WATER SCARCITY ON TWO CONTINENTS: *A PRELIMINARY REPORT*

IANAS
INTERAMERICAN NETWORK OF ACADEMIES OF SCIENCES

NETWORK OF AFRICAN SCIENCE ACADEMIES
NASAC

iap SCIENCE HEALTH POLICY
the interacademy partnership

Under the umbrella of the InterAcademy Partnership (IAP), more than 140 national, regional and global member academies work together to support the vital role of science in seeking evidence-based solutions to the world's most challenging problems. In particular, IAP harnesses the expertise of the world's scientific, medical and engineering leaders to advance sound policies, improve public health, promote excellence in science education and achieve other critical development goals.

The Inter-American Network of Academies of Sciences (IANAS) is a regional network of Academies of Sciences created to support cooperation to strengthen science and technology as tools for advancing research and development, prosperity and equity in the Americas.
https://ianas.org

Through its membership, NASAC facilitates the discussion of scientific aspects of challenges of common concern, make statements on major issues and provide mutual support to the academies. Drawing from this, NASAC specifically aims to provide credible science advice to governments and regional organizations on pertinent issues to Africa's development. NASAC's networking capacity serves as an effective resource for communicating appropriate thematic information, as well as coordinate efforts among different sectors and stakeholders in academia, policy and society.
https://nasaconline.org/

IANAS and NASAC are regional members of the InterAcademy Partnership (IAP).

WATER SCARCITY ON TWO CONTINENTS:
A PRELIMINARY REPORT
First edition - Córdoba, Argentina, August 2023.

IANAS Co-Chairs: Helena Nader and Karen Strier.
Executive Director: Beatriz L. Caputto
IANAS Water Program Co-Chair: Katherine Vammen (Nicaragua).

Editorial Committee:

From NASAC:

Professor Cheikh Becaye Gaye, Senegal
Professor Salif Diop (deceased, Senegal)
Dr. Emmanuel Naah, Cameroon
Professor Daniel Olago, Kenya
Dr. Omogbemi Omoleju, Nigeria

From IANAS:

Professor Henry Vaux, USA
Professor Katherine Vammen, Nicaragua
Professor Guillermo Donoso, Chile
Professor Martin Forde, Caribbean
Professor Ricardo Izurieta, Ecuador
Professor Maria Louisa Torregrosa, Mexico

Authors:
Professor Salif Diop, Senegal
Professor Guillermo Donoso, Chile
Professor Martin Forde, Grenada
Professor Ernesto Gonzales Rivas, Venezuela
Professor Hugo Hidalgo, Costa Rica
Dr. Emmanuel Naah, Cameroon
Professor Katherine Vammen, Nicaragua
Professor Henry Vaux, USA

Spanish Translation: Paula Bajo Moreno
French Translation: Transterp, Cabinet de Traduction
Editorial Design: Alejandra Rodriguez

Printed by

Printed in Argentina.

WATER SCARCITY ON TWO CONTINENTS: *A PRELIMINARY REPORT*

Network of African Science Academies (NASAC)

and

InterAmerican Network of Academies of Sciences (IANAS)

JOINT NASAC/IANAS PROJECT ON WATER SCARCITY

TABLE OF CONTENTS

DEDICATION

This volume is dedicated to the memory of our dear friend and colleague, Professor Salif Diop, who passed away unexpectedly as the project was nearing completion.

Salif Diop worked for 16 years at the United Nations in UNEP's Early Warning and Assessment (DEWA) as a Senior Officer. He was a water specialist with extensive experience in various aspects of coastal oceanography, freshwater assessment, aquatic and marine issues, sustainable management and development. He received a 3rd cycle doctorate from the Louis Pasteur University in Strasbourg, France in 1978 and a state doctorate in 1986. He had more than 40 referred publications and 6 books and was awarded a Nobel Peace Prize Certificate – IPCC 2007. He was a University Professor, member of the National Academy of Sciences and Technologies of Senegal, the African Academy of Sciences (ASS) and the World Academy of Sciences for the Advancement of Sciences in the Developing Countries (TWAS). His long serving colleague and friend, Dr. Emmanuel Naah stated:

"I am the co-author with Professor Salif Diop of the chapter on Africa in this volume. Salif Diop was both a colleague at the UN Office in Nairobi, Kenya and a dear and close friend of many of us working in the fields of water sciences, climate change, ecosystem services and sustainable livelihood. His professional and academic credentials were impressive by any standards.

