these areas include imaginaries and representations associated with the natural features of the area and their management (water, wetlands, vegetation, associated flora and fauna), and uncertainty in the face of extreme events involving water (rain, flooding, deterioration) and representation as institutionalized waste spaces. The representation of the marginalized space has to do with occupation in places conceived of as peripheral, "backward areas, with low value and high risk, not included in planning processes, where the presence of state institutions, monitoring and control is less visible (Delgado, 2018).

In the present and future, the challenge is to use a multidisciplinary approach to rethink the policies regarding the management of water resources and environmental quality, which requires an integrating approach that recognizes the profound link between populations and ecosystems and the need to create management strategies focusing on their mutual well-being.

3.5 Economic instruments for water quality management

Uruguay has very few economic instruments for issues related to water quality management, although regulation mechanisms do exist in the form of prohibitions and regulations that impose fines for non-compliance, which, if they were well designed and their monitoring capacity were credible, would serve as a market mechanism. These include the land use and management plans, implemented by the Directorate of Natural Resources of the MGAP, as a code of good agricultural practices since they promote the implementation of cultural practices, which ensure sustainability in land use and management for agricultural production. Another example is the practice of the Directorate of Environmental Control of DINAMA and/or the Industrial Effluent Unit of the Municipality of Montevideo, responsible for granting and monitoring industrial drainage authorizations.

On the other hand, Law No. 18,840 of 2013 makes connection to the public water and sanitation network compulsory for all owners or potential buyers of properties, which includes lines of financing or subsidies to facilitate connection by households with fewer resources.

The National Water Plan, passed in 2017 (MVOTMA, 2017), proposes the incorporation - within the development of economic instruments - of a fee for water use, which is mentioned in the Water Code (1978) and the Law on National Water Policy (2009), but never regulated. Moreover, it should be noted that this instrument is mainly designed to manage the resource rather than its quality. At the same time, there may be economic instruments that cause negative externalities on the environment, such as exonerations for the use of fertilizers in agricultural activities.

In short, if a national policy is to be developed to ensure compliance with national standards regarding water quality, it must be developed in an integrated manner, considering both those who generate the externality and those who perceive it.

4. Water quality evaluation, control and protection

Uruguay achieved high levels of urban coverage of both drinking water supply and sanitation at an early stage, which probably contributed to the widespread perception among the population of an abundance of water resources as regards quantity and quality. However, measures designed to protect water at the watershed level came to a standstill, coinciding with the rapid increase in productive activities, particularly agriculture. This chapter provides a general description of the progress Uruguay is making in the evaluation, control and protection of water quality, which includes monitoring water quality, action plans for the protection of water and the improvement of its quality at the basin level and lastly the challenges of supplying drinking water to the population.

4.1 Sanitation and Solid Waste Management

Uruguay was a pioneer in Latin America in the implementation of dynamic sanitation systems, with Montevideo being the first city in the region to have this type of service. The expansion of the system towards the interior of the country initially included the construction of sewerage networks in the main cities and their gradual extension to other urban areas. This made it possible to achieve general coverage of dynamic sanitation of 58.9% in 2011, according to the Population and Housing Census conducted by the National Institute of Statistics (INE, 2015).

In the 1990s, construction began on new plants for the treatment of domestic effluents prior to their final discharge, in order to improve the quality of receiving water bodies. Thus, attempts were made to enable its use for recreation by direct contact, to preserve the biota and quality of the environment. Since applied treatment technologies have changed over the decades, there are currently several treatment and final disposal solutions operating in the country.

The Montevideo sewer system serves more than 82% of the department's population. It has unitary network zones and separate network zones, which lead the effluents to pre-treatment and final disposal systems in Río de la Plata through an underwater outlet. In the interior of the country, where coverage at the urban level is below 40%, treatment and final disposal solutions include: pretreatment, primary treatment, advanced primary treatment (physicochemical treatment), secondary treatment (conventional activated aeration sludge, extended activated aeration sludge, percolating beds, oxidation ditches, UASB reactors), tertiary treatment (activated sludge with nitrogen and phosphorus removal), stabilization pond systems. However, there are still some localities in which direct discharge is undertaken without prior treatment (López, 2015).

Both the Municipality of Montevideo, responsible for sanitation management in the capital of the country, and the Administration of the Sanitary Works of the State (OSE), responsible for sewerage systems in the interior of the country, have sanitation plans to guide future works in terms of expanding coverage and incorporating treatment and final disposal facilities. Both institutions are implementing the plans sustainably. Other existing systems in the country correspond to the sanitation solutions implemented by the Movement for the Eradication of Rural Insufficient Housing (MEVIR). MEVIR systems include small towns or neighborhoods of localities in the interior of the country. They have dynamic sanitation networks for the treatment of this type of effluent, generally with treatment systems for stabilization ponds prior to their final disposal into the water body.

The main challenge in terms of domestic effluents currently concerns sanitation solutions to be considered for areas that do not have sewerage. The systems implemented in Uruguay, which reached 41.8% of the country's population in 2011 (INE, 2015), mostly comprise fixed impermeable tanks, fixed filtering tanks and septic tank systems. Although these solutions could be considered as adequate sanitation under certain conditions, in practice, they do not usually guarantee the minimum criteria of design, construction, operation and maintenance that would enable them to be considered as such.

Individual systems currently in the country include: waterproof tanks with periodic cleaning by means of a barometric truck (or vacuum), waterproof tanks with a robber that discharges the liquid effluent onto the land or public roads, filtering tanks, septic tanks (with or without cleaning by barometric truck) with effluent discharge liquid into the ground or public highways, septic tanks followed by an infiltration system into the ground or irrigation system, septic tanks followed by constructed wetland or treatment plant, uncontrolled discharge onto the land or public thoroughfare, etc. A similar situation occurs with the sludge discharged by barometric trucks for cleaning waterproof tanks and septic tanks.

In 2004, the Constitution of the Republic incorporated in its Article 47 the fact that access to sanitation constitutes a fundamental human right, which implies ensuring that the entire population has adequate sanitation solutions. To this end, the various available solutions and technologies must be considered -both dynamic and static solutions, collective and individual systems-, analyzing the advantages and limitations of each one in order to define the viable options for each case. In all of these, design, construction, operation and maintenance aspects must be contemplated that guarantee a level of protection for users and the environment comparable to that achieved through a dynamic system with centralized treatment. This involves considering not only the level of quality that can be achieved by putting the solution into operation, but also the effort required to maintain the standard of operation throughout the entire life of the system.

The sanitation component of the National Water Plan (MVOTMA, 2017) is currently under development, to delineate the roads to be followed in terms of sanitation at the country level in order to universalize service.

Final disposal of solid waste

The success of waste management lies in the correct performance of its various stages, especially in regard to the analysis of alternatives, design, construction, operation and maintenance of the recovery and disposal sites. At the national level, due to the investment levels required, as well as to the operation and maintenance costs involved, only the landfill alternative is usually considered (OPP, 2011).

With the exception of the leachate treatment plants at the Felipe Cardozo (Montevideo) and Las Rosas (Maldonado) sanitary landfills, which have leachate collection and treatment systems, in most of the rest of the country, there is a low level of attention to the final disposal services (SDF) of solid waste, which operate with an insufficient degree of investment. They usually do not have waterproofing of the base of the cell or rain drainage systems or leachate collection or treatment (OPP, 2011). This obviously causes negative environmental impacts, such as the generation of gases, soil contamination, contamination of surface and groundwater -as a result of poor leachate management - and the proliferation of vectors, among other factors. This is compounded by the disadvantages of the limited control of the type of waste received, meaning that potentially hazardous solid waste can be received and disposed at these sites.

The challenge in this sector is the improvement of waste management in various departments in the interior of the country, with the resulting minimization of environmental and health impacts, especially as regards final disposal projects.

4.2 Water treatment national challenges

The Administration of the Sanitary Works of the State (OSE) is the state agency responsible for the production and distribution of drinking water throughout Uruguay. Maintaining adequate quality for this supply poses a series of growing challenges, since many of the water bodies used as a source of raw water are affected by the intensification of land use in the contribution basin, urban and specific pollution. industrial and climate change, but also by the changes in the regulations that are becoming increasingly stringent. In this respect new investments in infrastructure and inputs are required, as well as the development and local adaptation of new technologies to address emerging problems.

Another aspect that should be highlighted is the pressure exerted by the Uruguayan population and the media, which demand high quality water, partly due to the tradition established by OSE, and to the fact that in recent years, there has been growing knowledge and public information on the care of the environment and water quality.

As a way to guarantee the safety of its drinking water supply systems, since 2012 the agency has been developing a strategy based on Water Safety Plans. These plans are an integral form of risk assessment and management encompassing all stages of the supply system, from the catchment basin to its distribution to the consumer. They are designed to systematize and organize the management practices traditionally used for drinking water and guarantee their implementation.

The company operates 62 water purification plants for surface water and more than 800 underground water wells, most of which are treated conventionally for the purification of surface water and chlorination in drilling for groundwater supply.

Underground sources

As regards drilling for groundwater supply, laboratory analysis routines performed as a means of control in the OSE have failed to reveal problems of pollution in the aquifers, with the exception of the occasional presence of nitrates in specific urban areas and Atrazine in an isolated case that led to the suspension of the drilling located in an area of intensive agricultural use. The main problem of aquifer quality is linked to the presence of naturally occurring arsenic, common in the western and southern coastal regions of the country. This problem has been exacerbated since the change of regulations in 2011. As a result, levels of arsenic present in certain drilling holes meant that the water is no longer acceptable for consumption. Consequently, there has been a need to adapt and innovate in treatment, which is being carried out through four different lines of action according to the particular situation: i) strengthening hydrogeological studies that allow drilling in areas with a low presence of arsenic (the most commonly used alternative); ii) conventional treatment: flocculation and filtration; iii) Reverse osmosis: being successfully applied in four locations; iv) Adsorption, at the study stage: the development of filters with OSE's own technology, using waste material from the filters used for iron removal.

Surface sources

Episodes of algal blooms in the past five years in both the Santa Lucía river basin, the source of supply for the country's capital and metropolitan area, as well as in the area of Maldonado and Punta del Este (main resort) have increased the population's concern regarding the occurrence of such episodes. In particular, these were linked to the presence of taste and odor in the water distributed to the population, causing enormous repercussions. Although the management of these situations is not seen as the greatest challenge, due to its low frequency of occurrence, the OSE is working on the incorporation of technology in the aforementioned plants that would enable treatment to be improved by applying ozone in combination with activated carbon or biological filters. These improvements aim to complement the treatment used for many years to control the effects of algal blooms, by incorporating activated carbon at the beginning of the process. The communication strategy and the provision of timely information for the population during these events is also regarded as a challenge for the organization.

A critical aspect of algal bloom events is the possible presence of algae toxins. The OSE analyzes the presence of four toxins in both raw and high water: microcystin, saxitoxin, cilidrospermopcin and anatoxin. Microcystin is the only one of these currently regulated by national guidelines and its removal does not pose specific difficulties, since it is achieved through the combination of conventional treatment and activated carbon. Its presence has not been detected in the water leaving any plant, even in those places where significant concentrations have been detected in water from the sources (e.g. the Negro River). Conventional treatment has also been successful in the complete removal of cilidrospermopsin and anatoxin, although only one case of presence in raw water has been detected. The toxin that currently poses the greatest challenge in terms of its removal is saxitoxin. The most notorious episode involving this toxin occurred in 2015 in the water treatment plant of Laguna del Sauce, which supplies the Maldonado-Punta del Este area.

The presence of high contents of organic matter in raw water and the consequent generation of trihalomethanes (THMs) as a consequence of their reaction with the chlorine used in conventional treatment for disinfection, is regarded as one of the main challenges to be solved in relation to the quality of the water supplied. This problem becomes critical when supply points are a long way from the plant, meaning that it is important to minimize the use of chlorine and use other oxidants (chlorine dioxide or ozone) to reduce the amount of organic matter.

Another important aspect is the growing presence of agrochemicals in water sources. In this issue, institutional interaction is key, which is why work is undertaken in conjunction with MGAP, which provides advice on the preparation and coordination of the monitoring OSE undertakes within the framework of water safety plans, according to which compounds are used in agricultural production and at what times. In this respect, the challenge is to achieve an efficient follow-up of the variability of compounds and application frequencies. Another critical associated point is the control of the washing of machinery at points of access to the sources; short courses are particularly vulnerable to this problem.

Accidents that may affect the quality of water, both in the plant and in the sources and distribution systems, are aspects that are addressed in the Water Safety Plans (**see Box 4**), in which the identification of risks associated with the basin, the supply source and the treatment and distribution system is crucial. In this respect, work is being done to incorporate routine indicators that will permit the early detection of problems associated with possible critical events identified as risks.

Lastly, although the actions currently planned to maintain and improve the quality of the water supplied to the population are based on technological improvements of treatment in the plants with the aforementioned methodologies, a great deal of work must be done to improve the hydraulic management of water bodies. In the particular case of the Santa Lucía river basin, recently contracted consulting studies show the need to maintain adequate flow rates as a fundamental measure to reduce the occurrence of algal blooms. One line of action in this respect is to increase the capacity of the hydraulic regulation of the basin to achieve the permanence of adequate flows and the reduction of residence times in water bodies through reservoir management.

4.3 The experience of the Municipality of Montevideo in water quality monitoring and the control of industries

Montevideo extends along the coastal strip of the Río de la Plata and its numerous beaches are one of the most outstanding features of the city. There is also an extensive network of water courses, the most important one being the Santa Lucia River and its wetlands, which, upstream of the Department, is used as a source to supply drinking water to the capital and the metropolitan area. Historically, the main streams in Montevideo -Pantanoso, Miguelete, Carrasco and Las Piedras- have been linked to the sewerage network, receiving wastewater discharges, both industrial and domestic. The Río de la Plata and Montevideo Bay are the final receivers of streams and the sanitation system (**Figure 7**).

In keeping with the environmental policy of the Department, the Municipality of Montevideo, through the Service for the Evaluation of Quality and Environmental Control, systematically monitors the water quality of beaches and the main watersheds of the department.

Beaches and coastal contributions: This monitoring includes 40 sampling points along the coast of the Department (**Figure 7**) and is undertaken throughout the year. Monitoring is carried out twice a week in the non-summer season (April to October), intensifying to three/four times a week during the summer period (November to March). Although its main objective is to control the quality of beaches for recreational use and thus prevent risks to swimmers' health, the sampling design allows for the study of long-term time series to interpret, for example, the influence of external factors on the behavior of the sanitation system and their impact on water quality. Physicochemical (salinity, turbidity, temperature) and microbiological parameters (fecal coliforms) are studied and cyanobacterial blooms (visual detection, chlorophyll, cyanobacterial toxins) are monitored.

Historically, the water quality of Montevideo beaches was affected by the sanitation of the city. Their recovery for recreational use was made possible by the construction of a 2300m pipeline in Punta Brava, through which sewage from the eastern part of the city was discharged. However, given that the sanitation system is unitary, in other words sewage and rainwater flow through the same pipes, one of the factors determining the water quality of Montevideo beaches is the impact of the intense rains at the local level, which requires performing discharges on the coast. For this reason, the Municipality of Montevideo discourages the use of beach water for bathing in the 24 hours after rainfall, since studies have shown that after that period, the quality of water for recreational use is restored. This information is disseminated through the institutional website (IMM, 2018a) and signs on all swimming beaches.

The second important factor with an impact on water quality is the phenomenon of freshwater cyanobacterial blooms. This usually occurs during

Box 4. Water Safety Plans

WHO considers that "*The most effective means of consistently ensuring the safety of a water supply system is through a risk assessment and management approach that includes all steps of the water supply from source to consumer*" (Bartram *et al*., 2009) in what are called Water Safety Plans (WSP). The purpose of WSP is to systematize and organize the management practices used in drinking water and to guarantee their applicability. WSP methodology is based on many principles and concepts from other risk management approaches such as the multiple barriers approach and Hazard Analysis and Critical Control Points, as well as the ISO 9000 quality management systems (Torres Ruiz and Pardón Ojeda, 2009).

In Uruguay, there has been significant progress in regulatory matters, since the WSP Regulation prepared by the Regulatory Body (URSEA) was recently approved and, in addition, the National Water Plan (MVOTMA, 2017) set goals for the number of systems with the use of WSP. Taking into account the specificities of a given system, a WSP should provide a reference framework to identify hazards, assess and manage risks, including control measures, monitoring and management plans (under routine conditions and establishing contingency plans for exceptional conditions), as well as documentation relating to all stages of the water supply system.

Considering the instructions in the latest editions of the WHO Guidelines (WHO, 2011), and understanding the importance of incorporating the concepts of drinking water supply safety, the OSE has launched a program for the development and implementation of safety plans for drinking water throughout the country. The design and implementation of PSA began in 2012 in a pilot system, which selected the Supply System of the City of Dolores with 17,174 inhabitants (INE, 2015). This town already had a water production management system certified in accordance with ISO 9001:2008. To begin with the dissemination of the WSP in other supply systems, training activities were undertaken to introduce the topic at the institutional level, raise awareness and train government employees. A series of general documents were also prepared, including a General Manual for the Preparation of Water Safety Plans and a generic Risk Matrix, whose objective is for Supply Systems to have an initial document from which specifics can be generated.

As a continuous training strategy, a course was included in the company's training plan, which addresses the WSP as a central issue and its implementation in the OSE's supply systems. We also worked on the use of support tools for WSP developed by the Information Technology Management Section of the OSE, and its use for the analysis and follow-up of various aspects related to the performance of the supply system. The country scale of the company, and its responsibility for the management of drinking water service from source to home, places the OSE in a particularly favorable position for the successful implementation of this methodology.

Box 5. Water quality monitoring in the Atlantic coastal lagoons

In 2015, DINAMA, the Eastern Regional University Center of the University of the Republic (CURE), the OSE, the National Directorate of Aquatic Resources (DINARA-MGAP) and the Departmental Intendancy of Rocha established a collaborative monitoring among the various institutions based on in their abilities, experience and interest. This agreement includes the monitoring of the Garzón, Rocha and Castillos lagoons at least in summer, autumn and spring. In this monitoring program, CURE undertakes the logistics of collecting samples in the lagoons, the Regional Laboratory of the OSE performs the collection of samples in streams, the SNAP and the IDR collaborate in the field logistics, and samples are analyzed by the various institutions according to their analytical capabilities. Within this framework, an approach is adopted at the high, medium and low basin level, with sampling sites where the streams rise, downstream and in the various zones of the lagoons (North, Center and South), and the adjacent coastal area. Physicochemical variables, nutrients in water and sediment, chlorophyll, BOD, dissolved and particulate organic matter, bacterial diversity, fecal coliforms, abundance and phytoplankton composition, zooplankton and ichthyoplankton and submerged plant cover are analyzed. The general policy of this agreement is to feed the DINAMA database and share information among institutions.

The ecosystem functioning of coastal lagoons is highly complex, which requires long-term studies. The scale at which this approach is carried out will make it possible to capture a greater degree of spatial and temporal complexity of these ecosystems, which in turn will contribute to the understanding of fundamental processes such as the maintenance of water quality, and biodiversity, among other factors. This will make it possible to identify sites with the highest level of deterioration and need for monitoring, while relating it to changes in land use and the climate, and making it possible to draw up strategies for sustainable use, regulation and control, and to evaluate the effectiveness of the policies currently in force.

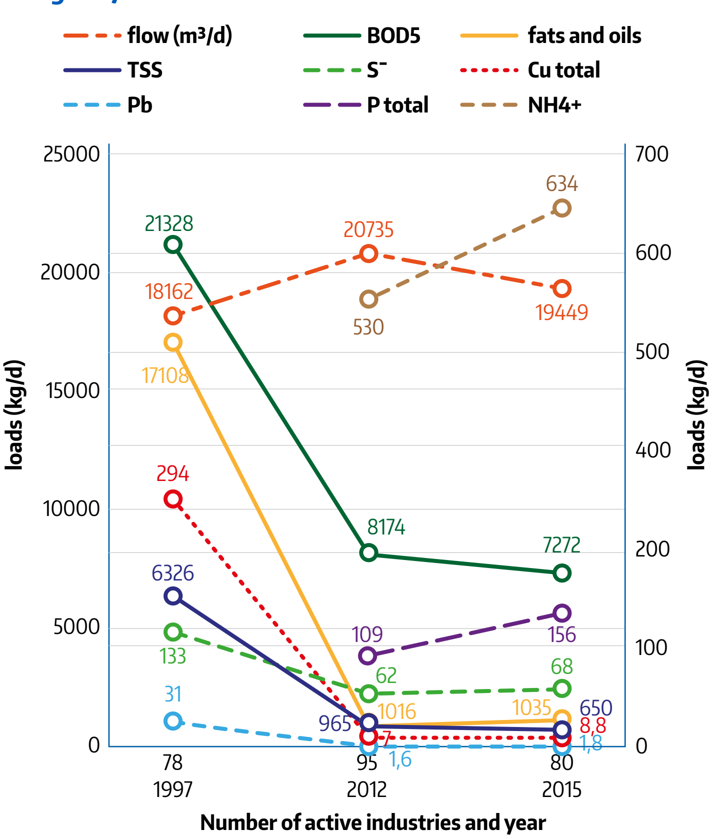
It is essential to note that this collaborative and inter-institutional form of work allows for the generation of long-term basin monitoring at the regional level, which a single institution would be unable to do. The experience and lessons learned in this program can serve as an example for designing future programs throughout the country for water quality monitoring.

the summer season, more in the years affected by the El Niño phenomenon, when discharge from the Uruguay and Paraguay rivers is extremely high and, therefore, salinity of the Río de la Plata is low. The predominant genus in blooms in Montevideo is *Microcystis*, distinguished by its potential to produce toxins called microcystins. Monitoring results are periodically reported to the population in reports published on the institutional website (IMM, 2018a). Weekly reports are drawn up in the summer season and an annual report is also published summarizing the results for the whole year. It should also be noted that the Municipality of Montevideo achieved the ISO 14001 Certification for the environmental management of many of the beaches, which contributed to the environmental and tourist development of the city.

Inland water bodies: In 1997, the main streams in Montevideo began to be monitored in 1997 to evaluate the impact of sanitation plans. This program has continued to the present and incorporated points in minor watersheds. Sampling is carried out four times a year and comprises 29 points in the Miguelete, Pantanoso, Las Piedras and Carrasco streams and 10 points in the lower basin of the Santa Lucía River. Given the strategic importance of the Santa Lucia River and its wetlands, which was incorporated into the National System of Protected Areas in February 2015 (Decree 55/015), this basin was incorporated into the Monitoring Program for major basins in Montevideo in 2009. This program proposes to evaluate water quality from a microbiological, physicochemical and ecotoxicological point of view, in order to identify the main pressure elements and their evolution over time, using the ISCA (Simplified Water Quality Index) as a simplifying, integrating tool of multiple factors (IMM, 2018b).

Montevideo streams currently have varying degrees of environmental deterioration in the various basins. This is due to wastewater discharges, which, in some cases, come from the formal sanitation system, but mainly from irregular population settlements on its edges, as well as from the indiscriminate disposal of solid waste (IMM, 2018c). In addition to extending the coverage of the public sanitation service to previously unserved urbanized areas, sanitation plans have made it possible to eliminate direct discharges into the Miguelete, Pantanoso and Carrasco streams in dry weather. Landscaping works have also been carried out, together with the rehousing and re-furbishment of irregular population settlements within the framework of coordinated management plans, which have had a major impact on the water quality of the streams in Montevideo, particularly in the urban area of the Miguelete stream. This made it possible to improve water quality in terms of the ISCA index, from the category of "diluted wastewater" in 2001, to the category of "raw water" or "medium water", which has remained constant since 2003. The water and sediment quality of the lower basin of the Santa Lucía River, although good in microbiological and ecotoxicological terms, has extremely high nutrient levels.

Figure 7. Evolution of the industrial loads in Montevideo



4.3 Action plan for the protection of environmental quality and the availability of drinking water sources in the Santa Lucía river basin

The Santa Lucia River and its watershed have a high strategic value for the country, since it is the source of raw water for potabilization and supply to Montevideo and its metropolitan area with 1,873,199 inhabitants (INE, 2015). The soils in its river basin (13,433 km^2) are mainly used for livestock and the industrial planting of a wide variety of crops, although they are also used to support a large sector of horticultural, fruit, wine, poultry and pig farming, and the country's dairy activity, together with an industrial park used for processing these products. In the past 15 years, the productivity of certain sectors has experienced a major increase, as in the case of the dairy sector, which has doubled its production without significantly increasing the area occupied. This situation accelerated the eutrophication of water courses, which had been observed in the water indicators (OAS, 1992, JICA, 2010, 2011), but had not prompted concrete actions designed to prevent and mitigate the effect until March 2013, when an odor and taste were detected due to the presence of geosmin in drinking water in Montevideo and the Metropolitan Area.

It was then that the National Directorate of the Environment of the Ministry of Housing, Territorial Planning and the Environment (DINAMA-MVOTMA) drew up the Action Plan for the Santa Lucía River (MVOTMA, 2015). This Plan established two areas with different types of work: Zone A, the Montevideo System, which corresponds to the watershed of Aguas Corrientes, in addition to the San José River Basin and the stretch of the Santa Lucía River between Aguas Corrientes and the mouth of San José; Zone B, the remainder of the Santa Lucía river basin until it flows into the Río de la Plata.

The Plan was designed as a series of measures to control the contribution of nutrients to watercourses within the basin to halt and reverse the deterioration of water quality. These measures consisted of:

- The implementation of a sectoral program to improve environmental compliance of industrial discharge into the entire Santa Lucía River basin and demand the reduction of BOD5, nitrogen and phosphorus levels.

Box 6. Water, sediment and biota quality study of the Río de la Plata

This study has been carried out in the context of the Environmental and Social Management Plan of the works included in the Urban Sanitation Plan (PSU) IV since 2009 (IMM, 2018d). In addition to extending sanitation coverage to previously unserved areas, PSU IV entails the construction of an underwater pipe in Punta Yeguas for the final disposal of sewage effluents from the west side of the city and enables the recovery of water quality in Montevideo Bay. This monitoring, which began in 2007 to evaluate the impact of the works, is designed to study the environmental quality of the system, through physical, chemical, microbiological and biological variables, before, during and after the construction of this pipe and to ensure that these works do not affect the ecosystem uses of the receiving body. 43 sampling points are studied 200 and 2000 m from the coast between the mouth of the Santa Lucia river and the Carrasco stream.

The results confirm that Montevideo is located within the zone of the salinity and turbidity front of the Río de la Plata, whose location varies depending on the flow of the river, and show that the system is in an advanced trophic state, with high nutrient concentrations (IMM, 2018e). Rainfall fluctuations in the entire Río Uruguay-Paraná basin, linked to El Niño-La Niña events, produce major variations in the discharge from Río de la Plata and consequently modify salinity, turbidity, nutrient load and organic matter on the coast of Montevideo. These oscillations influence fecal contamination indicators, as well as the occurrence of cyanobacteria blooms. In the summer season, when salinity in the Río de la Plata remains low, there is a higher incidence of cyanobacterial foams with high toxicity and concentration of chlorophyll a. The high variability in rainfall, which is expected to increase in the context of climate change, is a challenge.

Control of Industries in the Department of Montevideo

The industrial sectors that emit the greatest amount of discharges are food, beverages and tobacco, electricity, gas and water, chemicals and textiles. Approximately 12.3% of these effluents are emitted as a result of the production of inputs for other productive sectors of the country, while the remainder represent a direct sale by the sectors that discharge effluents into water resources to meet their final demand for either the domestic or external market (Piaggio, 2013).

Since 1967, the Municipality of Montevideo has had regulations related to the disposal of industrial wastewater (Decree 13.982 and Resolution 16.277), which establish the obligation for all industrial establishments located in the Department to have an effluent treatment system, prior to the discharge of the latter, either into collectors, water bodies or by scattering and/or infiltrating the land.

In 1997, a management tool was launched, based on the presentation by the industries of the quarterly activity report (WQI), in which they provide data on the production, supplies, emission and operation of their effluent treatment plants (PTE), with physical-chemical analyses of effluent, under the technical responsibility of a competent professional. The aim is for the company to develop a system that will enable it to evaluate its operating processes for treatment daily and assume its responsibility in the self-control of the PTE and therefore the effluent discharged.

In 2014, UEI was incorporated into the UNIT ISO 9001:2008 certification, the quality management system of the Quality Assessment and Environmental Control Service, through the “Industrial effluent monitoring program” process. This program applies to businesses located in the Department of Montevideo which, due to their productive activity, produce residual effluent daily and/or because of their characteristics, create or may create significant environmental impacts. The objectives of the Program include: a) evaluating pollution from the companies involved, b) establishing a monitoring plan that makes it possible to guarantee compliance with current regulations, and c) evaluating the spatio-temporal evolution of industrial pollution.

The companies responsible for 90% of the pollution of industrial origin in Montevideo have been identified, according to their actual or potential contribution, creating the Industrial Effluent Monitoring Program, which are inspected on a quarterly basis. Industries responsible for less than 10% of pollution of industrial origin are controlled with the aim of ensuring annual monitoring and control. One of the goals of the Program is to continue with the publication of a semi-annual report on the Municipality of Montevideo website, showing the degree of compliance with the regulations by each company enrolled in the program.

Figure 7 shows the evolution of the loads contributed by industries located in Montevideo, first controlled by the Pollution Reduction Plan (period 1997-2012) and subsequently by the Industrial Effluent Monitoring Program (period 2012 to 2015). In 2012, the authorities began to evaluate the loads of nutrients directly discharged by industries into the Department’s water courses

- Implementation of a sectoral program to improve environmental compliance regarding industrial discharge into the entire Santa Lucía River basin and demand the reduction of BOD5, nitrogen and phosphorus levels, prioritizing the cities of Fray Marcos, San Ramón and Santa Lucía.
- Declare as priority Area (A) sensitive to the river basin declared AREA A: Santa Lucía River (upstream of the confluence with the San José River, Santa Lucía Chico, Arroyo de La Virgen, San José River, Canelón Grande Stream and Canelón Chico Stream) and compulsorily require all the rural localities located in this basin to control the use of nutrients and pesticides through the implementation in the area of the Plans for the Use, Management and Conservation of Soils (Decree 450/008 of the MGAP). Fertilization will have to be undertaken on the basis of soil analysis to achieve and maintain the phosphorus concentration (below 31ppm of Bray phosphorus).
- Suspend in the hydrographic basin declared ZONE (A), the installation of new feed lots or other practices involving the permanent enclosure of cattle in open-air corrals. The suspension will remain in force until the new guidelines regulating the activity are issued and will also include the expansion of existing ventures.
- Demand the treatment and mandatory management of effluents in all the dairy farms located in the basin with different deadlines according to their size.
- Implement a definitive solution to sludge management and disposal from the drinking water treatment plant of Aguas Corrientes.
- Restrict the direct access of cattle to watering in the courses of the basin declared ZONE (A). Built a restricted perimeter in the area surrounding the Severino, Canelón Grande and San Francisco reservoirs.
- Establish a buffer zone in the basin declared ZONE (A) without land tillage or agrochemical use, for the conservation and restoration of the riparian forest as a way to re-establish the hydromorphological condition of the river, with variable bands according to their importance.
- Institute permit requests for the extraction of existing water (surface and underground) for those lacking permits, within a maximum period of six months, in the basin declared ZONE (A).
- Declare the "Casupá stream hydrological basin" a potable water reserve.
- Obtain opinions within the scope of the Santa Lucía River Basin Commission with regard to the measures comprising this Plan, ensuring the effective participation of the various stakeholders comprising it.

The full implementation of this Plan is a complex process due to the fact that several of the measures require the creation of legal and management tools to facilitate them, as well as the participation and coordination of various government agencies, not all of which were involved in its implementation in the same way , which is why the results today are uneven. Amorín and Larghero (2017) state that the greatest advances were made in the control of point sources, where approximately $30 million USD were invested in industrial effluent treatment, with a similar amount being invested in the implementation of treatment systems for domestic sources, which are still under development. Slower progress was made in the treatment of effluents from dairy establishments and watershed management practices (maintenance of the buffer zone of watercourses and placing a perimeter fence around reservoirs to prevent livestock from entering them). Finally, progress in the control of diffuse sources through modifications in agricultural practices has been minimal or nonexistent. Despite these difficulties, significant progress has been made in the implementation of the Plan, although its success is difficult to evaluate on the basis of existing information due to the lack of a sufficiently extensive baseline, as well as previously defined water quality indicators (Amorín and Larghero, 2017).

5. Water quality in the 2030 Agenda in Uruguay

Water quality is a condition included in the UN 2030 Agenda for Sustainable Development for the elimination of poverty and hunger, the protection of the planet, prosperity and economic and technical progress, and the maintenance of peace and global

Box 7. Dairy Effluent Management

Within the aforementioned Action Plan, measure No. 5 deals with dairy farms: *"Demand the treatment and mandatory management of effluents in all dairy farms located throughout the Santa Lucia River Hydrographic Basin"*. During its first stage of application, this measure was concentrated in establishments with over 500 milking cows. According to data from the National Environmental Observatory (2017), DINAMA has identified and registered 24 dairy farms within the Santa Lucía River Basin. This shows that a great deal of work remains to be done in this regard, since the number of dairy farms in the basin is much greater.

At the farm level, wastewater in dairy farms is produced as a result of cleaning the milking parlor and the waiting pen after each milking operation. Additionally, if there are feeding areas with impermeable floors, they also become wastewater generation areas, either because they are cleaned using water (usually by flooding) or because of the rainwater runoff on them. Generally speaking, the wastewater generated is rich in organic matter and nutrients (especially nitrogen, phosphorus and potassium). Consequently, they may affect the quality of surface or groundwater bodies.

There are several alternatives for wastewater management, and *The Manual for the Environmental Management of Dairy Farms* (MVOTMA, 2016) proposes the following at a basic level:

- Effluent management for landfill: This system comprises a roughing unit, a grit removal unit, a storage pond and an on-site effluent application system.
- Effluent management for discharge into water course: this system consists of a roughing unit, a de-sanding unit, an organic solid separation unit, a system of treatment ponds (which may include an artificial wetland as the last stage) and a device for discharges into watercourses.

At national and international levels, there has been a trend toward the adoption of effluent management systems for landfill. This type of systems has the advantage of the agronomic use of effluents. However, this use must be properly planned in such a way that it does not provide pastures with a nutrient overdose and complies with the necessary waiting times prior to grazing the irrigated crop, as well as allowing the inactivation of the pathogenic microorganisms applied to the land together with effluent. Another aspect that must be taken into account when designing this type of system is the size of the storage pond. This will work with a variable level and must have sufficient capacity to store wastewater during periods of rain or saturated soil, when it cannot be discharged into the land. Finally, all effluent management units are required to be waterproof, including the storage pond. In this regard, there are various materials that can be used for waterproofing it (HDPE, PVC, GCL, compacted clay).

In short, the implementation of the aforementioned Action Plan has begun to take effect in the establishments of the Santa Lucía River Basin with more than 500 milking cows, driving a trend towards the use of effluent management systems for on-site discharge to the detriment of management systems designed with a water course (treatment ponds) traditionally used.

alliances, as determined by its General Assembly in September 2015 with the desire to "transform our world". Uruguay has joined the 2030 Agenda and formed an alliance between the Office of Planning and Budget (OPP), the National Institute of Statistics (INE) and the Uruguayan Agency for International Cooperation (AUCI) to coordinate and monitor national indicators in order to comply with the various goals. The DINAGUA-MVOTMA will assume responsibility for following up on the Sustainable Development Goal (SDG) 6 which proposes, *"Guaranteeing the availability and sustainable management of water and sanitation for all"*, considering, on the one hand, the UN 2010 and 2015 declarations of the human right to water and the right to sanitation respectively and, on the other, the need to protect the entire water cycle from the perspective of integrated water resource management.

5.1 Access to water and sanitation

The main challenges in our country revolve around the small scattered rural populations accessing drinking water supplied by the OSE. The greatest challenge for sanitation is for households to be able to connect to the sewerage network (mainly due to affordability problems) and the extent of unconventional sanitation models in urban areas without dynamic sanitation. In rural and peri-urban populations living in MEVIR housing complexes, the challenge is to sustain the maintenance of autonomous wastewater treatment systems in public-community co-management.

5.2. Water quality improvement

Target 6.3 focuses on the issue of water quality. The indicators proposed are 6.3.1 and 6.3.2. Regarding the first indicator (Proportion of wastewater treated safely), the National Water Plan (MVOTMA, 2017) reports that in Montevideo, after de-sanding, 67% of domestic wastewater in the eastern part of the city is discharged into an underwater pipe measuring over 2 km in Río de la Plata. The same does not happen with the western wastewater that is discharged directly, although 100% of the wastewater in the capital is expected to be treated safely by 2020. In the interior of the country, figures are less encouraging: 41% of homes have a sewer connection and 80% of their wastewater is sent to an effluent treatment plant; *"However, almost all the cities located on the Uruguay River, the Negro River or Río de la Plata still discharge with pre-treatment (with the exception of Paso de los Toros). For these cities, projects exist to improve the quality of the landfill"* (MVOTMA, 2017). Most of the MEVIR housing nuclei have effluent collection and treatment, handled by the OSE. At the same time, 57% of households in the interior have fixed deposits (filtering or waterproof) or septic systems. Most of the wastewater in these systems is not treated safely, because on the one hand barometric truck services are insufficient to meet demand and, on the other, they have high costs, which means that households do not use them as often as necessary or directly infiltrate the soil, thereby contaminating soil and groundwater. On the other hand, in general there is a lack of suitable plants for these discharges, as a result of which the only function of trucks is often to remove wastewater from urban areas, directly disposing of it in fields or water courses. As for industrial wastewater, there are approximately 600 companies which have submitted authorization for industrial drainage to the environmental authority, the majority being located in the Río de la Plata basin. State control over industrial discharges is greater than over urban and domestic discharges.

Regarding the second indicator (the proportion of good quality water masses) it is extremely difficult to quantify it in Uruguay with the scientific information available. However, on the basis of studies conducted in 2013, the diagnosis of the National Water Plan states that, *"... most of the water bodies are above the limit at which they are considered eutrophic, indicating a deterioration of their quality. [...] There has been a continuous increase in eutrophication in most aquatic ecosystems which had already deteriorated, while very few cases have undergone improvements"* (MVOTMA, 2017). In the past 30 years, the occurrence of cyanobacterial blooms in various water bodies throughout the country has increased. Kruk *et al.* (2013) systematize information on surface water quality in the country on the basis of scientific articles and technical reports between 2007 and 2011. Of the 151 cases studied by various organisms and research centers, 70% were classified as eutrophic while 40% had high biomasses or harmful phytoplankton blooms at the time of their study.

The discussion in Uruguay on surface and groundwater quality points, on the one hand, to the interpretation of existing data - more optimistic on the part of the central public bodies and less optimistic on the part of natural science researchers - and, on the other, to the existing regulatory framework such as Decree 253/79, which classifies streams and rivers according to their priority use (human consumption, recreation, navigation, etc.) when the new paradigms seek to go beyond the sectoral perspectives this classification reproduces (Deci Agua, 2017).

5.3 Integrated water resource management and cross-border cooperation

Nowadays, there are a number of incipient antecedents of Integrated Water Resource Management (IWRM) at the watershed level, where water intakes for potabilization are located in the most populated regions of the country and raw water quality constitutes the main motivation to advance water management in new ways: the Santa Lucía river basin (since 2013), Laguna del Sauce basin (since 2010), and the Laguna del Cisne basin (2016). On the other hand, within the framework of the Cuenca del Plata Program, as a result of a process with different characteristics, marked by its cross-border nature, progress was made in the pilot plan for the integrated management of the Cuareim-Quaraí River Basin shared by Uruguay and Brazil.

In terms of cross-border cooperation, Uruguay is committed to several agreements regarding its transboundary waters that address water quality. The main agreements with Argentina include: the Administrative Commission of the Uruguay River (CARU), the Mixed Technical Commission of Salto Grande (CTMSG), the Administrative Commission of Río de la Plata (CARP) and the Mixed Technical Commission of the Maritime Front (CTMFM). All these have some function linked to the protection of the waters of their respective areas of activity. In the wake of the international conflict over the installation of a cellulose production plant in the vicinity of the city of Fray Bentos, located on the Uruguay River and linked to its Gualeguaychú counterpart by a bridge, the waters of the Uruguay river and some of its tributaries in the area of influence of the factory have been jointly monitored, following the verdict by the International Court of Justice of The Hague in 2010.

The Binational Salto/Concordia Commission of the Guaraní Aquifer operates in the Salto and Concordia area. The forerunner of this *ad-hoc* commission can be found in the Salto/Concordia Pilot Plan of the Project for the preservation and sustainable development of the Guaraní Aquifer System (SAG Project between 2003 and 2009), financed by the four countries with territories on the SAG: Brazil, Argentina, Paraguay and Uruguay, and the Global Environment Facility (GEF), and implemented by the OAS. The importance of this type of international cooperation for groundwater is particularly important in the present, because, according to international analysts, the recent approval by the Brazilian Senate of the Guaraní Agreement for international preventive management of the Guaraní Aquifer, creates a real possibility that this Agreement will come into force, which would put the four countries sharing this natural asset at the global forefront in the area of transboundary water management and mean that, *"They will be able to achieve target 6.5 of Sustainable Development Goal 6.5"* (Hirata *et al*., 2017).

Near the border with Brazil, there has been cooperation over the waters and transboundary territories of Laguna Merín, with the creation in the 1960s of the Merín Lagoon Mixed-Technical Commission, which was relaunched in 2010 with the aim of strengthening the waterway.

5.4 Protect and restore aquatic ecosystems

All watercourses –both surface and underground-enjoy a certain degree of protection in the country's environmental legislation. The main focus in on the waters that form part of protected areas defined in the National System of Protected Areas, as is also the case in the departmental protected areas.

Few cases exist of restoration of aquatic ecosystems, perhaps because the national environmental legislation prioritizes the prevention of environmental damage. The aforementioned plans in Laguna del Sauce, Laguna del Cisne and Santa Lucia River are now also oriented towards restoration. In the latter case, an Ecosystem Restoration Plan began to be implemented in the Santa Lucía Basin in June 2016, whose first task based on voluntary work has been reforestation with native species.

In Montevideo and other cities in the interior there are a number of examples of the restoration of the quality of streams and their banks. This is the case of the Miguelete Stream Special Plan and other small tributaries (Montevideo); the Ciudad de la Costa Sanitation Plan, in Canelones, which promotes the improvement of the quality of beaches on the coastal strip; the Cuñapirú Creek Recovery Plan, in the city of Rivera, with the creation of a linear park that mitigates floods and the consolidation of a coastal protection park in San Gregorio de Polanco, in the Department of Tacuarembó (MVOTMA, 2016). There have also been specific citizen initiatives to improve the banks of streams such as the Colorado, in the vicinity of the town of Sauce.

5.5 Cooperation for water and sanitation development

International cooperation in Uruguay has diminished its financial importance insofar as the country is now listed as a high income country in statistics and global forums. According to the latest available report from AUCI (2015) with data on 2014, the water sector received nearly 6% of all traditional international cooperation, amounting to approximately 9 million dollars, the vast majority of which comes from a Spanish fund for water and sanitation -run by the IDB- which focused on the Program for the supply of drinking water to small rural communities (2010-2016), where the OSE, the National Public Education Administration (ANEP) and the MGAP acted as counterparts. In this SDG 6 target, there is enormous potential for development, whereby Uruguay must partner with other countries and organizations to contribute and receive financial and technical support in the water and sanitation sector (6.a).

5.6 Citizen participation

Citizen participation has been a principle of national water policy since the constitutional reform in 2004 and the creation of DINASA (subsequently DINAGUA) immediately afterwards as the national authority in public policy planning and development. To this end, there is a program led by DINAGUA-MVOTMA for the creation and operation of three regional basin councils (Río Uruguay, Laguna Merín and Río de la Plata and maritime front) and nine basin commissions to date. In these areas, which have government representatives, users and organized civil society, the goal is to move towards integrated watershed management plans. To date, they have operated more as spaces for reporting and requesting information on water quality. In accordance with the Water Law, a National Water, Territory and Environment Committee should have been formed to coordinate the basin plans that both the councils and commissions should draw up.

On the other hand, specific, usually fragmented initiatives implemented for the improvement of water quality and the treatment of domestic effluents by NGOs and citizen groups at the local level, are found throughout the country, of which the UNDP Small Grants Program is a good example.

Collective and individual participation for environmental observation is encouraged by the DINAMA-MVOTMA on the basis of the installation of a system for receiving environmental complaints online. Among the 14 reasons the system presents to file a complaint are "contamination of water bodies" and "discharge of effluents", in addition to other items that could be indirectly linked to water quality (such as waste and pesticide containers).

The Santa Lucia River Water Assembly Collective, a member of the Santa Lucía River Basin Commission, presented scientific evidence of contamination of a glen in the town from what they call "popular laboratory", and opened a control file on industrial discharges activities by the DINAMA and the Municipality of Canelones. The modality of water quality analysis for reporting purposes, technically independent of state agencies, is novel in the country and according to its promoters, is a response to the slowness and inaction on the part of the laboratories responsible for these inspection tasks.