I have contributed to this volume because his health condition required that he rest and not engage in scientific activities. Words cannot describe how saddened I was to hear of his passing and realized that this chapter would be his last scientific paper…for me a sad paper. He will be dearly missed. May his soul rest in eternal peace."

STEERING COMMITTEES

NETWORK OF AFRICAN SCIENCE ACADEMIES

Professor Cheikh Becaye Gaye, Chair, Senegal
Professor Salif Diop*, Senegal
Dr. Emmanuel Naah, Cameroon
Professor Daniel Olago. Kenya
Dr. Omogbemi Omoloju Yaya, Nigeria

INTERAMERICAN NETWORK OF ACADEMIES OF SCIENCES

Professor Henry Vaux, Chair, U.S.A.
Professor Guillermo Donoso, Chile
Professor Martin Forde, Grenada
Professor Ricardo Izurieta, Ecuador
Professor Maria Luisa Torregrosa, Mexico
Professor Katherine Vammen, Nicaragua

* Deceased

AUTHORS

Professor Salif Diop*, Senegal
Professor Guillermo Donoso, Chile
Professor Martin Forde, Grenada
Professor Ernesto Gonzalez Rivas, Venezuela
Professor Hugo Hidalgo, Costa Rica
Dr. Emmanuel Naah, Cameroon
Professor Katherine Vammen, Nicaragua
Professor Henry Vaux, USA

PREFACE

As this report on water scarcity neared completion at the end of the summer of 2022 news services carried alarming reports about the condition of waterways throughout the world. In the southwestern United States the flows of the Colorado River, which serves 40 million people, had fallen to such an extent that the river's watermaster warned that without very significant reduction in withdrawals the entire river system was in danger of collapse. Similarly, the flows of the Rhine River in central Europe had fallen to the point where supplies of agricultural products and other commodities customarily transported by barge were endangered. In the Middle East flows of the Jordan River system have fallen to the point where Israelis are utilizing desalted sea water to stabilize the level of the Lake Kinneret (also known as the Sea of Galilee), a part of the Jordan River system from which significant water supplies are extracted. Additionally, there are reports that the Chinese are engaged in rain making regimes in an effort to augment the historically low flows of the Yangtze River. These are not isolated events and the simultaneity of them is unprecedented in modern times. These events portend a new era of water scarcity in which continents, nations and regions throughout the world will be compelled to live with less water than what has been available historically.

Against this backdrop of intensifying global water scarcity a group of water scholars associated with the Network of African Science Academies (NASAC) and the InterAmerican Network of Academies of Science (IANAS) agreed to undertake a project focused on the current and prospective states of water scarcity in the Americas and on the African continent. The project, intended to be a first step in a potentially larger work, was to consider the definitions and measures used to examine the nature of water scarcity in the Americas and Africa. The authors were also to search for characteristics of water scarcity that could be generalized across very large landscapes. These included not only the causes and consequences of water scarcity but also the outlook for the future in the face of population growth, economic growth and climate changes. The report begins with a summary of lessons learned and these are repeated as conclusions at the end.

The body of the report is presented in two parts. Part I, entitled "Water Scarcity: Principles and Problems" deals with the basic conceptual underpinnings and scientific language commonly used and associated with discussions of water scarcity. It examines (i) the different definitions of the term water scarcity and how those definitions may have very different lessons for the making of public policy, (ii) the critical variables used to determine the existence and extent of water scarcity as well as (iii) a list of terms and definitions which are frequently encountered in discussions of water scarcity. By contrast, Part II contains an overview of water scarcity in five regions of the Americas and in Africa. This part is largely descriptive and contrasts some with the more technical discussions in Part I. Part III contains the conclusions of the study.

SUMMARY OF FINDINGS

The continents of Africa and America are vast with a portion of each in both the northern and southern hemispheres. It is not surprising, then, that the single term, “variable”, applies not only to the patterns and quantities of rainfall across the continents but also to differences that include many features and circumstances, including landscapes, climates, available resources and demographic characteristics. It also describes these differences within the one hundred or so countries on these continents. So what can be learned from a study of water scarcity of two continents so vast and so variable? Are there universal lessons that transcend continental, regional and local variabilities? This brief study by specialists from the two continents suggests that the answer is yes.