In short, at the time of writing this chapter and in view of the commitments assumed by Uruguay to comply with the SDGs by 2030, the SDG 6 goals requiring most attention are the right of access to decent sanitation in urban contexts, the improvement of water quality by promoting sewage treatment in the residential and industrial sector, as well as the prevention of the contamination of surface waters by agricultural activities, bioremediation in streams and urban ravines, and advancing the implementation of IWRM plans at the basin level, beginning with those that provide water for human consumption.

6. Conclusions and challenges for water quality in Uruguay

People often used to say: *"Water is not a problem in Uruguay"*. This traditional perception, widespread in the largely urban population, about the abundance of water as regards quantity and quality may at least partly be due to the fact that the country achieved early high levels of urban coverage of both drinking water supply and sanitation. Thus, consideration of the quality of water resources is an issue that has been relatively overlooked by both public opinion and government institutions. This has resulted in a few, very recent actions designed to protect water resources to accompany, for example, the rapid growth of productive activities that have posed a threat to water sustainability.

This perception, which does not regard water as a problem, began to change rapidly in the past decade, particularly with regard to water quality. Although the situation is not spatially homogeneous (problems are usually more pressing in the southern half of the country and the coastal zone due to the intensity of land use and the greater population density), most surface water bodies fail to meet current standards in several key parameters. The particular case of phosphorus content in rivers and reservoirs is perhaps the most paradigmatic, and in some ways it was the one that triggered public awareness of the loss of quality of water resources. It has been gradually understood that the excess presence of phosphorus in water bodies used for human consumption is the key factor in the occurrence of cyanobacterial blooms (toxic in many cases), which in turn has led to increasing investment in potabilization.

The greater understanding on the part of many social sectors arose from the sudden emergence of events related to the turbidity and palatability of drinking water in 2013 and 2015. These effects on drinking water did not emerge suddenly, but are the result of gradual multicausal development, accelerated by the agricultural boom of the past 15 years. Although not enough evidence has been accumulated, there is a growing body of information linking the presence of toxins to effects on human health. In this respect, it remains a major challenge to modify the social understanding of the links and interdependence between human and ecosystem health (Carr and Neary, 2006).

Thus, eutrophication has gone from being a topic reduced exclusively to technical or academic discussions, to being a problem of which the public is at least slightly aware. This change of perception reflects the reality in Uruguay, given that the symptoms of eutrophication can be seen today in a large sector of the country's aquatic ecosystems, albeit with varying degrees of evolution. The construction of reservoirs and embankments poses another challenge as a result of the possible proliferation of cyanobacteria inocula from these water bodies. It is clear that eutrophication is a major problem can largely be explained by the basically agricultural nature of the country. However, problems are not exclusively limited to eutrophication, and information is increasingly available on other problems that may be linked to agroindustrial and urban development. There have been specific cases of the presence of heavy metals, particularly in areas of industrial activity, or viruses in water bodies near urban conglomerations. Other topics, on which conclusive data do not yet exist, also warrant attention such as the presence of agrotoxins in biota and the physical matrix of ecosystems.

The state of aquatic ecosystems depends primarily on the land uses that characterize their drainage basins. In this respect, according to the trends in productive agro-industrial development, in the short term, the progressive deterioration of water resources is unlikely to be able to be reversed. Being able to estimate the medium-term impact of policies and economic development requires having a full description of the current status of environments. In Uruguay, monitoring surface water quality is still limited and insufficient, beyond efforts by the government and academia. Recent initiatives to improve systematic monitoring, such as the Río Negro and the Santa Lucía River, as well as the inclusion of non-traditional parameters in samplings (biological indicators, pesticides in biological matrices, etc.), still constitute reactions to emerging problems, rather than strategic planning. The former occurred in the Negro River in response to the proposed installation of cellulose pulp production plants from 2009, whereas the case of monitoring lagoons on the Atlantic coast constitutes strategic planning. It is worth noting that in the management of the Santa Lucía river, tools are being created through legal instruments and sectoral programs - economic support from MGAP for farmers for technical advice, hydraulic works and actions to protect bodies of water – specifically designed to reduce the contributions of nutrients. Although this initiative is an unprecedented case of watershed management in Uruguay, it still lacks strong tools and, in some cases, empirical knowledge to support them.

Given the need for a description of the current status of the environments, as a baseline, the Technical Board of Water was created by DINAMA, with the participation of technicians from various state and public institutions (ministries , Udelar, INIA, LATU), with the aim of sharing their information and knowledge, to discuss and reach agreements on various scientific-technical issues related to water resources, to advise decision makers. The first reports, published in 2017, state that in order to support water quality monitoring and decision making, it is essential to focus on the joint monitoring of quantity and quality, and the use of technologies for the acquisition and automatic transmission of information, as well as remote sensors. These technologies make more sense when margins of error in the appreciation of information are reduced, which often happens when water quality is affected or in response to the greater likelihood of suffering extreme climatic events related to climate variability and change.

6.1 Development model and aquatic ecosystems

Due to the importance of agricultural production for the country's economy, both the government and other political and social actors seek to increase the level of this activity. At the same time, the goal is to achieve SDGs, which requires public policies designed to conserve natural resources, among other aspects. The tension between production and conservation is recognized in the country's environmental legal framework. Accordingly, the challenge for adequate protection of the environment lies in the implementation of norms to address the rapid advance of productive activities based on the intensive use of natural resources.

One of the greatest environmental challenges facing Uruguay is to reconcile the increase in agricultural production and productivity with the conservation of ecosystems. The government's response is expressed in the desire to achieve an "increase in productivity in an environmentally sustainable manner". However, today, beyond rhetoric, experience has shown that it is extremely difficult to achieve an increase in productivity without affecting water courses, given that the agricultural system -even when best practices are implemented- is based on the increased use of fertilizers and agrochemicals, part of which ends up leaching into watercourses.

Nowadays there is a bias that prioritizes the economic dimension of sustainable development, which damages the environment (unaccounted externalities), and creates conflicts in society expressed through the deterritorialization of rural family production, job loss and effects on health. Given that the economy dominates decision-making, it seems essential to advance the quantification of the benefits of activities that use natural resources and the cost of environmental damage. For example, a system of environmental accounts should be implemented to internalize the costs of the depreciation of the environment in national economic accounts. In this regard, the Office of Programming and Agricultural Policy (OPYPA) of MGAP and the National Environment Directorate (DINAMA) of the Ministry of Housing, Territorial Planning and Environment (MVOTMA) have made efforts to promote the implementation of a system of this nature, so that it can be incorporated into the system of national accounts drawn up by the Central Bank, a goal which is in turn reflected in the early drafts of the National Environmental Plan being studied by the National Environmental Cabinet. The challenge is therefore twofold. On the one hand, there is a need to improve accounting systems and, on the other, it is essential to determine who will pay the financial costs of a transition to productive systems in keeping with the notion of sustainable development.

For all the above reasons it is clear that a broad, democratic discussion should be started with reliable sources of information from the environmental, economic, health and social sciences, in which society as a whole can define the path and strategies of the country's future development.

6.2 Legal framework and participatory institutionality

The incorporation into the national legal framework of environmental protection in general, through the law of Environmental Impact Assessment in 1994, and of water resources in particular, as of the constitutional reform of 2004, and Law 18610, took place relatively recently, in 2009. The latter establishes the guiding principles of the National Water Policy through "the recognition of the watershed as a unit of action for water resource planning, control and management".

Control over point sources discharges -mainly of industrial origin- regardless of whether it may require modernization, has a clear, long-standing regulatory framework (the national law on this issue was passed in 1979, in addition to departmental norms). Conversely the control of pollutants from diffuse sources - specifically agriculture and livestock - is more incipient and still lacks an adequate regulatory framework. The obligation to present land use and management plans as of 2015 (Decree No. 405/2008) to prevent water erosion is also an important step forward in the control of water pollution from diffuse sources. This standard constitutes the first quantification based on scientific knowledge and the mathematical modeling of the relationship between land use and effects on natural resources, which has been incorporated into Uruguayan regulations and implemented as a state policy. This framework led to the first Uruguayan experience in a Plan of Action of the Santa Lucia River (MVOTMA, 2015) in 2013. However, the development of similar specific instruments of national scope has yet to reduce the contribution of pollutants from diffuse sources, particularly, of nitrogen and phosphorus into watercourses.

This raises two challenges: on the one hand, to continue with the development of the legal and normative framework that will make it possible to establish better criteria for controlling productive activities, essential for the preservation of water quality; and on the other hand, the need for scientific development and technical innovation, essential both to identify and quantify the effects of these activities and to implement the necessary measures for their minimization and mitigation. The greatest challenge would appear to be to achieve joint, balanced development between both aspects, since regulation adjusted to local conditions -which only good science can investigate- and effective controls, are crucial to a scheme of increased productivity, a scenario which seems inevitable in the economic and social reality of Uruguay.

In terms of citizen participation, in the regional and even global context, Uruguay is characterized by the possibility of public debate on environmental and water issues. In particular, following the 2004 referendum that led to a constitutional reform already mentioned, the technical aspects of water management were socialized and politicized. This gave rise to the proposal to create institutionalized spaces for information, consultation, discussion and advice to government authorities, such as the Advisory Commission on Water and Sanitation (COASAS), in close connection with the DINAGUA-MVOTMA, and the Basin Councils and Commissions , promoted by the National Water Policy. However, these new spaces overlap with other entities with more or less autonomous participation, not methodologically delimited by river basins. This new institutional construction of water conflicts with the conventional institutionalization of political-party representation at the national, departmental and municipal levels. There are also spaces for participation based on sectoral public policies, such as the rural development panels organized by MGAP and the MIDES department panels. The challenge is how to counteract the atomization of participation and lack of coordination between levels of governance, and how to achieve levels of efficiency in the combination of direct and representative democracies that will result in actions to protect water quality in coherent times and spaces.

The aforementioned realities and challenges regarding water quality in Uruguay have led to gradual yet profound transformations in the collective imaginary of the close links between the urban and rural environment. In the present and the near future, the culture of hegemonic water in the country in the 20th century, anchored in the urban experience, which domesticated the water problem and made it invisible, will shift to a more comprehensive view of the socio-hydrological water cycle, which transcends the borders of populated areas and agricultural lands and even national and international administrative limits. In the not so distant future, it may be insufficient and even counter-productive to write about water quality within national contexts alone.

7. References

Achkar M, Domínguez A, Pesce F. (2012). *Cuenca del Río Santa Lucía - Uruguay. Aportes para la discusión ciudadana.* Montevideo: REDES Amigos de la Tierra. 23 pp.

Agencia Uruguaya de Cooperación Internacional (AUCI) (2015). *Estado de situación de la cooperación internacional en Uruguay.* Montevideo: Presidencia de la República. Retrieved from: www.auci.gub.uy/images/pdf/Estado%20de%20situacin%202015_web.pdf

Alberti A. (2012). *Detección molecular y diversidad genética de norovirus en pacientes y en aguas residuales del Uruguay.* Tesis de Maestría (PEDECIBA). Universidad de la República (UdelaR). Montevideo.

Amorín C, Larghero S. (2017). *Informe de situación de las medidas que se están implementando para el aseguramiento de la potabilización del agua del sistema de abastecimiento de Montevideo y Laguna del Sauce.* Montevideo: Estudio Ingeniería Ambiental. 85 pp.

Arocena R, Chalar G, Fabián D, de León L, Brugnoli E, Silva M, Rodó E, Machado I, Pacheco JP, Castiglioni R and Gabito L. (2008). *Evaluación Ecológica de Cursos de Agua y Biomonitoreo.* Informe. Montevideo: DINAMA-Facultad de Ciencias, 122 pp. Retrieved from: http://limno.fcien.edu.uy

Arocena R, Chalar G, Perdomo C, Fabián D, Pacheco JP, González M, Olivero V, Silva M and Etchebarne V. (2013). Impacto de la producción lechera en la calidad de los cuerpos de agua. *Augmdomus* 5:42-63.

Banco Mundial (2011). *Montevideo Landfill Gas Recovery Project.* Uruguay. Retrieved from: http://documentos.bancomundial.org/curated/es/225461468317122489/pdf/E28940UG0SP0Montevideo0landfill.pdf

Banco Mundial (2018). *El Banco Mundial en Uruguay. Informe 2016.* Retrieved from: http://www.bancomundial.org/es/country/uruguay/overview

Bartram J, Corrales L, Davison A, Deere D, Drury D, Gordon B, Howard G, Rinehold A, Stevens M. (2009). *Manual para el desarrollo de planes de seguridad del agua: método pormenorizado de gestión de riesgos para proveedores de agua de consumo.* Ginebra: OMS.

Batthyány K. (2009). Autonomía de las mujeres y resistencias a la división sexual del trabajo al interior de las familias. En *Seminario Regional: Las familias latinoamericanas. Hacia la articulación del diagnóstico, legislación y políticas.* Santiago de Chile: CEPAL.

Bonilla S. (2009). *Cianobacterias Planctónicas del Uruguay; Manual para la identificación y medidas de gestión.* Montevideo: UNESCO, S. Bonilla.

Bonilla S, Haakonsson S, Somma A, Gravier A, Britos A, Vidal L, De León L, Brena B, Pírez M, Piccini C, Martínez de la Escalera G, Chalar G, González-Piana M, Martigani M, Aubriot L. (2015). Cianobacterias y cianotoxinas en ecosistemas límnicos de Uruguay. *INNOTEC* 10:9–22.

Carr GM, Neary JP. (2016). *Water Quality for Ecosystem and Human Health.* United Nations Environment Programme Global Environment Monitoring System / Water Programme. Burlington. 132 pp.

Carrasco-Letelier L, Eguren G, Teixeira de Mello F, P Groves (2006). Preliminary field study of hepatic porphyrin profiles of *Astyanax fasciatus* (*Teleostei, Characiformes*) to define anthropogenic pollution. *Chemosphere* 62:1245–1252.

Chalar G. (2006). Dinámica de la eutrofización a diferentes escalas temporales: Embalse Salto Grande (Argentina-Uruguay). En: JG Tundisi, T Tundisi-Matsumura, T Sidagis, C Gall (eds.) *Eutrofização na América do Sul: Causas, conseqüências e tecnologias de gerenciamento e controle.* Instituto Internacional de Ecología, Instituto Internacional de Ecología e Gerenciamento Ambiental, Academia Brasileira de Ciências, Conselho Nacional de Desenvolvimento Científico e Tecnológico, InterAcademy Panel on International Issues, InterAmerican Network of Academies of Sciences, pp. 87-101.

Chalar G, Arocena R, Pacheco JPand Fabián D. (2011). Trophic assesment of streams in Uruguay: A Trophic State Index for Benthic Invertebrates (TSI-BI). *Ecological Indicators* 11:362-369.

Chalar G, De León L, Brugnoli E, Clemente J, Paradiso M. (2002). Antecedentes y nuevos aportes al conocimiento de la estructura y dinámica del Embalse Salto Grande. En: Fernández-Cirelli A.

y Chalar G. [eds.]. *El agua en Sudamérica: de la Limnología a la Gestión en Sudamérica.* Buenos Aires: CYTED. pp. 123-142.

Chalar G, Gerhard M, González-Piana M, Fabián D. (2014). Hidroquímica y eutrofización en tres embalses subtropicales en cadena. En: Marcovecchio JE, Botté SE and Freije RH. [eds.]. *Procesos geoquímicos superficiales en Sudamérica.* Salamanca: Nueva Graficesa, pp. 121-148.

Colombo JC, Pelletier X, Brochu Ch, Khalil M, Catoggio JA. (1989). Determination of hydrocarbon sources using n-alkane and polyaromatic hydrocarbon distribution index. Case study: Rio de la Plata Estuary, Argentina. *Environmental Science and Technology* 23:888–894.

Commendatore MG, Nievas ML, Amin O, Esteves JL (2012). Sources and distribution of aliphatic and polyaromatic hydrocarbons in coastal sediments from Ushuaia Bay (Tierra del Fuego, Patagonia, Argentina). *Marine Environmental Research* 74:20–31.

Conde D, Pintos W, Gorga J, de León R, Chalar G. and Sommaruga R. (1996). The main forces inducing chemical spatial heterogenity in Salto Grande, a reservoir on the Uruguay River. *Arch. Hydrobiol. Suppl.* 1:571-578.

De León L, Yunes J. (2001). First report of a Microcystis aeruginosa toxic bloom in La Plata River. *Environ. Toxicol. Water Qual.* 16:110–112.

Deci Agua (2017). *Síntesis de aportes a la propuesta de Plan Nacional de Aguas (PNA).* Montevideo (mimeo). Recuperado de: www.deciagua.edu.uy

Delgado E. (2018). *Informe final Proyecto CSIC I+D "Participacion social en la conservación del patrimonio natural de Humedal del Arroyo Maldonado".* Comisión Sectorial de Investigación Científica (UDELAR).

Dirección de Estadísticas Agropecuarias (MGAP-DIEA) (2015). *Anuario estadístico agropecuario.* Ministerio de Ganadería Agricultura y Pesca. Montevideo. Retrieved from: http://www2.mgap.gub.uy/portal/page.aspx?2,diea,diea-anuario-2015,O,es,0.

Eguren G, Cabrera J, G Silva (2013). *Impactos del uso y manejo del cultivo de arroz sobre la integridad de los cursos de agua superficial en base a atributos de las comunidades de peces.* Informe final Proyecto ANII Nº PE FSA 1 1630.

Emerson R, Fretz R, Shaw L. (2011). *Writing Ethnographic Fieldnotes.* The University of Chicago Press Books.

Ernst F, B Alonso, M Colazzo, L Pareja, V Cesio, A Pereira, A Márquez, E Errico, A Segura, H Heinzen, A Pérez-Parada (2018). Occurrence of pesticide residues in fish from south American rainfed agroecosystems. *Science of the total environment* 631–632:169-179.

Evia V. (2018). Salud ambiental y antropología médica crítica. Aportes desde una investigación sobre exposición a plaguicidas agrícolas en Uruguay. *Ichan Tecolotl*. México: CIESAS/CONACYT. Retrieved from: http://ichan.ciesas.edu.mx/category/puntos-de-encuentro

Ferrari G, Pérez MC, Dabezies M Míguez D., Saizar C. (2011). Planktic Cyanobacteria in the Lower Uruguay River, South America. *Fottea* 11:225–234.

Font E. (2016). *Cianotoxinas en abrevaderos: peligrosidad y efectos negativos para el ganado.* Tesis de Maestría en Ciencias Ambientales. Facultad de Ciencias, UdelaR. Montevideo. 87 pp.

García-Rodríguez F, Hutton M, Brugnoli E, Venturini N, Del Puerto L, Inda H, Bracco R, Burone L, Muniz P. (2010). Assessing the effect of natural variability and human impacts on the environmental quality of a coastal metropolitan area (Montevideo, Uruguay). *Pan-American Journal of AquaticSciences* 5:91-100.

Gillman L. (2016). *Virus entéricos en aguas de uso recreacional en un contexto de escasa cobertura de saneamiento en Barros Blancos, Canelones, Uruguay.* Tesis de Maestría (PEDECIBA). UdelaR. Montevideo.

González-Piana M, Fabian D, Delbene L, Chalar G. (2011). Toxics blooms of Microcystis aeruginosa in three Rio Negro reservoirs, Uruguay. *Harmful Algae News* 43:16-17.

Hammersley M, Atkinson P. (2014). *Etnografía. Métodos de investigación.* Barcelona: Paidós.

Haro JA. (2000). Cuidados profanos: una dimensión ambigua en salud. En: Perdiguero, E y Comelles, JM (eds.) *Medicina y cultura. Estudios entre la antropología y la medicina.* Barcelona: Ediciones Bellaterra.

Hirata R, Sindico, F, Manganelli A. (2017) *El valor de la entrada en vigor del Acuerdo sobre el Sistema Acuífero Guaraní.* Policy Briefing Nº8, April 2017. Glasgow: University of Strathclyde.

Hutton M, Venturini N, García-Rodríguez F, Brugnoli E, Muniz P. (2015). Assessing the ecological quality status of a temperate urban estuary by means of benthic biotic indices. *Marine Pollution Bulletin* 91:441-453.

Instituto Nacional de Estadística (INE) (2015). *Censo 2011.* República Oriental del Uruguay: INE. Procesamiento censal en línea. Redatam. Disponible en: www.ine.gub.uy

Intendencia de Montevideo (2009). *Programa de Monitoreo de Agua de Playas y Costa de Montevideo. Informe 2008–2009.* Retrieved from: http://www.montevideo.gub.uy/playas/evaluacion-de-la-calidad-del-agua-en-las-playas

Intendencia de Montevideo (2018a). Retrieved from: http://www.montevideo.gub.uy/playas/evaluacion-d e-la-calidad-del-agua-en-las-playas

Intendencia de Montevideo (2018b). Retrieved from: www.montevideo.gub.uy/calidad-de-agua/indice-de-calidad-de-agua

Intendencia de Montevideo (2018c). Retrieved from: http://www.montevideo.gub.uy/calidad-de-agua/documentos-cursos-de-agua

Intendencia de Montevideo (2018d). Retrieved from: http://www.montevideo.gub.uy/plan-de-sanea miento-urbano-iv

Intendencia de Montevideo (2018e). Retrieved from: http://www.montevideo.gub.uy/calidad-de-agua/informes-estudio-de-la-calidad-de-agua-sedimento-y-biota-del-rio-de-la-plata

IPCC (2007). *Climate Change 2007: the physical science basis. A report of working Group 1 of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

JICA (Agencia de Cooperación Internacional del Japón) (2010). *Informe de situación sobre fuentes de contaminación difusa en la cuenca del río Santa Lucía.* Montevideo: MVOTMA. 194 pp.

JICA (Agencia de Cooperación Internacional del Japón) (2011). *Proyecto sobre el Control de la Contaminación del Agua y la Gestión de la Calidad del Agua en la Cuenca del Río Santa Lucía. Informe Final del Proyecto.* v.1. Montevideo: MVOTMA.

Kruk C, Segura A, Nogueira L, Carballo C, Martínez de la Escalera G, Calliari D, Ferrari G, Simoens M, Cea J, Alcántara I, Vico P, Miguez D, Piccini C. (2015). Herramientas para el monitoreo y sistema de alerta de floraciones de cianobacterias nocivas: Río Uruguay y Río de la Plata. *INNOTEC* 10:23–39.

Kruk C, Suárez C, Ríos M, Zaldúa N, Martino D. (2013). *Ficha: Análisis Calidad de Agua en Uruguay.* Montevideo: Asesoramiento Ambiental Estratégico/Vida Silvestre.

Lizasoáin A, Tort LF, García M, Gómez MM, Cristina J, Leite JP, Miagostovich MP, Victoria M, Colina R. (2015). Environmental Assessment of Classical Human Astrovirus in Uruguay. *Food Environ Virol.* 7:142-148.

López J. (2015). *Sistemas de Saneamiento Adecuado en Uruguay.* Tesis de Maestría en Ingeniería Ambiental. Facultad de Ingeniería, UdelaR. Montevideo.

Matteo L. (2008). *Análisis de los perfiles de porfirinas de cuatro especies de peces nativas expuestas a descargas urbano-industrial y agrícola (Canelones-Uruguay).* Trabajo final de la Lic. en Ciencias Biológicas, Facultad de Ciencias, UdelaR, Montevideo.

Mello LC. (2011). *Distribución espacial de metales pesados en la Cuenca del Arroyo Carrasco y su relación con el uso de la cuenca asociada.* Tesis de Maestría. Programa Maestría en Ciencias Ambientales, Facultad de Ciencias, UdelaR. Montevideo.

Menéndez E. (2009). *De sujetos, saberes y estructuras. Introducción al enfoque relacional en el estudio de la salud colectiva.* Buenos Aires: Lugar Editorial.

Ministerio de Desarrollo Social (MIDES) (2016). *Estadísticas de Género 2015.* Uruguay: MIDES, Instituto Nacional de las Mujeres, Sistema de Información de Género. Retrieved from: http://www.inmujeres.gub.uy/innovaportal/file/15091/1/estadisticas-de-genero-2015.pdf

Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (MVOTMA) (2009). *Informe del Estado del Ambiente.* Montevideo: MVOTMA/DINAMA.

Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (MVOTMA) (2013). *Programa de Mejoramiento de Barrios: Análisis Ambiental y Social, 2013.* Montevideo: MVOTMA, DINAVI.

Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (MVOTMA) (2015). *Plan de Acción para la protección del agua en la cuenca del Santa Lucía.* Montevideo: MVOTMA. Retrieved from: http://www.mvotma.gub.uy/portal/ambiente-territorio-y-agua/gestiona/instrumentos-de-gestion-ambiental/item/10006604-

plan-de-accion-para-la-proteccion-del-agua-en-la-cuenca-del-santa-lucia.html

Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (MVOTMA) (2016a). *El Sistema Nacional de Áreas Protegidas.* Montevideo: MVOTMA. Retrieved from: http://www.mvotma.gub.uy/portal/snap

Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (MVOTMA) (2016b). *Manual para la gestión ambiental de tambos.* Montevideo: MVOTMA/DINAMA. Retrieved from: http://www.mvotma.gub.uy/portal/ciudadania/biblioteca/documentos-de-ambiente/item/10008342-manual-para-la-gestion-ambiental-de-tambos.html

Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (MVOTMA) (2016c). *Hábitat III. Informe nacional de Uruguay.* Montevideo: MVOTMA. Retrieved from: http://www.mvotma.gub.uy/portal/uruguay-hacia-habitat-iii

Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (MVOTMA) (2017). *Plan Nacional de Agua.* Montevideo: MVOTMA-DINAGUA.

Moss B. (2010). *Ecology of fresh waters: a view for the twenty-first century.* Chichester: John Wiley & Sons.

Muniz P, Venturini N, Gómez-Erache M. (2004). Spatialdistribution of chromium and lead in sedimentsfromcoastalareas of the Río de la Plata estuary (Montevideo, Uruguay). *Brazilian Journal of Biology* 64:103–116.

Muniz P, Venturini N, Hutton M, Kandratavicius N, Pita A, Brugnoli E, Burone L, García-Rodríguez F. (2011). Ecosystem health of Montevideo coastal zone: a multiapproach using some different benthic indicators. *Journal of Sea Research* 65:38-50.

Muniz P, Venturini N, Martins CC, Munshi AB, García-Rodríguez F, Brugnoli E, Lindroth AL, Bícego MC, García-Alonso J. (2015). Integrated assessment of contaminants and monitoring of an urbanized temperate harbor (Montevideo, Uruguay): a 12-year comparison. *Brazilian Journal of Oceanography* 63:311-330.

O'Farrell I, Izaguirre I. (2014). Phytoplankton of the middle and lower stretches of the Uruguay River. En: G Tell and I Izaguirre [eds.]. *Freshwater Phytoplankton of Argentina. Advanc. Limnol.* 65. Schweizerbart Science Publishers, Stuttgart pp, 113-126.

Observatorio Ambiental Nacional (2017). *Indicadores 2016.* Retrieved from: https://www.dinama.gub.uy/oan/?page_id=53

Oficina de Planeamiento y Presupuesto (OPP) (2011). *Información de base para el diseño de un plan estratégico de residuos sólidos.* Uruguay. Retrieved from: http://www.mvotma.gub.uy/portal/ambiente-territorio-y-agua/conoce/residuos/item/10002823-informacion-de-base-para-el-diseno-de-un-plan-estrategico-de-resi duos-solidos.html

Organización de Estados Americanos (OEA) (1992). *Uruguay - Estudio Ambiental Nacional.* Washington: OPP/OEA/BID.

Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO) (2009). *El estado mundial de la agricultura y la alimentación. La ganadería a examen.* Roma. Retrieved from: http://www.fao.org/docrep/012/i0680s/i0680s 00.htm

Oyhantçabal G, Narbondo I. (2014). Radiografía del agronegocio sojero uruguayo. Alternativa. *Revista de Estudios Rurales* 1:1-30.

Pacheco J P, Arocena R, Chalar G, García P, González Piana M, Fabián D, Olivero V. (2012). Evaluación del estado trófico de arroyos de la cuenca de Paso Severino (Florida, Uruguay) mediante la utilización del índice biótico TSI-BI. *Augmdomus* 4:80-91.

Piaggio M. (2013). *Industrial water pollution in Uruguay: Polluting and non-polluting sectors' subsystems through input–output analysis.* Working Papers (201352), Latin American and Caribbean Environmental Economics Program.

Pírez M, Gonzalez-Sapienza G, Sienra D, Ferrari G, Last M. (2013). Limited analytical capacity for cyanotoxins in developing countries may hide serious environmental health problems: Simple and affordable methods may be the answer. *J. Environ. Manage.* 114:63–71.

Pistone G, Eguren G, D Rodriguez-Ithurralde (2012). Inhibition, recovery and field responses of *Astyanax fasciatus* (Cuvier, 1819) brain cholinesterases upon exposure to azinphos-methyl. *J. Braz. Soc. Ecotoxicol.* 7(2):105-114.

Presidencia de la República (Uruguay) (2014). Retrieved from: https://www.presidencia.gub.uy/comunicacion/comunicacionnoticias/dia-mun dial-alimentacion-inia-aguerre

Rivas-Rivera N, Eguren G, Carrasco-Letelier L, K Munkittrick (2014). Screening of endocrine disruption activity in sediments from the Uruguay River. *Ecotoxicology* 23(6):1137-1142.

Rodríguez-Gallego L, Achkar M, Defeo O, Vidal L, Meerhoff E, Conde D. (2017). Effects of land use changes on eutrophication indicators in five coastal lagoons of the Southwestern Atlantic Ocean. *Estuar. Coast. Shelf Sci.* 188:116-126.

Salas HJ, Martino P. (1991). A simplified phosphorus trophic state model for warm-water tropical lakes. *Wat. Res*. 25:341-350.

Smith VH, Tilman GD, Nekola JC (1999). Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environ. Poll.* 100:179-196

Soutullo A, C Clavijo, JA Martínez-Lanfranco (eds.) (2013). *Especies prioritarias para la conservación en Uruguay. Vertebrados, moluscos continentales y plantas vasculares.* Montevideo: SNAP/DINAMA/MVOTMA y DICYT/MEC. 222 pp.

Torres Ruiz R, Pardón Ojeda M. (2009). *Planes de Seguridad del Agua de Consumo Humano en la Gestión Integrada de los Recursos Hídricos Transfronterizos.* OPS/OMS, Área de Medio Ambiente y Desarrollo.

Tort LF, Victoria M, Lizasoáin A, García M, Berois M, Cristina J, Leite JP, Gómez MM, Miagostovich MP, Colina R. (2015). Detection of Common, Emerging and Uncommon VP4, and VP7 Human Group A Rotavirus Genotypes from Urban Sewage Samples in Uruguay. *Food Environ Virol.* 7(4):342-53.

Uruguay XXI (2016). Sector Agronegocios. Diciembre 2016. Retrieved from: https://www.uruguayxxi.gub.uy

Van Vliet MTH, Franssen WHP, Yearsley J R, Ludwig F, Haddeland I, Lettenmaier DP, Kabat P. (2013). Global river discharge and water temperature under climate change. *Glob. Environ. Chang.* 23:450–464.

Venkatesan MI, Kaplan IR. (1990). Sedimentary corpostanol as an index of sewage addition in Santa Monica Basin, Southern California. *Environmental Science and Technology* 24:208–214.

Venturini N, Bícego MC, Taniguchi S, Sasaki S, García-Rodríguez F, Brugnoli E, Muniz P. (2015). A multi-molecular marker assessment of organic pollution in shore sediments from the Río de la Plata Estuary, SW Atlantic. *Marine Pollution Bulletin* 91:461-475.

Victoria M, Tort LF, Lizasoáin A, García M, Castells M, Berois M, Divizia M, Leite JP, Miagostovich MP, Cristina J, Colina R. (2016). Norovirus molecular detection in Uruguayan sewage samples reveals a high genetic diversity and GII.4 variant replacement along time. *J Appl Microbiol.* 120(5):1427-35.

Vidal N. (2007). *Disrupción endócrina en* Cnesterodon decemmaculatus *(Jenyns 1842): Efectos a nivel individual y poblacional (Aº Colorado, Canelones-Uruguay).* Trabajo final de Lic. en Ciencias Biológicas, Facultad de Ciencias. Uruguay.

WHO (2011). *Guidelines for drinking water quality.* WHO, 4th ed.

Zhang CM, Xu LM, Xu PC, Wang XC. (2016). Elimination of viruses from domestic wastewater: requirements and technologies. *World J. Microbiol. Biotechnol.* 32(4):69

Venezuela

Although significant progress has been made in **Venezuela** in potable water supply coverage (approximately 90%) and wastewater collection (over 80%), less than 30% of wastewater is treated... The availability of water resources in adequate conditions and sufficient quantities to meet the growing demand for water are key factors in the progress towards sustainable development.

Camatagua reservoir, Venezuela, © iStock

Water Quality in Venezuela

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1. Introduction

The deterioration of water quality not only affects the population that consumes it, but also the entire associated ecological web (Ochoa Iturbe *et al*., 2015), and it has been estimated that it is responsible for a high death rate due to water-borne diseases and the contamination of many waterbodies (Gabaldón, 2015).

In Venezuela, although significant progress has been made in drinking water supply coverage (approximately 90% of the population) and wastewater collection (more than 80%), less than 30% of wastewater is treated (González *et al*., 2015b), which leads to the contamination of waterbodies, as well as changes in physicochemical parameters, negatively affecting quality. It is therefore necessary to increase efforts to conduct research on the quality of waterbodies, especially those used to supply populations and communities (Ochoa Iturbe *et al*., 2015).

This chapter will describe the relevant aspects related to water quality in Venezuela, such as the systematic knowledge of water quality, studies undertaken at research institutions, master plans for important watersheds in the country, institutionality in water quality management, public health and sanitary engineering, and the legal framework. The aim is to summarize data from various bibliographical sources as a starting point for more in-depth studies on the subject.

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2. Systematic knowledge of water quality in Venezuela

Advancing the achievement of the goals established in the sixth Sustainable Development Goal (SDG-6), of "ensuring the availability and sustainable management of water and sanitation for all" (CEPAL, 2016) involves developing integral water resource management systems, based on timely, reliable information.

In Venezuela , efforts have been made by official institutions, non-governmental organizations (NGOs), universities and other research centers related to the subject, to determine a range of physicochemical, bacteriological and hydraulic parameters in basins whose waters are intended for human consumption. Reviews of publications in bibliographic sources show that, although quality studies have been carried out on various waterbodies, especially in those affected by human activities, located mainly in the central-northern region of the country and other emblematic ones such as Lake Maracaibo and the Orinoco and Caroní rivers, very few meet the conditions that allow them to be classified as systematic. At the same time, a review of the dissemination sites (web portals) of the official bodies in charge of water management in the country, has shown that at present, there is no available (or at least no access to) truthful, up-to-date information, which would make it possible to undertake accurate diagnoses, detect variations in time and space, and make projections and adjustments, for the achievement of objectives in the short, medium and long terms.

Owing to the lack of detailed information at the basin level, it was decided to present the information at the level of five geographic regions: central, western, eastern, southern and Andean, and therefore to undertake a regional analysis based on information that has either been published or is in press.

To meet the objective, key characteristics that could serve as indicators of water quality for each region were summarized. The waterbodies for human consumption on which information is available, are mainly supply sources that serve between 20 and 42% of the inhabitants in each region, as well as other waterbodies. The information that can be used to characterize the supply sources is restricted to nutrient concentrations and the presence of plankton, and the rest is for the operation of water treatment plants (turbidity, color, pH, alkalinity, among other aspects). No systematic information related to pollutants was found –such as organic matter, heavy metals, hydrocarbons, biocides and pathogenic microorganisms-, which represents a limitation for the analysis of water quality associated with anthropogenic activities.

In general terms, the nitrogen and phosphorus values reported for the supply source far exceed the maximum concentrations considered for non-polluted waters. In the case of the specific data reported for other waterbodies in each region, indicators for organic matter are high, which reflects the anthropic intervention. It is important to point out that these studies begin to be undertaken precisely when obvious signs of contamination were detected, and were not the result of monitoring, as part of the comprehensive water resource management.

Table 1 was drawn up to estimate water quality in the case of supply sources in the main cities, which are home to approximately 25% of the population. It shows the situation in the central, eastern and western regions, using plankton concentration as a measured parameter (Iglesias *et al*., 2012). Quality is rated as good if the concentration of plankton is between 0 and 1,500 org./mL, normal to bad if it is between 1,501 and 9,000 org./mL and very bad if values exceed 9.000 org./mL of plankton (Iglesias *et al*., 2012).

In the central region, water quality varies from bad to very bad, probably as a consequence of the fact that its high densities do not make it possible to differentiate between production basins and receiving basins, as a result of which domestic and industrial wastewater -with no or very little treatment- is incorporated into waterbodies that eventually reach the supply sources.

In the eastern region, data is only available on one of the supply sources, the Turimiquire reservoir, which supplies approximately 25% of the region with low population density and, according to the figures, has very poor water quality.

In the western region, whose population density is similar to that of the eastern region (in the order of 40 inhabitants/km^2), information on the main supply sources in Zulia state, which supply approximately 20% of the region, rates the water quality as good, tending towards fair.

Table 1. Water quality in the main supply sources for human consumption based on plankton concentration

Year	Central Region							East Region	West Region	
	Pao Cachinche	La Mariposa	Lagartijo	Qda. Seca	Taguaza	La Pereza	Camatagua	Turimiquire	Manuelote	Tule
1998										
1999										
2000										
2001										
2002										
2003										
2004										
2005										
2006										
2007										
2008		Invaded with Bora								
2009										
2010										
2011										

Organisms / thousand	0 a 1500	1501 a 9000	>9001
Quality	Good	Average to poor	Very Poor

Source: Compiled by M.V. Najul, H. Blanco y R. Sánchez (PETA, UCV) on the basis of data from Iglesias *et al.*, 2012).

Table 2. Physical-chemical characteristics of the Orinoco River in its main channel and some of its tributaries

Parameter	Units	Orinoco in			Caroní	Caura	Mapire	Apure
		Musinacio	Ciudad Bolívar	Barrancas	Caruachi	Boca	Morichal	Boca
pH		6,6	6,5	6,8	6,3	6,1	5,8	7,7
EC	µS/cm	38,2	26,5	25,8	8,9	15,6	9,8	190,0
TSS	mg/L	110	82	34	10	9	15	353
Ca^{++}		3,67	2,79	2,59	0,57	0,64	0,11	16,20
Mg^{++}		0,91	0,52	0,66	0,16	0,27	0,08	3,00
Na^{+}		1,23	0,90	1,47	0,51	0,88	0,79	4,10
K^{+}		0,74	0,70	0,66	0,46	0,62	0,44	2,20
HCO_3^-		14,80	11,00	9,99	3,40	6,40	2,40	61,80
$SO_4^=$		4,20	---	2,31	---	1,00	1,10	10,70
Cl^-		0,60	0,85	0,86	0,74	0,50	0,90	1,70
DOC		3,14	2,87	4,40	5,87	4,16	2,33	6,20
OCP		---	1,68	1,40	0,60	1,09	---	4,10
$Si\text{-}SiO_2$		2,60	3,09	3,01	2,30	2,30	5,30	5,30

EC= electrical conductivity; TSS= total suspended solids; DOC = dissolved organic carbon; OCP = organic carbon in particles. Source: Compiled by J. Paolini (IVIC) based on data from (Lewis & Saunders, 1984, Saunders & Lewis, 1988, Paolini et al., 1987, Depetris & Paolini, 1991).

This analysis confirms that systematic knowledge of water quality, as an indicator of contamination, must be associated with the identification of basin conditions, such as occupation of the territory, anthropogenic activities and soil vocation, for the information to be representative.

3. National research on water quality

This section summarizes the research undertaken on surface and groundwater quality.

3.1 Rivers

Venezuela has a large number of rivers, making it a water producing country in terms of flow and quality. The country contains three major slopes: the Atlantic, formed by the basins of the Orinoco and Cuyuní rivers, the Amazon with the Negro River and the Caribbean, which includes Lake Maracaibo and the rivers that drain the coastal mountain range.

3.1.1 The River Orinoco Basin-Generalities

The Orinoco basin is located in the north of South America, between 59°30' and 74°50' west and 1°00' and 10°10' north. It covers an area of approximately 1.100.000 km^2 shared by Venezuela (74%) and Colombia (26%). The River Orinoco rises in the southeastern tip of the Venezuelan state of Amazonas, in Delgado Chalbaud Hill, at approximately 2°19' north and 63°21' west longitude, with a length of approximately 2.150 km. It has the third largest flow in the world with 36.000 m^3/s and the fifth largest amount of transported sediment, amounting to about 150 million t/year (Vila, 1960). The River Orinoco has a unimodal hydrograph, with minimum levels during the months of February-March and maximum levels in the middle of the second half of August and the first half of September. This basin is rich in natural, mineral and renewable resources that include forests and savannahs, freshwater fisheries, enormous biodiversity, agricultural and grazing lands. The Orinoco Basin is particularly important, since South America has the largest reservoir of fresh water in the world and for example, its fishing and exploitation of aquatic wildlife are considered to be of global importance (Barletta *et al*. al., 2010; Lasso *et al*., 2014b).

In Venezuela, studies have been carried out on aquatic ecosystems, their use and conservation in the Orinoco Basin and their management strategies, by universities and research institutes, private foundations and international research centers (Machado-Allison *et al*., 2010).

3.1.2 Water quality

The first physicochemical studies of the Orinoco River and its tributaries were carried out by the Ministry of Public Works (MOP) and subsequently continued by the Ministry of the Environment and Renewable Natural Resources (MARNR, currently the Ministry of People's Power of Ecosocialism and Water or MINEA),[1] oriented mainly towards the determination of flows and sediment transport (MOP, 1972), which have continued until the present. **Table 2** summarizes some of the most important physicochemical characteristics of the lower Orinoco in the main channel and some of its tributaries.

In 1982, The Institute of Natural Resources of the Universidad Simón Bolívar created the Orinoco Ecosystem Project (PECOR), conceived as a collaborative study by researchers from the Universidad Simón Bolívar (USB) and the Universidad Central de Venezuela (UCV) (focused on the upper and middle basin) and the University of Colorado-USA (focused on the lower basin). PECOR is regarded as the leading basic research project with the greatest continuity in the national limnological sphere, and its fundamental mission was the integral study of the structure and functioning of the terrestrial and aquatic ecosystems of the Orinoco Basin. The results of PECOR show the spatio-temporal variations between some of the tributaries in its middle basin in terms of the concentration of total suspended solids, total phosphorus, conductivity, pH, nitrates and discharges, which are reported in **Table 3**, showing a gradient that goes from a lower to higher concentration from rivers classified as black waters to those classified as white waters: black (Atabapo-Sipapo-Autana) <clear (Ventuari-Cuao-Cataniapo) <white (Guaviare-Meta) (Weibezahn, 1985, 1990, Carvajal, 1988, Álvarez *et al*., 1992, Astiz and Álvarez, 1998).

1. As of June 2018, the name of the Ministry of People's Power for Ecosocialism and Waters was changed to the Ministry of People's Power for Ecosocialism and the Ministry of Water Care was created.

At the same time, the Center for Ecology of the Venezuelan Institute of Scientific Research (IVIC) and the Carbon Unit of the Geological and Paleontological Institute of the University of Hamburg (Germany) conducted research in the lower Orinoco River Basin (in Musinacio and Ciudad Bolívar) and in the basins of the Mapire, Caura and Caroní rivers, with the objective of determining the contribution of organic carbon and minerals from the Orinoco to the Atlantic Ocean (Depetris & Paolini, 1991).

In the Caroní Basin (a tributary of the lower Orinoco basin), in the 1980s and 1990s, the electrification company of Caroní (CVG-EDELCA), responsible for coordinating the hydroelectric development of the basin, launched campaigns to measure the quality of its waters in stations included in the map in **Figure 1**.

Recent studies have revealed the presence of high concentrations of mercury in people living in the mining areas present in the basin (Red ARA, 2013). High levels of mercury in the sediments of waterbodies (between 1.37 and 37.74 mg/kg) and in fish used as food (3.71 µg) have been found in illegal mining areas in the Upper Orinoco. Hg/g), the limit allowed by the World Health Organization being 0,5 µg/g (Milano, 2014). Recently, a study conducted among indigenous communities living in the Caura river basin (tributary of the lower Orinoco) concluded that 92% of the women examined have levels well above the maximum established by the World Health Organization (Red ARA, 2013).

3.1.3 The wetlands of the Orinoco River basin

Article 1.1 of the Ramsar Convention defines wetlands as “the areas of marshes, marshes and peatlands, or surfaces covered with water, whether natural or artificial, permanent or temporary, stagnant or running, fresh, brackish or salt water, including areas of seawater whose depth at low tide does not exceed six meters”.