Despite the variability of waterscapes, landscapes, climate, governance institutions and personal behavior several common themes and findings emerge from this study. They relate to how water scarcity is defined and measured, some of the consequences of water scarcity and matters that need to be addressed if water is to be effectively managed in the future when various stressors on the resource will intensify. These are summarized in the conclusions below.

1. Care should be taken whenever using the term “water scarcity” to be clear on the definition as well as on the metrics available for measuring it. There are a host of definitions of water scarcity that mean different things to different people and thus have different implications for water policy and water management. Care should also be taken in selecting the metrics used to characterize water scarcity as different metrics require different data. Therefore, when addressing water scarcity it is important to know about the quality the data, as well as the strengths and weaknesses of the assumptions made in the absence of data.

2. Climate change poses threats and uncertainties to virtually every locale in Africa and the Americas. Two threats are frequently mentioned on both continents. The first is that for many places there will be a decline in precipitation from historical levels thereby reducing accustomed levels of water supply. In other locales modelling studies suggest just the opposite. The second is that both the frequency and intensity of adverse climatic events such as floods and droughts will increase. However, there are very few, if any, places on either continent where the precise impact of climate change is clearly understood. This is especially true for Africa. Therefore, adaptive water management and planning is an important and crucial step that must be taken now, and must include flexible approaches in anticipation of the current uncertainties about the timing, impact and extent of climate changes.

3. Develop and implement effective ground water management plans…..everywhere! This study reveals that there are few, if any, examples on either continent where ground water is effectively managed. This is despite the fact that ground water supplies are an increasingly important source of water everywhere as surface waters become fully appropriated and existing surface supplies are diminished because of climate change. Ground water can provide additional sources of supply even in countries that have small endowments of ground water. The sustainability of ground water resources is under threat whenever they are exploited in an individualistically competitive fashion. Effective and enforceable management schemes are needed to avoid persistent and premature decline in water tables and, in some cases, the physical and/or economic exhaustion of the resource. Effective management schemes are also needed to protect ground water quality. In many locales there is an absence of good data on the characteristics and conditions of local ground waters. Good management will require such data.

4. There is widespread need to protect and enhance water quality. The failure to protect the quality of both ground and surface waters will lead inevitably to a reduction in supplies available for most consumptive and some non-consumptive uses. Thus, there is a need for laws, policies and enforcement mechanisms to enhance and protect water quality though these will vary among regions and locales. Some countries lack enforceable laws and policies altogether while others may have a reasonable array of laws and policies fail that are ineffective because of a lack of monitoring and enforcement. Water quality protection needs to be high on the list of priorities for most nations in the Americas and Africa as a way of protecting existing supplies in the face of adverse changes in climate.

5. Water policies should be based on known water science and scientific research. Accelerated development of water science should be encouraged. Known science should be the basis upon which water policies are devised. At a minimum, policies that contradict available science should be avoided. Simultaneously, higher priority should be accorded to the support of appropriate scientific research on water as a straightforward way to address the water problems of the future. These may be somewhat different than those of the past because of increasing scarcity (by any definition) and the uncertain impacts of climate change. There is a need for adequate monitoring as well as the collection and storage of water quantity and quality data. The making of enlightened water policy depends upon the availability of knowledge about the qualitative and quantitative conditions of the water resources. Without monitoring the making of effective policy is severely constrained.

6. Where possible new economic activity should be steered away from dry lands. There are examples of countries such as Mexico where a majority of the economic activity is currently located in arid zones. In such circumstances, efforts should be made to locate new and expanded activities in more humid areas where the water supply is more generous. Clearly future water management challenges can be more easily addressed if economic activity and other drivers of water use are located where water is relatively plentiful. Such a strategy could be especially important in areas where precipitation will be diminished because of climate change. To the extent possible, actions that create and/or encourage economic and population growth in areas where drought is localized and permanent should be avoided.

7. Make efforts to disconnect water and economic growth. Historically, economic growth and population growth have been considered major drivers of the growth of water demands. There is some evidence that emerges from the southwestern United States that water and economic growth can be disconnected. This may be a short term phenomenon because much water has been freed up by water conservation practices. Such efforts cannot go on indefinitely because there are ultimately minimum quantities of water that must be devoted to agricultural and urban activities if they are to continue at all. Nevertheless, even if limited to the short term water can be freed up through conservation to serve population and economic growth as well as existing activities.