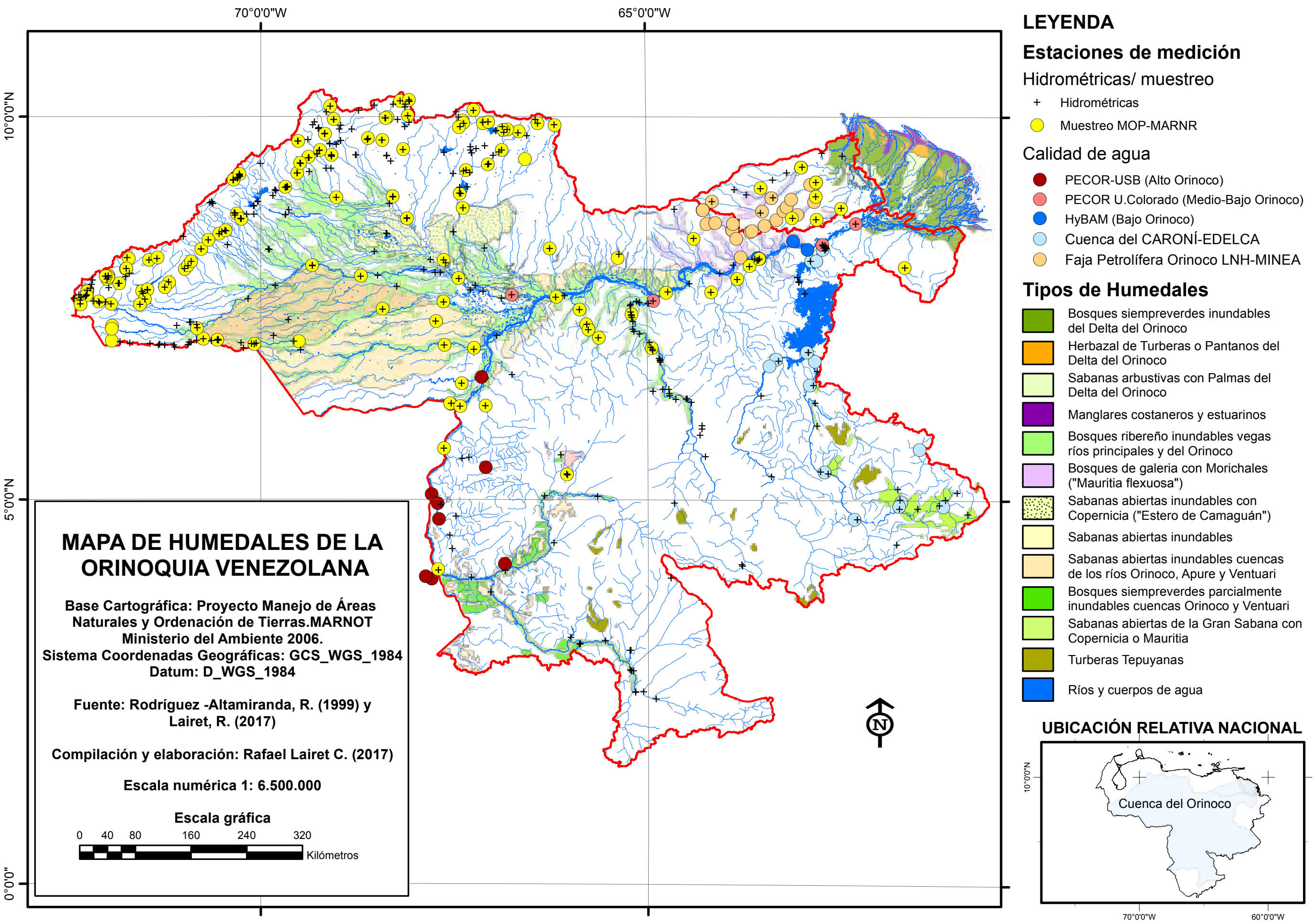
Several studies have been undertaken in Venezuela on the biology and ecology of the wetlands such as those by Figueroa and Seijas (1986), Lenti-

Table 3. Average, minimum and maximum values of physicochemical and hydrological variables analyzed in the rivers and hydrophases studied (n=3)

Hydrophases	Low waters (February)			High waters (September)		
Type of rivers *	Clear	Wastewater	White	Clear	Wastewater	White
Temperature (ºC)	29,6 (28,8-31,0)	30,1 (27,0-34,0)	29,3 (28,6-30,6)	26,5 (25,0-27,6)	25,8 (24,0-28,4)	27,6 (26,4-29,6)
Suspended solids (mg/L)	9 (5-15)	4 (2-6)	78 (21-189)	11 (6-21)	2 (1-2)	317 (186-507)
Transparency (m)	1,32 (1,10-1,50)	1,90 (0,60-2,60)	1,07 (0,8-1,4)	1,30 (1,20-1,40)	1,63 (1,3-2,0)	0,47 (0,1-1,1)
pH	5,7 (5,0-6,8)	4,7 (4,1-5,4)	7,4 (7,2-7,8)	5,9 (4,9-6,7)	4,2 (4,0-4,5)	6,3 (6,1-6,5)
Conductivity (µS/cm)	9,00 (8,70-9,40)	10,43 (9,40-12,50)	73,23 (41,8-132,9)	8,57 (4,90-13,30)	9,57 (5,80-13,10)	33,9 (24,8-49,5)
Orthophosphates (µg/L)	3,40 (3,00-3,80)	3,25 (3,00-3,50)	---	0,00	0,00	---
Nitrates (µg/L)	227,5 (125,7-331,4)	73,73 (10,5-127,7)	91,97 (31,3-136,3)	104,23 (25,20-173,0)	8,77 (3,6-18,2)	131,53 (78,4-203,0)
Total phosphorus (µg/L)	8,38 (5,70-11,45)	7,70 (5,40-12,00)	26,6 (19,5-34,5)	8,81 (0,70-20,72)	3,17 (2,5-4,0)	112,77 (71,5-206,5)
Dissolved Organic Carbon (mg/L)	1,38 (1,00-1,75)	10,0 (7,3-12,7)	4,55 (4,5-4,6)	3,76 (2,90-4,61)	11,55 (11,4-11,7)	6,89 (6,67-7,1)
Discharge (m^3/s)	238,3 (44,0-591,0)	466,0 (43,0-1255,0)	3189,3 (1845-4096)	1220,3 (160,9-2700)	3044,33 (350-7583)	28009,7 (15450-49762)

* = Clear (Ventuari, Cuao, Cataniapo), Wastewater (Atabapo, Sipapo, Autana), White (Guaviare, Meta, Orinoco).

Figure 1. Map of the wetlands and water quality stations of the Orinoco River basin compiled by Lairet (2017). HyBAM: Observation Service of the geodynamic, hydrological and biogeochemical controls of erosion/alteration and the transfer of matter in the Amazon, Orinoco and Congo basins



no and Bruni (1994), Rodríguez-Altamiranda (1999), Lara (2007), Lasso *et al.* (2010), Marrero (2011) and Lasso *et al.* (2014a, b). In Rodríguez-Altamiranda (1999), the first integral cartographic survey of the distribution of these ecosystems was conducted at the country level. As a result of this work, nine regions and 24 categories of wetlands were identified for a total of 158 wetlands.

The most important wetlands in Venezuela include the Orinoco Delta, with an area of 20,642 km^2, between Caño Mánamo and the Río Grande, drained by more than 22 channels to the Atlantic Ocean. The delta has been divided into several natural regions, related to the greater or lesser fluvial or marine influence and the origin and form of deposition of the sediments.

Figure 1 is a compilation of the data and information collected (for the Orinoco basin), and validated by satellite images from the LANDSAT series from 1973 to 2017. The hydrometric, sampling and water quality stations installed by the Ministry of Public Works (MOP), the Ministry of Environment of Natural Resources (MARNR, currently MINEA) and other institutions were also included.

3.2 Lakes and reservoirs

Of all the Venezuelan waterbodies, Lake Valencia, located in the center-north region of the country, is the one that has been most studied (Cressa *et al.*, 1993). Recent work has shown high concentrations of total phosphorus (more than 900 µg/L) and phytoplankton biomass of (values of up to 235 µg/L), with a predominance of cyanobacteria (with an average of 77% relative dominance), meaning that it is classified as hypertrophic (González *et al*., 2012).

There are very few studies related to water quality in the Venezuelan Andean region. The first studies on Laguna Mucubají and Laguna Negra were published by Gessner and Hammer (1967), who recorded low electrolyte concentrations, slightly acidic pH values and transparency of more than 5 meters. Subsequently, Weibezanh *et al*. (1970) and Lewis and Weibezahn (1976) reported slightly alkaline pH values for the Mucubají Lagoon, with low total nitrogen (1,120 µg/L) and total phosphorus (6 µg/L) values, meaning that it can be classified as an oligotrophic waterbody.

Throughout the country, although there are more than 100 reservoirs for different purposes, only about 20% of them have information on their water quality (López *et al*., 2001). Most of the studies have been conducted on waterbodies in the central-northern region of Venezuela and very few in the eastern, western and southern regions of the country. Some of them are over 20 years old and focus on the description and ecology of the planktonic communities, with isolated data on temperature, dissolved oxygen, pH, conductivity and certain nutrients such as dissolved inorganic nitrogen and orthophosphates. According to González and Quirós (2011), reservoirs located in protected areas with limited or no human activities have been classified as ultra-oligotrophic or oligotrophic while reservoirs located in areas with few human populations or with limited agricultural activity have been classified as oligo-mesotrophic. The artificial waterbodies located in highly impacted basins reflect higher concentrations of nutrients and, consequently, have higher biological productivity, and can be classified as eutrophic and hypertrophic. Some examples are shown below, according to Lewis and Weibezahn (1976), Infante *et al*. (1992), Soto *et al*. (1994), Marín *et al*. (1999), Páez *et al*. (2001), González and Quirós (2011), González *et al*. (2014 and 2015a) and González (2017):

Ultra-oligotrophic: Guri (Edo. Bolívar), Agua Fría and Taguaza (Edo. Miranda); Oligotrophic: Clavellinos (Edo. Sucre), Lagartijo (Edo. Miranda), Guanapito and El Pueblito (Edo. Guárico); Oligo-mesotrophic: Tierra Blanca (Edo. Guárico) and El Cují (Edo. Anzoátegui); Mesotrophic: El Andino (Edo. Anzoátegui), Camatagua (Edo. Aragua) and El Cigarrón (Edo. Guárico); Eutrophic: La Pereza (Capital District) and Manuelote (Socuy-Edo. Zulia) and Hypertrophic: Pao-Cachinche (Edos. Carabobo and Cojedes), La Mariposa (Capital District), Quebrada Seca (Edo. Miranda), Suata (Edo. Aragua) and Tulé (Edo. Zulia).

In Venezuela, two projects for restoring the water quality of reservoirs have been documented: 1) La Mariposa, located eight kilometers from the city of Caracas, where the development of the aquatic plant *Eichhornia crassipes* has been controlled by mechanical removal, albeit not systematically (González and Matos, 2012); and 2) Pao-Cachinche, in the center of the country, close to the city of Valencia, where an artificial aeration process has been implemented since 2001 in an area close to the uptake tower, which has managed to reverse the effects of eutrophication by deactivating nutrients through oxidation (Estaba *et al*., 2006). Unfortunately, the diversion of the Cabriales River towards the tributaries of the reservoir in 2005 cancelled out the benefits of the artificial aeration process of its waters (González and Matos, 2012).

Another important ecosystem for the country is Lake Maracaibo (Zulia state) Cressa *et al*., (1993), which has been treated separately from the rest of the country's natural lakes because of its communication channel with the waters of the Gulf of Venezuela, which has made it more of an estuary. Its waters have undergone a change in their chemical composition since 1938, the date of the start of oil exploitation activities and since 1956, the saline concentration due to the penetration of saline water from the Gulf of Venezuela has made the waters of the lake unacceptable sources for human consumption, irrigation and industrial uses (Herman de Bautista, 1997).

Parra Pardi (1979) conducted a comprehensive study on the pollution of Lake Maracaibo and its tributaries, obtaining 49,000 values of "in situ" measurements and laboratory analyses, determining the occurrence of a process of eutrophication, due to the concentrations of phosphorus, chlorophyll-a from plankton and the dominance of cyanobacteria (Parra Pardi, 1979, Rodríguez, 2000). The studies by Parra Pardi made it possible to establish the scientific basis for water quality standards and issue recommendations to take preventive measures (Rincón, 2013).

The most recent data on water quality in Lake Maracaibo include those published by Esclapés and Galindo (2000), who recorded total phosphorus values of up to 120 µg/L and total nitrogen of up to 1.300 µg/L, meaning that the lake can be classified as a eutrophic and even hypertrophic system, resulting in the development of enormous floating masses of the *Lemna obscura* aquatic plant, which occupied 8.3% of the total lake surface in 2004 (Rincón and Mejía, 2013).

3.3 Groundwater

In Venezuela, there is a general knowledge of the main factors controlling the movement and direction of the flow of groundwater, its recharge and discharge areas, as well as the thicknesses and dimensions of aquifers and the processes that control their variability, composition and chemical quality. These studies have been undertaken by the Ministry of Public Works (MOP), the Ministry of Environment and Renewable Natural Resources (MARNR) and the Ministry of People's Power for the Environment (MINAMB) and universities and now by the National Institute of Meteorology and Hydrology (INAMEH), an institution attached to the Ministry of People's Power for Ecosocialism and Water (MINEA), although not from a hydrogeochemical perspective. Silva (2000) and Montero (2006) note that the MOP promoted one of the first studies on groundwater quality at a regional level in Lake Maracaibo Basin and the Gulf of Venezuela, the results of which made it possible to identify a large number of aquifers with saline waters, as a consequence of the geological history of the region and the hydraulic connection between the waters of the lake and those of the Gulf.

Since the 1960s, the Institute of Earth Sciences of the Universidad Central de Venezuela and other government entities has undertaken research projects in hydrology, hydrogeology and hydrogeochemistry in other parts of the country in order to determine the characteristics and potentialities of the reservoirs.

Montero (1996) studied the groundwater north of Monagas State, identifying the presence of waters probably contaminated by oil and agricultural activities; while Vargas *et al*. (1997), Rodríguez (2000), Corsi (2006), D'Elia (2006), Michel (2006) and Toro (2012) studied the groundwater on Margarita Island, finding that water quality improves when catchment systems are located in zones with greater topographic height. Likewise, the concentration of total dissolved solids (TDS) led to the identification, in order of importance, of a group of brackish samples, followed by fresh and salt water.

Alvarado and Pérez (1998) reported the existence of pollution problems due to the use of biocides in regions such as Cojedes, Carabobo, Apure, Miranda, Lara, Portuguesa, Mérida, Táchira and Barinas, and virtually all the agricultural states. Nevado (1999) characterized the groundwater in the northeast region of Bolívar state, while Zambrano (1999) geochemically studied these waters in the Andean Hydrogeological Subprovince in a sector of the Chama River basin. Escalona-Pazo and Marrero-Clemente (2013) determined the chemical quality of these reservoirs in the Guacuripia-El Palmar areas, Bolívar State, concluding that only a small percentage of waters studied that do not exceed 10% can be classified as excellent or Type 1, according to Decree 883 (GORV, 1995). Likewise, Luna *et al*. (2007) evaluated the groundwater in the Güigüe sector of the Lake of Valencia Basin, observing a spatial variation in its chemical quality from the recharge areas towards the lake plain. Ayala *et al*. (2007) studied the chemical quality of the groundwater in the Santa Ana region, Paraguaná Peninsula, Falcón State, determining that only 6% of the samples are of good quality and suitable for human consumption, while the remaining 94 % are of low quality (Na^+ y Cl^-).

Montero (2006) and Montero *et al*. (2007b) studied the groundwater in the southern region of Lake Maracaibo Basin, concluding that anthropic influence appears to be responsible for nitrate contamination. The Valley of Caracas was evaluated by Montero *et al*. (2007a), who detected four hydrogeochemical zones with different water quality, namely: 1) an area prone to domestic pollution, 2) an area exposed to urban pollution, 3) an accumulation zone, located on a tectonic depression, where there is nitrate enrichment, and 4) an area prone to "karstification", controlled by the dissolution of carbonaceous minerals and pyrite.

Biondo and Estévez (2010) point out that anthropic activities in the Lake Basin of Valencia and the sub-basins contained therein are the cause of the contamination of most of the groundwater bodies that have been identified in the area. This was corroborated by Kutos and Montero (2013) during the hydrogeochemical study of groundwater in the sub-basin of the Taiguaiguay Lagoon, who found that 67% of these waters are unsuitable for domestic use, according to the limits established by Decree 883 (GORV, 1995), whereas in the Sucre Municipality, located north of this sub-basin, Mateus (2015) points out that 85% of the samples are optimal in terms of quality for all domestic and industrial use, despite the fact that the remaining 15% can be used for agricultural purposes, as established in Decree 883.

In Los Valles del Tuy, specifically in the Santa Lucía sector, Betancourt and Yessica (2012) determined that 69% of the water samples studied can be classified as fresh and the remaining 31% as brackish, while Ojeda (2013) states that for the Ocumare del Tuy area, the waters are classified as excellent or Type 1 waters for domestic, industrial and agricultural use, commerce and recreation.

Vegas (2016) conducted a hydrogeochemical study and a groundwater quality analysis in the Palmar River Basin, Rosario de Perijá Municipality, Zulia State, concluding that 73.7% of the water samples are classified as freshwater, while the remaining 26,3% are brackish. Likewise, in accordance with Decree 883 (GORV, 1995), he indicates that the largest number of samples were drawn from Type 1 waters, occupying most of the basin studied.

Márquez (2016) and Torrealba (2016) evaluated the chemical quality of groundwater in the Duaca, El Eneal and Perarapa regions and the Licua aquifer. The TDS values (Márquez, 2016) indicate that 90.5% of the water samples can be classified as fresh and the remaining 9.5% as brackish water. Nevertheless, 61.9% of the waters studied are unsuitable for domestic use, according to Decree 883 (GORV, 1995). On the other hand, Torrealba (2016) points out that only 55.5% of waters are suitable for human consumption, whose TDS values enable them to be classified as fresh.

The results obtained in the aforementioned studies are a reflection of the variability of groundwater at the national level in terms of its quality, as a result of the impact of natural factors and anthropogenic activities.

4. Master plans for water quality

The Venezuelan Law on Waters (GORBV, 2007) states that the integral management of the water quality of a basin will be undertaken using the master plans for waterbody control and management, which determine the cause-effect relationships between contaminating sources and water quality problems, alternatives for the control of existing and future effluents, and the conditions in which their discharges will be allowed, the limits of mass discharges for each pollutant source and the necessary complementary technical standards for the control and management of waterbodies. The master plans for the basins considered to require priority attention will be summarized below:

4.1 Lake Maracaibo Basin

Lake Maracaibo Basin encompasses an area of 89.756 km^2, 85.4% of which is located in Venezuela (Cressa *et al.*, 1993) and the remaining 14.6% in Colombia.

The Master Plan for the Control and Conservation of the Lake Maracaibo Basin of Parra Pardi (1986) is a technical document that identifies, specifies and rationally presents the strategy and necessary measures for correcting water quality problems in the basin, in order to coordinate and serve as a guideline for all decisions regarding water quality at the basin level. As a result of the Master Plan, activities must be established for the conservation of the lake basin and the orientation of other plans with more specific objectives, which focus on reducing or eliminating the discharges of nitrogenous sources in industrial and industrial wastewaters that enter the lake and/or the reuse of sewage for selective purposes, such as industrial use or irrigation and pumping waters outside the region.

4.2 Lake Valencia Basin

Lake Valencia Basin, located in the center-north region of Venezuela, has an area of 3,150 km^2. It is an endorheic basin, all of which has generated a series of pollution and eutrophication problems in this ecosystem.

The Master Plan (Water Quality Technical Group, 1998) provides guidance on the treatment plants that should be built and the control of various sources of pollutants, such as sewage and the discharge of solids into tributaries and the lake itself.

The “Integral Project for Sanitation and Level Control of the Lake of Valencia Basin” proposes the construction of wastewater collectors and treatment plants in the states of Carabobo (La Mariposa and Los Guayos) and Aragua (Taiguaiguay) (MINAMB , 2009), and the project to transfer water from the lake to the River Tucutunemo valley, which helps control the level of Lake Valencia, and the reuse of water for irrigation agriculture (MPPCI, 2009).

4.3 Yaracuy River Basin

Yaracuy River Basin, with an area of 2.380 km^2, is located in the central-western region of Venezuela. Its importance lies in the fact that the Yaracuy River waters are used for the irrigation of large plantations of sugar cane, corn and plantain, as well as for supplying water to the populations of San Felipe, San Pablo, Boraure, among others (INE, 2014).

According to Decree No. 883 (GORV, 1995), on September 28 1995, the National Commission of Technical Standards for the Conservation, Defense and Improvement of the Environment approved the selection of the Yaracuy River Basin as a pilot basin for the development of a methodology for drawing up specific technical standards and master plans for the control and management of water quality and liquid effluents for each river basin.

The first references to studies and legal provisions for the classification and quality control of the Yaracuy River appear in a comprehensive health study conducted by Parra Pardi and Blumenkratz (1977) and Presidential Decree N°. 2.181 (GORV, 1998).

4.4 Tuy River Basin

The Tuy River Basin is located in the center-north region of Venezuela. The importance of this basin is that its waters are collected in an area of 9.180 km^2, where the city of Caracas and its main satellite cities are located, together with industrial and agricultural areas, several national parks and tourist regions (Camargo, 2001; Ramos *et al*., 2014). Since 1956, this basin has experienced rapid population and industrial growth, and the construction of a system of aqueducts that supply drinking water to the city of Caracas and the surrounding areas, all of which has significantly impacted the water quality of the Tuy River and its tributaries, including the Guaire River, which crosses the city of Caracas.

In the Tuy River basin, an institutional solution based on a Single Area Authority and a Watershed Agency was adopted. In 1998, the Agency was restructured and subsequently eliminated. In 2002, the Single Area Authority (Ramos, 2014) was abolished. The study recommends: a) reviewing and recovering both the Comprehensive Sanitation Master Plan drawn up by the Tuy River Basin Agency, as well as the medium and long term measures in the Master Plan developed by the Japan International Cooperation Agency (JICA) in 1997; and b) recovering the definition of scenarios proposed by MARNR in the Master Plan for the upper and middle basin of the Tuy River proposed by the Ministry of Environment and Renewable Natural Resources (currently MINEA) in 1995.

4.5 Caroní River Basin

This basin is located in the southern region of Venezuela. It encompasses over 95. 000 km^2 and also forms part of the Orinoco basin. It consists of two large rivers, with very similar hydrographic characteristics: The Caroní River (59.8% of the total basin) and its tributary, the Paragua River. It provides 72% of the electricity for the entire country as well as producing 100% of the drinking water of Ciudad Guayana and the Pemón indigenous people (CVG-EDELCA, 2004).

The Venezuelan Corporation of Guayana (CVG), through the Electricification Company of Caroní (EDELCA), undertook a study in 2004 to prepare the Master Plan for the Caroní River basin (CVG-EDELCA, 2004), which includes a diagnosis and geographical characterization of the basin, the evaluation of planning scenarios, as well as the definition of criteria and basic guidelines for its development and conservation and the mechanisms for its application. The aim is to for economic and social activities to be included in the environmental objectives of the basin, and coexist harmoniously with energy production.

5. Water quality and agriculture

Agriculture is considered one of the main factors in the degradation of surface and groundwater resources as a result of erosion and chemical runoff (Ongley, 1997). In addition to the problems linked to water quality inherent in irrigation and drainage agriculture, another serious environmental effect is the degradation of the quality of water resources downstream due to the effect of salts, agrochemicals and toxic leachates.

5.1 Water quality in water sources for irrigation

The physical, chemical and bacteriological quality of water is an important factor in the choice of sources to be used in agricultural activity (Rojas, 2015). Article 3 of Decree N° 883 of the Norms for the Classification and Control of the Quality of Waterbodies and Discharges or Liquid Effluents (GORV, 1995) classifies waters according to their uses. According to this article, Type 2 Waters are intended for agricultural activities, Subtype 2A waters correspond to the irrigation of vegetables destined for human consumption, while Subtype 2B waters can be used for the irrigation of any other type of crop and livestock These subtypes of water refer to limits and ranges for microorganisms, chemical elements, biocides and radioactivity in water.

The classification of water for irrigation in Venezuela to prevent salinization or high levels of sodium in the soil, has been the subject of various research projects and proposals that deviate from the traditional standard established in Handbook No. 60 of the US Department of Agriculture (USDA, 1954). In fact, Pla Sentis and Dappo (1974) published a system for evaluating water quality for irrigation. Subsequently, Pla Sentis (1983) advanced his proposal by considering the permanence in the soil solution of the salts and ions available in irrigation waters. On the basis of this, he incorporated considerations regarding crop tolerance of salinity, drainage conditions and hydrological properties of soils, climate and irrigation practices. The resulting system makes it possible to undertake diagnoses and establish alternatives and possibilities of recovery.

Studies on irrigation water and salinization reveal the geographical distribution of the occurrence of problems of this nature and their causes. The basins of Lake Valencia (Romero de la Cuba, 1982), the Turbio River basin, Lara State (Zérega *et al*., 1991) and the Paraguaná Peninsula have been singled out as having problems derived from groundwater salinity. (Fernández *et al*., 2011). Waters of inappropriate quality and soil limitations have led to the accumulation of salts in Quíbor Valley (Lara State), although good cultural practices have prevented secondary salinization (Villafañe *et al*., 1999).

Other problems that have arisen include the acidification of soils due to inadequate drainage practices on Guara Island (Delta Amacuro State), in the 70s (Buroz and Guevara, 1980) and the increase in sulfur content in the Aquifer of Lake Valencia (Alvarado *et al*., 1996).

Both human and environmental health can be affected by biological contents and chemical pollutants, whether they are transported by irrigated water, or by surplus water from the agricultural process that spills into waterbodies or infiltrates and percolates into waterbodies. aquifers, as in the case indicated by Traviezo Valles *et al*. (2004), who studied the contamination of vegetables when eaten raw in markets of the city of Barquisimeto (Lara State).

Contamination caused by agricultural practices was studied by Molina Morales *et al*. (2012) in the area of Bailadores (Mérida State), who found that water had been polluted by biochemical agents, specifically organophosphorus with values exceeding the limits established by Venezuelan legislation. The authors indicate that it is possible to control the situation if techniques already evaluated in other parts of the country are adapted. Benítez-Díaz and Miranda-Contreras (2013) reviewed the existing information at the national level on water pollution due to pesticides and found that it is disperse, unofficial and drawn from academic studies and undergraduate theses.

The vulnerability of aquifers to contamination by infiltration and percolation of waters with high concentrations of pesticides and fertilizers in agricultural areas was demonstrated by Durán (2006), through the study of the Maracay aquifer.

As for the waters resulting from oil production, Villafañe *et al*. (2004) evaluated the possibility of using the salt waters that emerge together with oil. It was found that by reducing a third of the original salinity, water can be used to irrigate *Brachiaria dictyoneura* pastures without adverse effects on the soil.

Irrigation with treated wastewater is a possible practice and used in many countries. In Venezuela, the sewerage systems of Lake Maracaibo and Lake Valencia incorporated large-scale projects that envision the use of this water source. Decree No. 883 (GORV, 1995) contains regulations that consider the reuse of wastewater.

In 2016, WHO published the *Manual for the Use and Safe Disposal of Wastewater, Gray Water and Excreta*, an important instrument for complementing the practices and procedures for irrigation with this kind of water.

In Venezuela, the use of treated wastewater as a source of supply for agriculture has already begun, as a measure to reduce the demand for drinking water and, at the same time, to reduce or eliminate the pollution produced when wastewater is discharged into the waterbodies (Isea *et al*., 2004). Several national universities, through their Faculties of Engineering and Agronomy, have conducted research aimed at improving treatments, design parameters and practices used for this purpose. In this regard, the Water Research Center of the University of Zulia (CIA-LUZ), developed a system of stabilization ponds with a combined residence time of 20 days (Trujillo *et al*., 2000; Isea *et al*., 2004).

5.2 Water management for irrigation. Planning

Buroz (2016) points out that with regard to water quality for agriculture, the *National Plan of Agriculture for Irrigation and Land Sanitation. Phase I (2015-2019) should be reviewed in order to:* 1) Control the water quality required and produced by the development of peri-urban agriculture (vegetables and fruits) in high technology; 2) Draw up a national inventory of dam sites, including runoff lakes or small reservoirs, making sure that their watershed maintains high production and water quality values and minimum sediment production; 3) Integrate the sectoral management of irrigation water into the basin management, considering the water quality; 4) Increase the knowledge of aquifers, including the quality of their waters and establish general operating rules; 5) Develop specific rules that regulate the reuse of wastewater for irrigation according to the types of crops and levels of treatment required.

6. Public health and sanitary engineering

Sanitary Engineering has traditionally involved the supply of water for human consumption, and the management of wastewater and municipal solid waste. Public Health will deal with issues related to water-borne diseases.

6.1 Drinking water supply and wastewater management

In Venezuela, water is a public good of the Nation. At present, the Ministry of People's Power for Ecosocialism and Water (MINEA) exercises authority over water and Hidrológica de Venezuela (HIDROVEN) -together with its regional subsidiary companies- is the agency responsible for capturing it, adapting its quality and distributing it to the population, as well as the collection, treatment and disposal of the wastewater produced.

The country’s sewerage infrastructure lack municipal, domestic and industrial wastewater treatment systems in the urban and rural areas. It should be acknowledged that the Venezuelan state has made and continues to make significant investments in sewerage works to purify wastewater at the national level. However, when these works begin operating, they lack a management model to guarantee the adequate operation and maintenance of this infrastructure. The inventory of treatment technologies at the municipal level is neither accurate nor complete. Little is known about the operation of these plants, and even less about the quality of their effluents, except for information provided by the scant academic research. Estimates based on information published by the Ministry of Popular Power for the Environment (MINAMB) in 2010 and general data existing by states, suggest that 30% of municipal wastewater in Venezuela is treated (Blanco *et al*., 2015).

The Universidad Central de Venezuela (UCV), Universidad de Simón Bolívar (USB) and Universidad Católica Andrés Bello (UCAB) drew up the Living Conditions Survey (ENCOVI) between 2014 and 2015. According to the results, the supply of drinking water through aqueducts decreased from 83.6% to 81.3%. Moreover, 38.4% of the population lack daily access to the service. The survey also indicates that the indoor storage of water, generally in inappropriate conditions, which users resort to as a result of poor service, is the main cause of the waterborne diseases that constitute endemic diseases in the country. Another valuable data from the survey is that 89.7% of the households report the existence of wastewater collectors. The study concludes that although a large part of the population has these services, the main environmental and sanitary problem is the final disposal of wastewater effluents.

In 2016, a Special Commission of the National Assembly of Venezuela, designated to investigate the water problem in the country, prepared a report in which they indicate that there are few formal studies that confirm the potability of the water supplied. Later on, they state that several towns in the states of Sucre and Nueva Esparta have prolonged periods of rationing, sometimes lasting 21 days. As for the central zone of the country, they point out that untreated wastewater is discharged into the Pao-Cachinche and Camatagua reservoirs -which supply the city of Caracas and the states of Carabobo and Aragua- and that they show signs of eutrophication.

In the states of Zulia, Apure, Barinas, Táchira, Cojedes, Guárico, Bolívar and Delta Amacuro, the main agricultural producers in the country, the availability of water resources exceeds demand. Conversely, the petrochemical, chemical, steel, food and paper production sectors have created a tendency to increase demand in areas where there was an existing water shortage. In some cases, water used for irrigation has been compromised to supply the population or industry (FAO, 2015).

One can therefore conclude that the situation regarding the supply of drinking water and the collection and purification of wastewater in Venezuela is complex. Although institutions have been working to improve services, to date they have failed to resolve the severe deficiencies in these basic services. All the sectors of the Nation involved must therefore work in a coordinated manner to be able to guarantee that the population will have access to drinking water and sewerage in the near future.

6.2 Municipal solid waste management

The contamination of surface and groundwater, by leachates (residual liquids, generally toxic, filtered from a landfill) from final disposal sites, is one of the environmental impacts associated with this activity. Studies on the subject in the country included one by Polo and Guevara (2001) conducted at the La Guásima landfill, in the state of Carabobo. In the analysis performed on five samples in observation wells located in the area of influence, they concluded that contaminants from the leachate from the landfill were probably being transferred to the groundwater of the sector, as borne out by the presence of fecal and total coliforms, hydrogen sulfide and organochlorine pesticides.

Another reference is an evaluation of the integral management of the La Bonanza landfill, in Miranda State, undertaken by Blanco (2015), which identifies, among other environmental impacts, the contamination of soils, surface water and groundwater by leachates with high content of BOD, COD and metals, associated with leachate percolation into ground and surface water, from sectors that do not have leachate collection systems, coupled with operating problems of the leachate control system. Blanco suggests completing and improving both surface drainage and the network for leachate capture and treatment.

6.3. Public health

Drinking water and effluent collection services, together with poverty conditions, involve the emergence of waterborne diseases, with diarrhea in children being one of the most important (Martínez, 2013). In Venezuela, accumulated results in the 52nd week of 2016 showed a total of 1,354,925 cases of diarrhea in children under 5 years, compared with an accumulated total for the same date of 1,160,625 in 2015 (MPPS, 2016).

Vector-borne diseases account for over 17% of all infectious diseases. In recent years, the globalization of displacements and trade, unplanned urbanization and environmental problems, have considerably influenced the transmission of this type of diseases (WHO, 2017). In Venezuela, conditions such as malaria, Chagas, leishmaniasis, dengue, Chikungunya and Zika are among the diseases with currently high levels, especially in the interior of the country.

One example is malaria which, by the end of 2016, registered a total of 240,613 cases, an increase of 76.4% over the previous year (n=136,402). The 24 federal states reported cases, with 16 states reporting epidemics. The current status of the disease is exacerbated by the lack of specific medicine. At the same time, restrictions on the availability of insecticides and environmental measures for the control and elimination of *Anopheles*, the agent responsible for the transmission of the disease, suggest that figures may increase exponentially in the coming years.

Zika figures are unknown. Venezuela ranks third in the number of Zika cases in the Americas (behind Brazil and Colombia), according to the Pan American Health Organization.

7. The institutionality of water quality management

7.1 Institutionality in water management

In accordance with the Water Law of 2007 (GORBV, 2007), the institutional organization of water management comprises: 1) The Ministry with competence in the matter, which will be the National Water Authority. 2) The National Water Council, composed of: the Ministry with Competence in Environmental Issues, which will chair it; the Ministry of Planning and Development; the Ministry of Agriculture and Lands; the Ministry of Participation and Social Development; the Ministry of the People's Economy; the Ministry of Defense, through the corresponding component; the Ministry of mines, Basic Industries; and the Ministry of Science and Technology, as well as a representative of each of the Hydrographic Region Councils, a representative of the National Assembly, a representative of users or users of water institutions and a representative of the National Institute of Indigenous Lands. 3) The Hydrographic Region Boards, or entities responsible for coordination between the National Government and the state and municipal governments, and at the same time entities to liaise with communities and organized neighborhood groups. 4) The Hydrographic Basins Councils, comprising the ministry that will be the National Water Authority, governorships and mayorships, organisms that are part of the Council of the Hydrographic Region, which have a presence in the basin, users or water users, Community Councils, and indigenous peoples and communities where they exist. 5) Users or institutional users. 6) Communal Councils, Technical Boards and Irrigation Committees. 7) The National Institute of Indigenous Lands. 8) The Ministry with competence in matters of defense, through the corresponding component. 9) State Public Policy Planning and Coordination Councils. 10) Local Public Planning Boards.

7.2. Institutions involved in water quality management

The hydrological company HIDROVEN currently operates and supervises the drinking water and sanitation sector, together with nine regional hydrological subsidiaries (HIDROCAPITAL, HIDROCENTRO, HIDROLAGO, HIDROFALCON, HIDROSUROESTE, HIDROANDES, HIDROPAEZ, HIDROCARIBE and HIDROLLANOS), all attached to the Ministry of People's Power for the Environment (now MINEA) (GORBV, 2001).

There are also decentralized companies for the provision of drinking water and sanitation services, with the participation of governorships and city halls, as well as the Corporación Venezolana de Guayana (CVG), which administers the Sanitary and Hydraulic Works Management (GOSH), in the Amazonas and Delta Amacuro states. The most important decentralized companies are HIDROLARA, Aguas de Monagas, Aguas de Mérida, HIDROSPORTUGUESA, Aguas de Yaracuy, HIDROBOLIVAR, CVG-GOSH and Aguas de Ejido.

The Ministry of People's Power for Ecosocialism and Water has Liquid Effluent Laboratories in various states of Venezuela, which perform water quality analysis (MINEA, undated), while HIDROVEN, the Regional Hydrological Companies and the Decentralized Companies also have laboratories to undertake the study of the physicochemical and biological characteristics of water bodies in each of the geographic regions they serve.

Other autonomous government institutions that undertake water quality management include the following: The Institute for the Control and Conservation of the Lake Maracaibo Hydrographic Basin (ICLAM), the National Institute of Meteorology and Hydrology (INAMEH), the National Institute of Agricultural Research (INIA) and the National Institute of Parks (INPARQUES).

Contributions have also been made by the laboratories, centers and institutes of the Autonomous Universities of Venezuela, as well as those of other scientific research institutes, Civil Associations and

Non-Governmental Organizations (NGOs), whose research and activities have helped generate water quality management policies in the country. Without intending to make an exhaustive list, some of these institutions include the following:

- National Autonomous and private universities: Universidad Central de Venezuela (UCV), Universidad Simón Bolívar (USB), Universidad Zulia (LUZ), Universidad Oriente (UDO), Universidad de Los Andes (ULA), Universidad Carabobo (UC), Universidad Experimental de los Llanos Ezequiel Zamora (UNELLEZ), Centro-Occidental Lisandro Alvarado (UCLA), Universidad Nacional Experimental de Guayana, Pedagógica Experimental (UPEL), Nacional Experimental Francisco de Miranda (UNEFM) and the Universidad Católica Andrés Bello (UCAB).
- Research Institutes: The Venezuelan Scientific Research Institute (IVIC), Venezuelan Institute of Technology for Petroleum (INTEVEP) assigned to the State Company Petróleos de Venezuela (PDVSA), the National Institute of Agricultural Research (INIA).
- Non-Profits and Non-Governmental Organizations (Tierra Viva Foundation, 2010): ACOANA, Asociación Civil Phynatura, Asociación Venezolana para el Agua (AveAgua) also known as Global Water Partnership (GWP/Venezuela), Fundación Aguaclara, Fundación La Salle de Ciencias Naturales La Salle (FLSCN), Fundación Tierra Viva, Instituto para la Conservación del Lago de Valencia (INCOLAGO) now defunct, PROVITA, VITALIS A.C.

8. Legal water quality regime in Venezuela

The Legal Regime represents the set of regulations of the regulatory framework for Water Quality in Venezuela. The Chapter of Environmental Rights of the Constitution of Venezuela (1999) establishes the fundamental obligation to ensure that elements of the environment, including water, are specially protected. Article 304 declares that all waters are in the public domain, and the responsibility of the state itself.

8.1 Organic Law of the Environment (GORBV, 2006)

This law establishes the provisions and guiding principles for environmental management, including the conservation and sustainable use of natural resources and water as a resource in particular (Articles 2 and 4). With respect to water quality, it regulates the integral management of the resource, based on the sustainability of the water cycle (Article 55). On the sustainability of water resources, it points out the need to conserve soils, forested areas, geological formations and the recharge capacity of aquifers (Article 56).

8.2 Organic Law for the Organization of the Territory (1983)

Territorial planning (GORV, 1983) is one of the basic aspects of the Constitution (Article 128). Article 3 establishes that Territorial Planning includes, among other aspects, "the protection of the environment and the conservation and rational use of water, soils, etc., as a function of territorial planning".

This Law provides for the declaration of Areas under Special Administration Regime (ABRAE), comprising Protective Areas that include those of waterbodies, Reserve Areas for the Construction of Dams and Reservoirs, Special Aquatic Habitats for Exploitation or Intensive Controlled Use, floodplains, National Hydraulic Reserves and Critical Areas with priority treatment (Articles 15 and 16).

8.3 Water Law (2007)

The water law (GORBV, 2007) is designed to establish the provisions governing the Integrated Management of water, as an essential element for life, human welfare and the sustainable development of the country (Article 1). Integral water management is the central axis of the provisions of the law, where the Hydrographic Basin is the basic unit of management.

In terms of conservation and sustainable use of water, the Law ratifies what is stated in the Organic Law on the Environment on the Integral Management of the Resource (Article 12).

The law creates special units of reference for institutional organization and water management: Hydrographic Regions and Hydrographic Basins – referring to surface waters- and Provinces and Hydrogeological Basins -referring groundwater-, indicating the obligation to establish conservation programs, projects and actions.

The Law establishes Areas under the Special Administration Regime for integral water management, in the terms of the Organic Law for the Organization of the Territory: 1) Protective areas of water bodies, and 2) Hydraulic reserves.

Regarding the control of water use, the Law indicates the uses that are not subject to control: domestic, watering livestock and navigation; and those involving exploitation, subject to concessions, assignments and licenses.

With regard to discharges into water bodies, effluent generators must adopt the necessary measures to minimize the quantity and improve the quality of their discharges (Article 13).

The law grants powers to the National Environmental Authority to take preventive, corrective or mitigating measures regarding the damage to water quality. And it establishes a set of sanctions for acts that threaten the quality of the water, such as actions that cause the degradation of the physical or biological environment (Article 119); undertaking prohibited activities in protective zones (Article 122) and non-compliance with water quality controls (Article 125).

8.4 Law on Water and Air Quality (2015)

This law (GORBV, 2015) establishes the norms for water and air quality management; environmental disruptions, and the conditions under which the management of liquid and gaseous waste must be carried out. In terms of water quality, it establishes the physicochemical and bacteriological parameters (Article 2).

It also provides for the Adequacy Schedule contained in the technical standard, indicating that establishments and facilities that have not complied with the established limits must comply with it.

8.5 Penal Law of the Environment (GORBV, 2012)

In matters of water quality (surface and groundwater, Article 102), it establishes a chapter for the facts that cause the degradation, alteration, deterioration of waters and other actions capable of causing damage, establishing that modifying the control system or runoff from water, obstructing the flow or natural bed of rivers, or causing sedimentation are crimes (Article 56).

Likewise, it sanctions with imprisonment and fines the contamination and poisoning of waters of public use; the dumping of degrading materials in water bodies, in contravention of the technical provisions issued by the National Executive.

8.6 Decree No. 883. Rules for the Classification and Control of the Quality of Spilled Water and Liquid Effluents (1995)

Several of the norms of Decree No. 883 (GORV, 1995) were modified or translated verbatim into the Law on Water and Air Quality, but it remains valid as regards the determination of the activities subject to control, the classification of the constituents in the liquid discharges and the establishment of the maximum limits of pollutant discharges, and remains a technical norm of the Penal Law of the Environment.

It should be noted that other regulations are in force, such as those of the Organic Law for Drinking Water and Sanitation Services (GORBV, 2001) which are related to water quality. However, the main regulatory provisions are collected here, strictly from the point of view of environmental quality.

9. Venezuela and Goal 6 of the United Nations Sustainable Development Program (SDG-6)

Goal 6 of the United Nations Sustainable Development Program (SDG-6) involves: Guaranteeing the availability of water and its sustainable management and sanitation for all (ONU, 2016). This objective proposes a series of goals for 2030 which, in the case of water quality in Venezuela, have been evaluated as follows:

Achieve universal and equitable access to drinking water, at an affordable price for all, through a rigorous watershed management process that guarantees the treatment of discharges and erosion process controls.

Equitable access to adequate sanitation and hygiene services for all and putting an end to open-air fecalism, paying special attention to the needs of women, girls and people in vulnerable situations.

Improve water quality by reducing pollution, eliminating dumping and minimizing the discharge of hazardous materials and chemicals, halving the percentage of untreated wastewater, and substantially increasing safe recycling and reuse, reducing the sharp decline in water quality in basins that have already been affected and the spread of these processes to several other basins. The integral water management plan until 2030 must provide for the task of determining the actual status of deterioration of the water bodies affected at the national level, evaluating the trophic status of reservoirs and providing solutions for their recovery.

10. Final considerations

The considerations and recommendations presented here are the result of the Workshop on the "Water Quality in Venezuela", held at the Academy of Physical, Mathematical and Natural Sciences, in the city of Caracas, on August 2, 2017 and attended by 30 people. At this workshop, the authors presented the contents of this chapter and the contributions of the participants were received.