8. Water Governance. Effective water governance is essential if scarcity is to be addressed. Such governance is inadequate in virtually every setting in Africa and the Americas. Where it does exist it relates to current circumstances and lacks the flexibility to respond to future conditions that are likely to be far more constraining and challenging than those of today. Therefore, it is essential that appropriate water governance institutions are established to ensure that flexible and adaptive water policies are devised and implemented.

PART I

WATER SCARCITY: PRINCIPLES AND PROBLEMS

I. Introduction

The term "water scarcity" is widely used but its meaning varies and is subject to ambiguity. The debates about water scarcity and how to define it are relevant for policy decisions. There is no commonly accepted definition of the term and its use in one report may refer to something quite different than the use of the same term in another report. This creates confusion and leads to different, and often inconsistent, policies and management proposals. In a broad sense water scarcity will depend upon: a) hydrologic availability over time and space; b) water quality; c) whether return flows are considered at a basin scale: d) municipal, industrial, agricultural and other demands; and e) whether the needs for environmental water are taken into account.

II. The Problem of Definition: Principles and Concepts

The failure to specify clearly the definition of water scarcity is only the initial part of the problem of comprehensively addressing the meaning of the term. An additional, but equally important part of the problem relates to the selection of the method of assessing water scarcity. This is crucial since different indicators capture different parameters of water scarcity and none captures all parameters. The selection of metrics will depend upon whether they are needed to characterize: 1) quantitative features of water scarcity; 2) the scale of the area to be considered, whether local or basin-wide and 3) the time period to be considered, whether daily, monthly or annually. In addition to the many different ways of defining water scarcity, there are also many parameters that can be used to assess water scarcity. Thus, both the manner in which water scarcity is defined and measured will influence the conclusions drawn. Consequently, it is possible that two assessments of the same situation may complicate the policy decision-making process. Ideally, a fully satisfactory expression of water scarcity would embody measures of water availability (supply, adjusted for the quality and the timing of availability) measures of use (demand adjusted for whether the use is consumptive or not and for the timing of it). In reality, such a hypothetical measure is virtually impossible to achieve because of the absence of adequate data or the cost of acquiring adequate data. The result is that virtually all measures are approximations or rely on assumptions that may or may not approximate reality. The definitions discussed below either fail to include both elements of supply and demand or are inadequate because of the absence of data.

A. Physical Definitions of Scarcity

Physical definitions usually express scarcity and the intensity of scarcity in terms of well defined physical metrics. An example is the Falkenmark Index in which different levels of water availability are defined based on estimates of water uses in different sectors (Gleick, 2003). Another example is the work of Shiklomanov (1998) and his colleagues Vorosmarty, et.al. (2000)who arrived at measures of scarcity by examining total annual water withdrawals as a percent of available water resources (Shiklomanov, 1998).

1. Falkenmark Water Stress Index. Water scarcity is defined in terms of the relationship between water availability and human populations. It is expressed as water available per capita and measured on a national basis. The metric definitions are: >1700 m^3/capita/yr = water stress is either absent or infrequent; <1700 m^3 - >1001 m^3/capita/yr = water stress appears regularly; <1000 m^3 - >501 m^3/capita/yr = water stress appears regularly and water scarcity limits economic, human health and human welfare; <500m^3/capita/yr = water is severely scarce.
Strengths: The data needed to employ this index are generally available. The index is commonly used.
Weaknesses: Water demands are inadequately characterized by simply assuming that each person is using some fixed amount of water each year. Furthermore, it ignores regional and temporal availability of water

supplies. The importance of climatic effects on demand and availability as well as the effectiveness of water management institutions are also ignored (Falkenmark and Lindh, 1976; Falkenmark and Rockstrom, 2004).

2. Ohlsson Social Water Stress. Modifies the Fallkenmark indicator by accounting for the adaptive capacity which is defined as the ability to change through economic, technological and other means.
Strengths: Acknowledges the existence of multiple variables that impact water availability.
Weaknesses: The data requirements are enormous and difficult to organize and analyze.

3. Shiklomanov/Vorosmarty Water Vulnerability Index. This index also measures scarcity in terms of total estimated withdrawals as a percent of available resources but uses are cast in flexible terms rather than fixed values. Shiklomanov defines scarcity as any values falling between 20% and 40% and severe scarcity as any value exceeding 40%. Vorosmarty, et.al analyze demand through the use of climatic models (Shiklomanov, 1998; Vorosmarty, et.al.,2000).
Strengths: Acknowledges that water demands are variable. The use of climatic models is a positive.
Weaknesses: Definitions of scarcity are arbitrary. The causes of variability in water demand are not rigorously specified. Data on availability fail to account for how much water is available for use. Water withdrawal data do not distinguish between consumptive and non-consumptive uses.