10.1 Considerations

- Insufficient information on lotic water bodies. At present, there is insufficient information to make accurate diagnoses, detect temporal and spatial variations, make projections and adjustments, for the achievement of objectives in the short, medium and long terms, all with the systemic vision required for the integral management of water quality, despite the obligation established in the Venezuelan legislation to generate this type of information and guarantee free access to it.
- Restricted monitoring. The information that can be used to characterize the sources of supply is restricted to nutrient concentrations and the presence of plankton, and the challenge remains for the operation of water treatment plants (turbidity, color, pH, alkalinity, among other aspects). No systematic information related to pollutants was found –such as organic matter, heavy metals, hydrocarbons, biocides and pathogenic microorganisms-, which represents a limitation for the analysis of water quality associated with the anthropogenic activities prevailing in each region, associated with the respective hydrographic basin.
- Limited continuity of records. The shortage of information, due to the lack of continuity of data generation programs in a systematic way, makes it impossible to rate the quality of many waterbodies in the country.
- Insufficient information on lentic water bodies. The country currently has over 100 dams built for various purposes but information on the quality of their waters is only available for approximately 20% of them. Most studies have been conducted on water bodies in the central north region of Venezuela, with very few studies being undertaken in the eastern, western and southern regions of the country.
- Special, surface drainage and leachate treatments. It is important to build or improve the surface drainage infrastructure, as well as the network for the collection and treatment of leachate from the sites destined for the final disposal of waste, in order to minimize or eliminate the risks of contamination of surface and groundwater by these leachates.
- Lack of knowledge on groundwater quality. Despite the high variety of existing aquifers in Venezuela and the importance of the latter as freshwater reservoirs, studies from a hydrogeological and hydrogeochemical point of view are limited. In Venezuela, there is a general knowledge of the main factors controlling the movement and direction of the flow of groundwater, its recharge and discharge areas, as well as the thicknesses and dimensions of aquifers and the processes that control their variability, composition and chemical quality.
- Need to develop master water quality plans. Very few hydrographic basins have master water quality plans, regarded as requiring priority attention, due to their current degree of and potential for contamination. Currently, the institutional weakness in terms of human and financial resources and the asystematic inter-institutional coordination programs undermine the implementation of water quality master plans.

- Institutional development without successful results. Venezuela has implemented decentralized models with very limited success. Various institutional modalities have been tested to ensure water quality at the resource level. Faults were attributed to the lack of a coordination culture, little control by the State, coupled with a lack of budgetary and programmatic coordination. Part of this failure can be attributed to a condition of "institutional rebellion", high costs associated with the management of water quality, aggravated by the limited economic resources earned for the use of water by different users due to casualties and outdated rates set officially, in response to populist government policies.
- Concentration of studies and data in particular areas. Most water quality studies have concentrated on courses that drain the Venezuelan lowlands, with some focusing on the southern states of Bolívar and Amazonas.
- Need to add the ecocentric to the anthropocentric approach. The water quality approach has been generally oriented for human use (anthropocentric approach). Little emphasis has been placed on water quality for biodiversity and wildlife (ecocentric approach). Research on alterations and impacts on aquatic ecosystems due to water pollution must be systematized and it will be necessary to establish a quality standard to guarantee the quality of natural waters, the preservation of ecosystems and the suitability of the food from them. . Similar conditions are required in marine-coastal environments, where, in addition, quality controls are required due to tourism and recreation, an aspect that has systematic records of campaigns carried out by the environmental authorities in seasons of maximum use of these resources.
- Little knowledge of the water quality regime in wetlands. In Venezuela, there have been few studies on water treatment through the use of wetlands.
- New approaches for the study of water quality in agriculture. Water quality in agriculture should include, aspects such as (i) irrigation with sewage, treatment requirements, safety practices and occupational hygiene that should be part of good practices; (ii) specific rules for wastewater treatment according to the crops to be irrigated; (iii) post-harvest management with untreated waters or due controls; (iv) applications of biocides and fertilizers and consequences for the biodiversity and biological activity of the receiving and riverside bodies where agricultural drainage is discharged, and (v) consequences of biocides and fertilizers on aquifers.
- Public health and water quality must include post-harvest processing. The competent authorities must control and ensure that food processing is carried out with sufficiently treated water that complies with the national and international standards regulating this issue. It is necessary to implement a process of certification of agricultural products whereby “non-contamination” by pathogens and agrochemicals is proved.
- Requirement of standards for irrigation with wastewater. Water quality management in agriculture must include, in addition to what is relevant to the water-soil relationship to avoid salinization, consideration of the aspects related to the way food quality is affected, both through irrigation by wastewater, and post-harvest manipulation of food using contaminated water.
- Improvement of implementation of legal regime. Venezuela has an environmental legal framework that is clearly suitable for the management of the quality of Venezuelan waters, both preventive and corrective. However, the application or fulfillment of this legal framework depends on the development of the latter.
- Priority to water quality in the new Integrated Water Management Plan. At present, all the evidence shows a marked deterioration of the water quality in the basins already affected and the spread of these processes to numerous other basins. The integral water management plan until 2030 must provide for the task of knowing the real status of deterioration of the water bodies affected at the national level. It is crucial to evaluate the trophic state of reservoirs and explore solutions for their recovery.
- The necessary integration in water quality management. It is clear that progress must be made in achieving the appropriate quality of water for supply, developing water treatment

systems, maximizing controls of wastewater in different basins, conserving and protecting basins and water-related ecosystems, specifying the integrated management of watersheds, continuing and strengthening training programs in water resources management, and continuing and reinforcing the incorporation of urban and rural communities in water management.

10.2 Recommendations

- Water quality is a human right. It is necessary and a matter of principle to frame access to water as a human right; and citizens as subjects with the right to water access in terms of quality, quantity and continuity.
- Quality assurance in the provision of water sanitation services. Implement, through agreements and due interinstitutional coordination, the conditions, measures and actions to implement an appropriate management model to ensure the operation, maintenance and sustainability of the health infrastructure, with emphasis on the supply of drinking water and wastewater treatment.
- Comprehensive and systematic information on treatment systems in Venezuela. Update, systematize and complete the inventory of treatment technologies at the municipal level, in order to increase and improve knowledge on the operation and operation of these plants and determine the quality of their effluents, since 30% of municipal wastewater in Venezuela is treated.
- Sufficient, transparent information on health service indicators. Increase, through solid, planned and sustained public policies, the population with a daily supply of drinking water, as an indicator of quality of life and, thereby reduce the risks of affecting the population due to water-borne diseases caused by improper water storage.
- Criteria for the selection of indicators and registration quality. The information must be the result of the processing of reliable, timely and regular data that responds to an established method, to visualize the spatial and temporal variations of physical, chemical and biological quality in a body of water. It is therefore necessary to establish indexes or quality indicators for regions and watersheds that not only allow the monitoring of water quality parameters, but also of the natural characteristics of the basin and land use.
- Consideration of hydrobiological quality. The goal in water-producing basins is to maintain water quality to preserve the biota and thereby guarantee any other use of the resource, and in receiving basins to maintain a level of water quality that will guarantee conditions of well-being for the surrounding populations.

11. References

Alvarado, J.; Seiler, K.P. & Trimboin, P. (1996). Investigación hidrogeológica, isotópica e hidro química de la cuenca del Lago de Valencia (Venezuela). En: International Atomic Energy Agency (IAEA)–UNESCO. *Isotopes in Water Resources Management Proceedings of a Symposium on Isotopes in Water Resources Management.* Viena: 281-300.

Alvarado, Y. y Pérez, C. (1998). El uso de biocidas: un problema ambiental. *Interciencia*, 23: 20-25.

Álvarez, H.; Carvajal, H. y Martínez, A. (1992). *Monitoreo de parámetros fisicoquímicos y del plancton en el alto y medio Orinoco.* Proyecto Ecosistema Orinoco (PECOR). Quinta etapa. Informe de resultados. Caracas: Instituto de Recursos Naturales, Universidad Simón Bolívar. 98 pp.

Asamblea Nacional de la República Bolivariana de Venezuela (2016). *Problemática de agua en Venezuela.* Informe de la Comisión Designada. Caracas, Venezuela.

Astiz, S. y Álvarez, H. (1998). El zooplancton en el alto y medio Río Orinoco, Venezuela. *Acta Científica Venezolana,* 49: 5-18.

Ayala, L.M.; Montero, R.L. y Tosiani, T. (2007). *Procesos, factores y calidad química de las aguas subterráneas de la región de Santa Ana, Península de Paraguaná, estado Falcón, Venezuela.* IX Congreso Geológico Venezolano. Versión CD.

Barletta, M.; Jaureguizar, A.; Baigum, C.; Fontura, N.; Agostinho, A.; Almeida-Val, V.; Torres, R.; Jiménez, L.; Giarrizos, T.; Fabre, N.; Batista, V.; Lasso, C.; Taphorn, D.; Costa, M.; Chaves, P.; Viera, J. & Correa, M. (2010). Fish and aquatic habitat conservation in South America: A continental overview with emphasis on Neotropical system. *Journal of Fish Biology,* 76: 2118-2176.

Benítez-Díaz, P. y Miranda-Contreras, L. (2013). Contaminación de aguas superficiales por residuos de plaguicidas en Venezuela y otros países de Latinoamérica. *Revista Internacional de Contaminación Ambiental,* 29: 7-23.

Betancourt, D. y Yessica, C. (2012). *Estudio de la calidad química y tipos de aguas subterráneas en el Sector Santa Lucía de los Valles del Tuy, estado Miranda.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 159 pp.

Biondo, D. y Esteves, N. (2010). *Evaluación hidrogeológica de la Laguna de Taiguaiguay, Municipio Zamora, Estado Aragua.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 138 pp.

Blanco, H.; Najul, M.V. y Sánchez, R. (2015). La calidad del agua y su contaminación. En: A. Gabaldón, A. Rosales, E. Buroz, J.R. Córdova, G. Uzcátegui y L. Iskandar (eds.). *Agua en Venezuela: Una riqueza escasa.* Tomo 1. Fundación Empresas Polar. Caracas: 253-284.

Blanco, S. (2015). *Evaluación de la gestión integral del relleno sanitario La Bonanza.* Trabajo de Grado presentado a la Universidad Simón Bolívar como requisito para optar al grado de Magíster en Desarrollo y Ambiente. Universidad Simón Bolívar, Caracas.

Buroz, E. (2016). *El agua en Venezuela: Pasado, Presente y Futuro. Parte II: Diseñando la Carta de Navegación.* Academia Nacional de Ciencias Físicas, Matemáticas y Naturales. Trabajo de Incorporación como Individuo de Número. Caracas.

Buroz, E. y Guevara, J. (1980). Prevención de crecidas en el Delta del Orinoco y sus efectos ambientales. En: ONU, CEPAL y ONU, PNUMA. *Agua, Desarrollo y Medio Ambiente en América Latina.* Santiago de Chile.

Camargo, G. (2001). *Manejo integrado de recurso Agua. Caso de aplicación: Cuenca del río Tuy, Venezuela.* Trabajo de Ascenso a la categoría de Profesor Titular. Universidad de Los Andes. Facultad de Ingeniería, Mérida.

Carvajal-Chitty, H. (1988). Nuevos géneros y especies de fitoplancton para Venezuela colectados en las aguas del alto y medio Orinoco. *Memorias de la Sociedad de Ciencias Naturales La Salle,* 48: 91-103.

Comisión Económica para América Latina y el Caribe (CEPAL) (2016). *Agenda 2030 y los Objetivos de Desarrollo Sostenible. Una oportunidad para América Latina y el Caribe.* Naciones Unidas, Chile. Disponible en línea: www.sela.org/media/2262361/agenda-2030-y-los-objetivos-de-desarrollo-sostenible.pdf. Consultado: mayo, 2017.

Constitución de la República Bolivariana de Venezuela (1999). Gaceta N° 36.860. 30 de diciembre de 1999. Caracas.

Corporación Venezolana de Guayana, Electrificación del Caroní (CVG-EDELCA) (2004). Estudio Plan Maestro de la Cuenca del Río Caroní. Síntesis. CVG-EDELCA, Ciudad Guayana.

Corsi, J. (2006). *Procesos hidrogeoquímicos que controlan la composición de las aguas subterráneas de la cuenca Pedro González, Isla de Margarita, Edo. Nueva Esparta.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 94 pp.

Cressa, C.; Vásquez, E.; Zoppi, E.; Rincón, J.E. y López, C. (1993). Aspectos generales de la Limnología en Venezuela. *Interciencia*, 18(5): 237-248.

D´Elia, K. (2006). *Estudio hidrogeoquímico de las aguas subterráneas de la cuenca Santa Ana, Isla de Margarita, Edo. Nueva Esparta.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 80 pp.

Depetris, P. & Paolini, J. (1991). Biogeochemical aspects of South American rivers. The Paraná and the Orinoco. En: E.T. Degens, S. Kempe & J.E. Richey (eds.). *Biogeochemistry of Major World Rivers. SCOPE* 42. Wiley, London: 105-125.

Durán, L. (2006). Evaluación de la vulnerabilidad a la contaminación de aguas subterráneas por actividades industriales. El caso del acuífero de Maracay, Distrito Girardot, Aragua, Venezuela. Trabajo de Grado para optar al título de Magister Scientiae en Gestión de Recursos Naturales Renovables y Medio Ambiente, con énfasis en Estudios de Impacto Ambiental. Universidad de Los Andes, CIDIAT, Mérida.

Escalona-Pazo, G. y Marrero-Clemente, S. (2013). Calidad química de las aguas subterráneas pertenecientes a las zonas Guacuripia-El Palmar, estado Bolívar. *Revista Venezolana de Ciencias de la Tierra* (GEOS), 44: 45-50.

Esclapés, M. y Galindo, I. (2000). Calidad de las aguas del Lago de Maracaibo. En: G. Rodríguez (ed.). *El Sistema de Maracaibo. Biología y ambiente.* 2ª edición. Caracas: Instituto Venezolano de Investigaciones Científicas. pp. 125-146.

Estaba, M.; González, E.J. y Matos, M.L. (2006). Desestratificación artificial en el embalse Pao-Cachinche: Primer y exitoso caso de mejoramiento de la calidad del agua en Venezuela. En: J.G. Tundisi, T. Matsumura-Tundisi & C. Sidagis-Galli (eds.). *Eutrofização na América do Sul: Causas, conseqüências e tecnologias de gestão.* Rede EUTROSUL, PROSUL, Instituto Internacional de Ecología. São Carlos, Brasil: 429-455.

Fernández, A.; Villafañe, R. y Hernández, R. (2011). Calidad del agua de riego y afectación de los suelos por sales en la península de Paraguaná, Venezuela. *Agronomía Tropical,* 61(3-4): 253-261.

Figueroa, D. y Seijas, E. (1986). Humedales en Venezuela. En: D. Scott & M. Carbonell (eds.). *A directory of Neotropical Wetlands.* Cambridge, UK: IUCN Conservation Monitoring Centre.

Fundación Tierra Viva (2010). *Directorio de Organizaciones No Gubernamentales Ambientales de Venezuela.* Caracas: Fundación Tierra Viva, Proyecto de Redes Ambientales y Unión Europea.

Gabaldón, A. (2015). Agua y desarrollo. En: A. Gabaldón, A. Rosales, E. Buroz, J.R. Córdova, G. Uzcátegui y L. Iskandar (eds.). *Agua en Venezuela: Una riqueza escasa.* Tomo 1. Caracas: Fundación Empresas Polar. pp. 59-77.

Gaceta Oficial de la República Bolivariana de Venezuela (GORBV) (2001). *Ley Orgánica para la Prestación de los Servicios de Agua Potable y Saneamiento.* Gaceta Extraordinaria N° 5.568. 31 de diciembre de 2001. Caracas.

Gaceta Oficial de la República Bolivariana de Venezuela (GORBV) (2006). *Ley Orgánica del Ambiente.* Gaceta N° 5.833. 22 de diciembre de 2006. Caracas.

Gaceta Oficial de la República Bolivariana de Venezuela (GORBV) (2007). *Ley de Aguas.* Gaceta N° 35.595. 2 de enero de 2007. Caracas.

Gaceta Oficial de la República Bolivariana de Venezuela (GORBV) (2012). *Ley Penal del Ambiente.* Gaceta N° 39.913. 2 de mayo de 2012. Caracas.

Gaceta Oficial República Bolivariana de Venezuela (GORBV) (2015). *Ley de la Calidad de las Aguas y el Aire.* Gaceta Extraordinaria N° 6.207. 28 de diciembre de 2015. Caracas.

Gaceta Oficial de la República de Venezuela (GORV) (1983). *Ley Orgánica para la Ordenación del Territorio.* Gaceta Extraordinaria N° 3.238. 11 de agosto de 1983. Caracas.

Gaceta Oficial de la República de Venezuela (GORV) (1995). *Normas para Ia clasificación y el control de Ia calidad de los cuerpos de agua y vertidos o efluentes líquidos.* Decreto N° 883 del 11 de octubre de 1995. Gaceta Extraordinaria N° 5.021. 18 de diciembre de 1995, Caracas.

Gaceta Oficial de la República de Venezuela (GORV) (1998). *Normas para la clasificación y el control de la calidad de las aguas del Río Yaracuy.* Gaceta N° 36.344. 28 de noviembre de 1998. Caracas.

Gessner, F. & Hammer, L. (1967). Limnologischen Untersuchungenan Seen der venezolanischen Hochanden. *Int. Revue Ges. Hydrobiol.,* 52(3): 301-320.

González, E.J. (2017). *Evaluación limnológica del embalse Camatagua (Edos. Aragua y Guárico).* Informe final del Proyecto PEII 20110001396. Informe técnico presentado al Fondo Nacional de Ciencia, Tecnología e Innovación (FONACIT). Caracas. 37 pp.

González, E.J. y Matos, M.L. (2012). Manejo de los Recursos Hídricos en Venezuela. Aspectos Generales. En: B. Jiménez-Cisneros y J.G. Tundisi (eds.). *Diagnóstico del Agua en las Américas.* México: Red Interamericana de Academias de Ciencias–Programa de Aguas, Foro Consultivo Científico y Tecnológico, AC. pp. 437-447.

González, E.J. & Quirós, R. (2011). Eutrophication of reservoirs in Venezuela: Relationships between nitrogen, phosphorus and phytoplankton biomass. *Oecologia Australis,* 15(3): 458-475.

González, E.J.; Álvarez, M.A.; Barrero, M. y Finol; H. (2012). *Limnología y efecto de los impactos antrópicos sobre los peces de interés comercial del embalse de Suata (Estado Aragua) y del Lago de Valencia (Estados Aragua y Cara-*

bobo). Informe final del Proyecto de Grupo PG 03.00.6495.2006/2. Informe técnico presentado al Consejo de Desarrollo Científico y Humanístico (CDCH-UCV). Caracas. 42 pp.

González, E.J.; Malaver, N. y Naveda, J. (2015a). Los ecosistemas acuáticos y su conservación. En: A. Gabaldón, A. Rosales, E. Buroz, J.R. Córdova, G. Uzcátegui y L. Iskandar (eds.). *Agua en Venezuela: Una riqueza escasa.* Tomo 1. Caracas: Fundación Empresas Polar. pp. 187-251.

González, E.J.; Matos, M.L.; Buroz, E.; Ochoa Iturbe, J.; Machado-Allison, A.; Martínez, R. y Montero, R. (2015b). Agua Urbana en Venezuela. En: G. Roldán, M.L. Torregrosa, K. Vammen, E.J. González, C. Campuzano y A. de la Cruz (Eds.). *Desafíos del Agua Urbana en las Américas. Perspectivas de las Academias de Ciencias.* México: Inter-American Network of Academies of Sciences (IANAS)–Programa de Aguas, con apoyo de IHP-UNESCO. pp. 574-619.

González, E.J.; Peñaherrera, C.; López, D. y Rodríguez, L. (2014). *Aspectos limnológicos de los embalses Suata y Camatagua (Edo. Aragua).* Memorias del Instituto de Biología Experimental, 7: 81-84.

Grupo Técnico de Calidad de Aguas (1998). *Plan Maestro para el control y manejo de la calidad de las aguas de la cuenca del Lago de Valencia.* Caracas: Ministerio del Ambiente y de los Recursos Naturales Renovables-Dirección General Sectorial de Calidad Ambiental-Comisión Nacional de Normas Técnicas para la Conservación, Defensa y Mejoramiento del Ambiente.

Herman de Bautista, S. (1997). *Proceso de Salinización en el Lago de Maracaibo.* Maracaibo: ICLAM-CORPOZULIA,.

Iglesias, I.; De la Vega, G. y Egaña, I. (2012). *Conceptualización de Soluciones para la Rehabilitación y Optimización de las Plantas Mayores de Potabilización de Agua de Venezuela.* Informe Técnico. Barcelona: Hidroven, CAF.

Infante, A.; Infante, O.; Vegas, T. y Riehl, W. (1992). *Proyecto Multinacional de Medio Ambiente y Recursos Naturales. I. Embalses Camatagua, Guanapito y Lagartijo.* Caracas: Universidad Central de Venezuela y Organización de los Estados Americanos. 63 pp.

Instituto Nacional de Estadística (INE) (2014). *Sistema de Indicadores de Calidad de Agua. Parte alta del Río Yaracuy.* San Felipe. 41 pp.

Isea, D.; Bello, N.; Vargas, L.; Yabroudi, S.; Durán, J. y Delgado, J. (2004). Estudio de la acumulación de metales micronutrientes en suelos sometidos a riego con aguas residuales tratadas. *Ciencia*, 12(2): 179-194.

Kutos, O. y Montero, R. (2013). Estudio hidrogeoquímico de las aguas subterráneas de la cuenca de la laguna de Taiguaiguay, estado Aragua. *Revista Venezolana de Ciencias de la Tierra (GEOS),* 44: 59-72.

Lairet, R. (2017). *Humedales llanos Centro Orientales: Modelos para evaluar sostenibilidad del uso del recurso hídrico.* Tesis Doctoral en Desarrollo Sostenible. Decanato de Estudios de Postgrado, Universidad Simón Bolívar, Caracas, Venezuela.

Lara, B.J. (2007). *Validación de un instrumento para la caracterización e Inventario de Humedales Altoandinos, sector Micarache, subcuenca de Gavidia, Parque Nacional Sierra Nevada, Mérida, Venezuela.* Tesis de Grado, Título de Ingeniero Forestal, Escuela de Ingeniería Forestal, Mérida, Venezuela.

Lasso, C.A.; Gutiérrez, F.P. y Morales-B., D. (eds.) (2014a). X. *Humedales interiores de Colombia: Identificación, caracterización y establecimiento de límites según criterios biológicos y ecológicos.* Serie Editorial Recursos Hidrobiológicos y Pesqueros Continentales de Colombia. Bogotá, D.C., Colombia: Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (IAvH). 255 pp.

Lasso, C.A.; Rial, A.; Colonnello, G.; Machado-Allison, A. y Trujillo, F. (eds.) (2014b). *XI. Humedales de la Orinoquia (Colombia-Venezuela).* Serie Editorial Recursos Hidrobiológicos y Pesqueros Continentales de Colombia. Bogotá, D. C., Colombia: Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (IAvH). 303 pp.

Lasso, C.A.; Usma, J.S.; Trujillo, F. y Rial, A. (eds.) (2010). *Biodiversidad de la Cuenca del Orinoco: Bases científicas para la identificación de áreas prioritarias para la conservación y uso sostenible de la biodiversidad.* Bogotá, D.C., Colombia: Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, WWF Colombia, Fundación Omacha, Fundación La Salle, Instituto de Estudios de la Orinoquia (Universidad Nacional de Colombia). 609 pp.

Lentino, M. y Bruni, A.R. (1994). *Humedales Costeros de Venezuela: Situación ambiental.* Caracas, Venezuela: Sociedad Conservacionista Audubon de Venezuela.

Lewis Jr., W.M. & Saunders, J.F. (1989). Concentration and transport of dissolved and suspended substances in the Orinoco River. *Biogeochemistry*, 7: 203-240.

Lewis Jr., W.M. & Weibezahn, F.M. (1976). Chemistry, energy flow, and community structure in some Venezuelan fresh waters. *Arch. Hydrobiol.,* Suppl. 50: 145-207.

López, C.; Villalobos, M. y González, E.J. (2001). Estudio sobre el zooplancton de los embalses de Venezuela: Estado actual y recomendaciones para futuras investigaciones. *Ciencia*, 9(2): 217-234.

Luna, M.W.; Montero, R.L. y Yanes, C. (2007). *Procesos geoquímicos que controlan la composición química de las aguas subterráneas en el sector Güigüe en la Cuenca del Lago de Valencia.* IX Congreso Geológico Venezolano. Versión CD.

Machado-Allison, A.; Lasso, C.; Usma, J.S.; Sánchez, P. y Lasso, O. (2010). Peces (Cap. 7). En: C. Lasso, J.S. Usma, F. Trujillo y A. Rial (eds.). *Biodiversidad de la Cuenca del Río Orinoco: Bases científicas para la identificación de áreas prioritarias para la conservación y uso sostenible de la biodiversidad.* Serie Editorial Recursos Hidrobiológicos y Pesqueros Continentales de Colombia. Bogotá, D.C., Colombia: Instituto de Investigación de los Recursos Biológicos Alexander von Humboldt (IAvH). pp. 217-257.

Marín, J.C.; Ledo de Medina, H.; Hernández, J.L. y López, C. (1999). Variación vertical y temporal de la productividad primaria y su relación con algunos elementos nutritivos en un reservorio de agua tropical, Río Socuy. Venezuela. *Ciencia*, 7(2): 163-180.

Márquez, I. (2016). *Estudio hidrogeoquímico de las aguas subterráneas en la región de Duaca, El Eneal y Perarapa, Municipio Crespo, Barquisimeto, edo. Lara.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas.

Marrero, C. (2011). La vegetación de los humedales de agua dulce de Venezuela. *BioLlania* Edición Especial, 10: 50-263.

Martínez, R. (2013). *La gestión del agua potable y el saneamiento en el Área Metropolitana de Caracas.* Instituto Latinoamericano de Investigaciones Sociales (ILDIS). Caracas: Oficina en Venezuela de la Fundación Friedrich Ebert. 23 pp.

Mateus C., N.A. (2015). *Estudio de la calidad química y tipos de aguas subterráneas presentes en la cuenca de la Laguna de Taiguaiguay, estado Aragua, Venezuela.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 172 pp.

Michel, J. (2006). *Estudio de la evolución hidrogeoquímica de las aguas subterráneas de la cuenca La Fuente Paraguachí, Isla de Margarita, Edo. Nueva Esparta, Venezuela.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 126 pp.

Milano, S. (2014). Venezuela. En: C. Heck y J. Tranca (eds.). *La realidad de la minería ilegal en países amazónicos.* Lima: Sociedad Peruana de Derecho Ambiental, Negrapata S.A.C. pp. 219-247.

Ministerio de Obras Públicas (MOP) (1972). *Mediciones en ríos grandes.* Caracas: Ministerio de Obras Públicas. Dirección General de Recursos Hidráulicos. División de Hidrología. 90 pp.

Ministerio del Poder Popular de Comunicación e Información (MPPCI) (2009). Obras de Saneamiento y Control del Lago de Valencia. Disponible en: http://www.venezueladeverdad.gob.ve/obras Consulta: febrero de 2009.

Ministerio del Poder Popular para Ecosocialismo y Aguas (MINEA) (s/f). Laboratorios Ambientales. Disponible en línea: www.minea.gob.ve/laboratorios-ambientales Consultado: junio de 2017.

Ministerio del Poder Popular para el Ambiente (MINAMB) (2009). Proyecto Cuenca Lago de Valencia. Viceministerio del Agua. Disponible en: http://www.minamb.gob.ve/index.php?option=com_content&task=view&id=24&Itemid=38 Consulta: febrero de 2009.

Ministerio del Poder Popular para la Salud (MPPS) (2016). *Boletín Epidemiológico.* En D.d.V. Epidemiológica (ed.). Vol. 52. Caracas: Ministerio del Poder Popular para la Salud.

Molina-Morales, Y.; Flores-García, M.; Balza-Quintero, A.; Benítez-Díaz, P. y Miranda-Contreras, L. (2012). Niveles de plaguicidas en aguas superficiales de una región agrícola del estado Mérida, Venezuela, entre 2008 y 2010. *Revista Latino Americana de Contaminación Ambiental,* 28(4): 289-301.

Montero, R.L. (1996). *Caracterización hidrogeoquímica de aguas subterráneas asociadas a zonas de* *explotación de hidrocarburos.* Trabajo de Ascenso. Instituto de Ciencias de la Tierra, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 203 pp.

Montero, R.L. (2006). *Estudio geoquímico de las aguas subterráneas de la cuenca del Lago de Maracaibo, Venezuela.* Tesis Doctoral. Universidad Central de Venezuela. Facultad de Ciencias, Instituto de Ciencias de la Tierra, Facultad de Ingeniería, Escuela de Geología, Minas y Geofísica, Caracas. 344 pp.

Montero, R.L., Yanes, C. y Bolívar, V. (2007a). *Hidrogeoquímica de las aguas subterráneas de la región nor-central del Valle de Caracas, Distrito Capital, Venezuela.* IX Congreso Geológico Venezolano. Versión CD.

Montero, R.L., Yanes, C. y Redondo, R. (2007b). *Evolución geoquímica e identificación de los procesos que controlan la composición química de las aguas subterráneas de la región sur-central, Cuenca del Lago de Maracaibo, Venezuela.* IX Congreso Geológico Venezolano. Versión CD.

Nevado, N.A. (1999). *Caracterización geoquímica de aguas subterráneas asociadas a rocas ígneo-metamórficas.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 113 pp.

Ochoa Iturbe, J.; Uzcátegui, G.; Rosales, A.; Córdova, J.R.; Buroz, E. y López, J.L. (2015). Agenda para la investigación y formación de recursos humanos para el aprovechamiento integral de las aguas. En: A. Gabaldón, A. Rosales, E. Buroz, J.R. Córdova, G. Uzcátegui y L. Iskandar (eds.). *Agua en Venezuela: Una riqueza escasa.* Tomo 2. Caracas: Fundación Empresas Polar. pp. 949-981.

Ojeda, H.V. (2013). *Caracterización hidrogeológica, contaminación y uso de acuíferos del sector Ocumare del Tuy, estado Miranda.* Trabajo de Grado de Maestría. Escuela de Geología, Minas y Geofísica, Facultad de Ingeniería, Universidad Central de Venezuela, Caracas. 114 pp.

Ongley, E. (1997). *Lucha contra la contaminación agrícola de los Recursos Hídricos.* Roma: Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO).

Organización de las Naciones Unidas (ONU) (2016). *Objetivos de Desarrollo Sostenible.* En: http://www.un.org/sustainabledevelopment/es/water-and-sanitation/ Consultado: junio 2017.

Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO) (2015). *Sistema de Información sobre el Uso del Agua en la Agricultura de la FAO.* Disponible en línea: http://www.fao.org/nr/water/aquastat/countries_regions/ven/printesp1.stm Consultado: junio de 2017.

Organización Mundial de la Salud (OMS) (2016). *Planificación de la seguridad del saneamiento: Manual para el uso y la disposición seguros de aguas residuales, aguas grises y excretas.* Ginebra: Departamento de Salud Pública y Medio Ambiente. 156 pp.

Organización Mundial de la Salud (OMS) (2017). *La Asamblea Mundial de la Salud llega a una serie de acuerdos sobre el control de vectores, las enfermedades no transmisibles y los ODS.* Disponible en línea: http://www.who.int/mediacentre/news/releases/2017/vector-control-ncds-cancer/es/ Consultado: junio de 2017.

Páez, R.; Ruiz, G.; Márquez, R.; Soto, L.M. Montiel, M. & López, C. (2001). Limnological studies on a shallow reservoir in western Venezuela (Tulé Reservoir). *Limnologica*, 31: 139-145.

Paolini, J.; Hevia, R. & Herrera, R. (1987). Transport of carbon and minerals in the Orinoco and Caroní rivers during the years 1983-1984. *Mitt. Geol.-Paläont.* Inst. Univ. Hamburg, 64: 325-338.

Parra Pardi, G. (1979). *Estudio Integral sobre la Contaminación del Lago de Maracaibo y sus Afluentes.* Parte II. Evaluación del Proceso de Eutrofización. Ministerio del Ambiente y los Recursos Naturales Renovables. Caracas, Venezuela. 235 pp.

Parra Pardi, G. (1986). *La conservación del Lago de Maracaibo: diagnóstico ecológico y plan maestro.* Caracas: Publicaciones LAGOVEN. 86 pp.

Parra Pardi, G. y Blumenkratz, G. (1977). *Estudio sanitario integral del Río Yaracuy.* Caracas: Ministerio de Sanidad y Asistencia Social. Dirección de Malariología y Saneamiento Ambiental. 25 pp.

Pla Sentis, I. (1983). Sistema Integrado Agua–Cultivo–Suelo–Manejo para evaluar la calidad de agua para riego. En: *Proceedings of a Symposium on Isotope and Radiation Techniques in Soil Physics and Irrigation Studies:* 191-206.

Pla Sentís, I. y Dappo, F. (1974). Sistema Racional para la Evaluación de la Calidad de Aguapara

Riego. Suplemento Técnico N° 12. *Boletín Informativo FUDECO.* Barquisimeto.

Polo, M. y Guevara, E. (2001). Contaminación de acuíferos por efecto de los lixiviados en el área adyacente al vertedero de desechos sólidos La Guásima, Municipio Libertador, Estado Carabobo. *Revista Ingeniería UC* (en línea) 8(2), pp.0. Disponible en: http://www.redalyc.org/articulo.oa?id=70780201 Consultado: junio 2017.

Ramos, M. (2014). *Análisis de la variación temporal y espacial de la calidad del agua de la cuenca media del Río Tuy en el periodo 1969–2008.* Trabajo de Grado para optar al título de Magister Scientiarum en Ingeniería Sanitaria. Universidad Central de Venezuela, Facultad de Ingeniería, Caracas.

Ramos, M.; Berroterán, D. y Najul, M.V. (2014). Patrones de ocupación del territorio en la Cuenca Media del Río Tuy y su impacto en la calidad del agua. *Revista de la Facultad de Ingeniería de la Universidad Central de Venezuela,* 29(3): 17-28.

Red Ara (2013). *La contaminación por mercurio en la Guayana Venezolana: Una propuesta de diálogo para la acción.* Caracas. Disponible en: http://red-ara-venezuela.blogspot.com Consultado: mayo 2017.

Rincón, J.E. (2013). Pasado, presente y perspectivas de la eutrofización del Lago de Maracaibo. En: J.E. Rincón y M. Boves (eds.). *Eutrofización del Lago de Maracaibo: Pasado, presente y perspectivas.* Editorial de la Universidad del Zulia (Ediluz). Maracaibo: 5-26.

Rincón, J.E. y Mejía, L. (2013). Factores ambientales asociados al sobrecrecimiento de *Lemna obscura* en el Lago de Maracaibo: Evaluación de una hipótesis. En: J.E. Rincón y M. Boves (eds.). *Eutrofización del Lago de Maracaibo: Pasado, presente y perspectivas.* Editorial de la Universidad del Zulia (Ediluz). Maracaibo: 167-206.

Rodríguez, D. (2000). *Estudio hidrogeoquímico de las aguas subterráneas de la zona La Fuente–Paraguachí, Isla de Margarita, Venezuela.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 157 pp.

Rodríguez, G. (2000). El plancton del Sistema de Maracaibo. En: G. Rodríguez (ed.). *El Sistema de Maracaibo. Biología y ambiente.* 2ª edición. Caracas: Instituto Venezolano de Investigaciones Científicas. pp. 61-73.

Rodríguez-Altamiranda, R. (1999). *Conservación de Humedales en Venezuela: Inventario, diagnóstico ambiental y estrategia.* Caracas: Comité Venezolano UICN. 110 pp.

Rojas, R. (2015). El agua y la agricultura. En: A. Gabaldón, A. Rosales, E. Buroz, J.R. Córdova, G. Uzcátegui y L. Iskandar (eds.). *Agua en Venezuela: Una riqueza escasa.* Tomo 2. Caracas: Fundación Empresas Polar. pp. 481-520.

Romero de la Cuba, R. (1982). *Alternativas de Riego en la cuenca del Lago de Valencia.* Trabajo Especial de Grado para optar al grado de Magister Scientiae en Riego y Drenaje. Mérida: Universidad de Los Andes, CIDIAT.

Saunders, J.F. & Lewis, W.M., Jr. (1988). Transport of phosphorus, nitrogen, and carbon by the Apure River, Venezuela. *Biogeochemistry*, 5: 323-342.

Silva, G.A. (2000). Historia resumida de la hidrología venezolana. *Rev. Geog. Venez.* 41: 139-166.

Soto, L.; López, C. y Bello, C. (1994). Química del agua del embalse Socuy, Estado Zulia, Venezuela. *Boletín del Centro de Investigaciones Biológicas,* 28: 1–21.

Toro, D. (2012). *Estudio de la calidad química y tipos de aguas subterráneas en la zona sur-oriental de la Isla de Margarita, Edo. Nueva Esparta, Venezuela.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 155 pp.

Torrealba, R. (2016). *Evaluación hidrogeoquímica y geofísica de las aguas subterráneas del Acuífero Licua, Municipio Crespo, edo. Lara.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 160 pp.

Traviezo Valles, L.; Dávila, J.; Rodríguez, R.; Perdomo, O. y Pérez, J. (2004). Contaminación enteroparasitaria de lechugas expendidas en mercados del estado Lara, Venezuela. *Parasitología Latinoamericana,* 59: 167-170.

Trujillo, A.; Cárdenas de Flores, C.H.; Valbuena, M.; Herrera, L.; Araujo, I. y Saules, L. (2000). *Tratamiento de aguas residuales en el trópico mediante lagunas de estabilización y su reúso para riego agrícola.* Memorias del XXVII Congresso Interamericano de Engenharia Sanitária e Ambiental. Porto Alegre: Asociación Interamericana de Ingeniería Sanitaria y Ambiental (AIDIS) / Associação Brasileira de Engenharia Sanitária e Ambiental (ABESA).

Universidad Central de Venezuela (UCV), Universidad Simón Bolívar (USB) y Universidad Católica Andrés Bello (UCAB) (2014). Encuestas sobre Condiciones de Vida en Venezuela 2014. Disponible en línea: http://www.rectorado.usb.ve/vida/presentaciones Consultado: junio de 2017.

Universidad Central de Venezuela (UCV), Universidad Simón Bolívar (USB) y Universidad Católica Andrés Bello (UCAB) (2015). Encuestas sobre Condiciones de Vida en Venezuela 2015. Disponible en línea: http://www.rectorado.usb.ve/vida/node/58 Consultado: junio de 2017.

US Department of Agriculture (USDA) (1954). Diagnosis and Improvement of Alkali Solis. Washington (DC). *Agriculture Handbook* N° 60.

Vargas, M.J.; López, C.; Montero, R. y Benavides, A. (1997). *Factores Fisiográficos que afectan la Composición Química de la Aguas Subterráneas de Isla de Margarita, Estado Nueva Esparta, Venezuela.* VIII Congreso Geológico Venezolano. Tomo II, pp. 485-491.

Vegas, D.S. (2016). *Estudio hidrogeoquímico y de la calidad de las aguas subterráneas a partir del método estadístico* fuzzy set *en la cuenca del río Palmar, Municipio Rosario de Perijá, estado Zulia.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 157 pp.

Vila, P. (1960). *Geografía de Venezuela. 1. El territorio nacional y su ambiente físico.* Caracas: Ministerio de Educación, Depto. de Publicaciones, Dirección de Cultura y Bellas Artes. 454 pp.

Villafañe, R.; Abarca, O.; Azpúrua, M.; Ruíz, T. y Dugarte, J. (1999). Distribución espacial de la salinidad en los suelos de Quíbor y su relación con las limitaciones de drenaje y la calidad de agua. *Bioagro*, 11(2): 43-50.

Villafañe, R.; De León, N.; Camachos, F.; Ramírez, R. y Sánchez, L. (2004). Acumulación y lavado de sales en columnas de suelo regadas con agua salina procedente de un pozo petrolero. *Agronomía Tropical,* 54(1): 93-120.

Weibezahn, F. (1985). *Concentraciones de especies químicas disueltas y transporte de sólidos suspendidos en el alto y medio Orinoco y sus variaciones estacionales (febrero 1984-febrero 1985).* Proyecto Ecosistema Orinoco (PECOR). Informe de resultados. Convenio USB-MARNR-PDVSA. Caracas. 229 pp.

Weibezahn, F. (1990). Hidroquímica y sólidos suspendidos en el alto y medio Orinoco. En: F. Weibezahn, H. Álvarez y W.M. Lewis (eds.). *El Río Orinoco como ecosistema.* Caracas: Editorial Galac. pp. 151-210.

Weibezahn, F.M.; Volcán, J.M.; González, A. y Reyes, F. (1970). Estudio morfométrico e hidrográfico de dos lagunas en los Andes de Venezuela. *Boletín Soc. Ven. Cienc. Nat.,* 28: 447-455.

Zambrano, F. (1999). *Caracterización hidrogeoquímica de las aguas subterráneas en el Estado Táchira.* Trabajo Especial de Grado. Instituto de Ciencias de la Tierra, Escuela de Química, Facultad de Ciencias, Universidad Central de Venezuela, Caracas. 209 pp.

Zérega, L.; Hernández, T. y Valladares, J. (1991). Caracterización de suelos y aguas afectadas por sales en zonas cañameleras de Azucarera Río Turbio. *Caña de Azúcar,* 9(1): 5-52.

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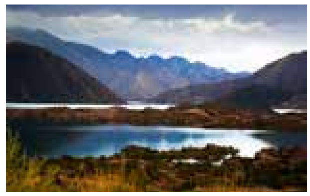
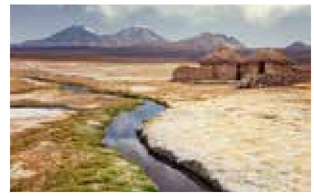


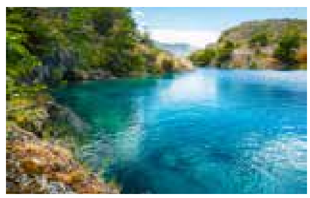

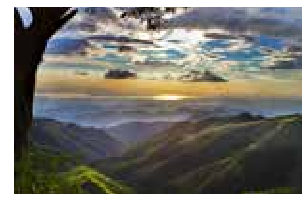
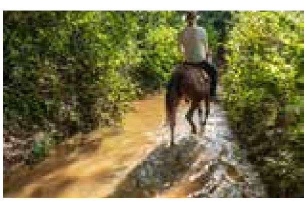
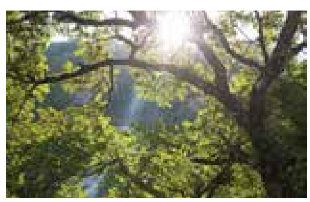
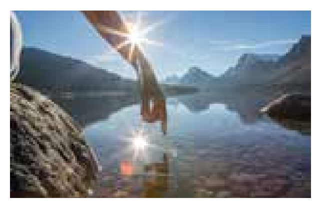
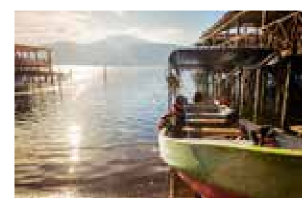
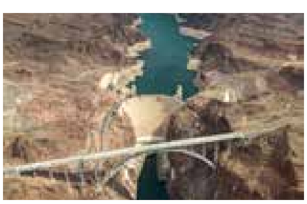
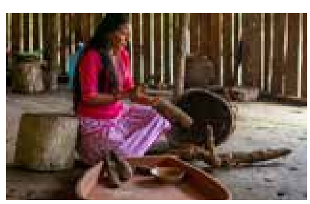
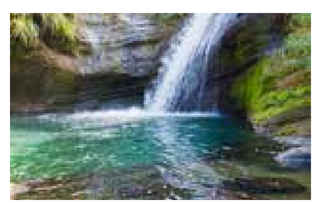
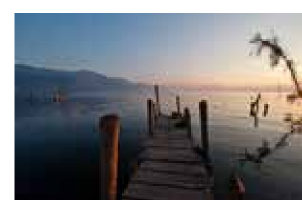
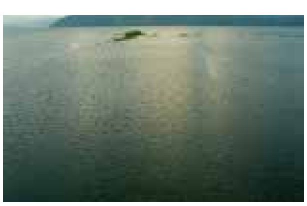
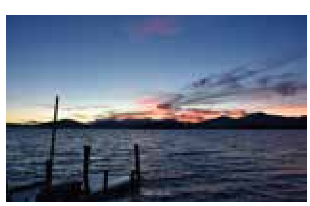
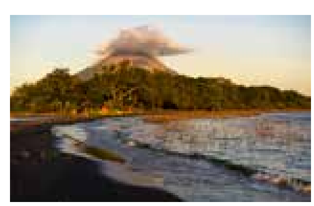
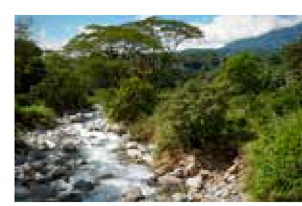
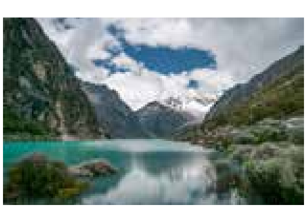
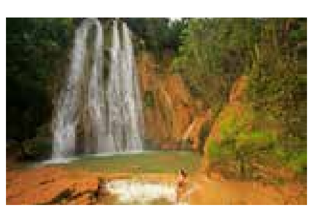
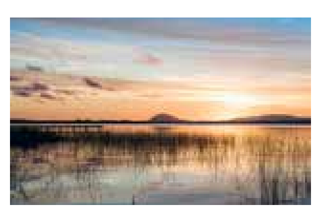
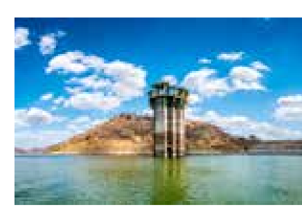

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