4. Water Poverty Index: This index accounts for the physical availability of water together with the extent to which humans are served by that availability and also acknowledges the need for water to maintain the ecological integrity. It considers five dimensions: access to water; water quantity, quality and variability; water uses for domestic, food and productive purposes; capacity for water management; and environmental aspects. It is calculated considering five components (X_i): (1) available water resources; (2) access to water; (3) capacity for water management; (4) water uses for domestic, food and production purposes and (5) environmental concerns, each of which are weighted (w_i),

(1) $$WPI = \frac{\sum_{i=1}^{N} w_i X_i}{\sum_{i=1}^{N} w_i}$$

where

N = the number of time periods (in weeks, months or years)
X_i = the independent variables
w_i = the weights

Strengths: It is comprehensive as it acknowledges the importance of water for the environment and employs multiple variables in calculating water availability. The index is intended to reflect comprehensively the determinants of water scarcity.
Weaknesses: The index is complex and not easily understood. The data required to employ it are not easy to acquire or utilize. It is difficult to estimate due to complexity of accounting for water supply fluctuations and the need to combine very different kinds of information and estimate accurately the weights to be employed in aggregation. Component (1), available water resources, does not, in general, consider temporal variability in water resources which plays a critical role in enabling access to a reliable amount of water. Challenges include objectively normalizing, weighting and aggregating this multi-component metric.

B. Economic and Social Indications of Scarcity

Water is an important scarce resource that is critical to social and economic development. Economists typically define and characterize water scarcity as circumstances of imbalance between freshwater availability and demand where the wants for fresh water exceed its availability. However, economic water scarcity may occur when water is physically available but the lack of effective institutions and infrastructure limit its accessibility. Thus, assessments of whether water is scarce or not require analyses of how much water of a specified quality is needed and how much of that water is available, or can be made available where and when it is needed.

Economic water scarcity is considered to occur in countries where renewable water resources may be satisfactory but where there is a lack of adequate management or significant investments in water infrastructure in order to make these resources available. Effective management of water resources requires the management of both supply and demand. Demand side management treats water as an economic good and relies on tools including: pricing, market exchange, rationing, education and various other schemes of allocating scarce water. Social definitions of scarcity tend to focus on institutions for managing water and the effectiveness of those institutions. They also focus on cultural and social determinants of water demand.

Economic and social water scarcity indices vary in both comprehensiveness and focus and there is no one index that accurately represents complex human-water systems globally. This is because a single index cannot encompass all of the parameters that affect scarcity. It follows that there is no unique economic or social index that is suitable for all regions, uses and populations. Consequently, different indices need to be employed according to the needs and proposed objectives of the assessment in question and understanding the different indices and identifying their strengths and weakness is crucial. Appropriately employed, commonly used economic and social water scarcity indices can be helpful as decision-making tools to aid in selecting optimal water management policies and the mixes of those policies.

1. Economic Scarcity. Economic or allocation efficiency deals with net values generated with limited water resources (Wichelns, 2002; Rosa et al., 2020) this allows for performance comparisons among alternative allocations of water as among different and often competing claimants (Molden, 1997). Value can be expressed as total revenue as specified in equation (2) or net value as defined in equation (3).

(2) $$EP_R = \frac{Revenue}{W_c} = \frac{P*Y}{W_c}$$

where

EP_R = total economic revenue ($)
P = product price ($)
Y = output (quantity)
W_c = water consumption (m^3)

(3) $$EP_\pi = \frac{\pi}{W_c} = \frac{P*Y-C(Y)}{W_c}$$

where

EP_π = net economic revenue
Y = output (quantity)
$C(Y)$ = the cost of producing Y
P = the price of output ($)
Y = output (quantity)
π = net economic revenue ($) (total revenue – total cost)

To avoid biases due to particular conditions such as price spikes, it is suggested to use annual average prices a time series.

Strengths: Incorporates both the elements of supply and demand and simplifies the data acquisition and management problems via abstraction through the use of assumptions in place of data. Economic water productivity (as previously defined) provides a tool to attribute value and productivity to all water uses and users within a hydrological domain. When based on hydrological accounting of actual water consumption, economic water productivity can be attributed to all water uses and reuses, including those that tend to be left unaccounted for in irrigation efficiency approaches as in which uses other than irrigation treated as "wasted fractions."
Weaknesses: Often fails to account for distortions introduced by the failure of markets, including equity issues such as affordability. Frequently neglects important variables that are not priced accurately or at all. Fails to incorporate adequately institutional issues that can lead to artificial scarcity and "institutional drought."

2. Household Water Security Index (HWSI). It is an index that considers all water needs of a household such as domestic, irrigation and other productive purposes. It is estimated by weighting the following components:

2.1 Water resource availability (R): An assessment of a qualitatively adjusted value of the per capita quantitative measure of ground and surface water availability for a household.
2.2 Access to available water (A): Estimates the effort a household exerts to obtain water.
2.3 Purposes and means water used for (C): Reveals the level of human, economic, infrastructure, and technology to contribute to household water security. It considers, for example: frequency of health and hygiene education, morbidity and mortality related to water, household income, access to electricity, and literacy rate of the household head, among others.
2.4 Capacity of household to manage water (U): Estimates the level of water use for various household activities for diversified economy and the economic returns the household earned.
2.5 Ecological integrity of water (E): Assesses water quality and frequency of flood/drought events.
2.6 Organizations and institutions mediating the process of water access and use (I): Estimates people's perception of institutional issues such as conflict resolution capacity, transparency, participation, and trust on water leadership, among others.
Formally, HWSI is calculated as follows:

(4)
$$HWSI = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e}$$

Where $w_i \ (i = r, a, c, u. e)$ represents the weight applied to each component.
Strengths: Integrates different components which affect household water scarcity.

Weaknesses: Differences in units of each component requires normalizing diverse quantitative and qualitative measures into single index or sub-index.

3. International Water Management Institute (IWMI) Measure. IWMI proposes an indicator, based on a water balance approach, to derive estimates of water supply and demand for countries. The estimates are adjusted to take explicit account of return flows and water recycling. This measure accounts for supply as the renewable water resources available for human needs. Demands are based upon consumptive use and all other withdrawals are defined as return flows. Nations are the basic geographical unit. Countries unable to meet estimated water demands by 2025 are called physically water scarce and those with sufficient renewable resources that require investment in infrastructure to make them available to humans are defined as economically water scarce (Rijsberman, 2006; Seckler. et. al. 1998; Seckler, et. al., 2003)

Strengths: Acknowledges that non-consumptive uses do not necessarily deplete the available water resource.
Weaknesses: The complexity of assessment and the lack of date require expert judgement. Data are not, in general, available to evaluate all components of the indicators. Assumes that water which is not consumptively used is available through return flows for reuse. Definitions of the quantity of investment in infrastructure needed to improve water availability are inadequate. Definitions of scarcity are arbitrary. Dependency on national level data underestimates scarcity problems due to regional, inter-annual and seasonal variations in water supplies.

4. Cumulative Abstraction to Demand Ratio—Considering Temporal Variations This index is expressed as the ratio of the cumulated daily water abstractions from rivers to the cumulated daily potential water demand (i.e., consumptive water requirement for agricultural, industrial, and domestic use) for a specific year. Economic water scarcity occurs when the ratio falls below unity.

Strengths: takes hydrological seasonality into consideration, which is often overlooked in the assessments adopting classical physical water scarcity indicators and acknowledges that non consumptive uses do not necessarily deplete the available water resource.
Weaknesses: complexity of assessment and requires expert judgement because data are not, in general, available to evaluate all components of the indicator. Assumes that water which is not consumptively used is available through return flows for reuse. Dependency on national level data underestimates scarcity problems due to regional, inter-annual and seasonal variations in water supplies.

5. Social water stress index (SWSI) applies the Human Development Index (HDI) which considers life expectancy, educational level and GDP per capita as a proxy for adaptive capacity to water shortages. It is estimated by dividing the number of people in a country that share one million cubic meters of annual renewable water by the HDI

(4) $$SWSI_{country} = \frac{Inverted\ Fallenmark_{country}}{HDI_{country}} * \frac{1}{2}$$

Strengths: considers societal adaptive capacity (defined by HDI).
Weaknesses: HDI includes a narrow selection of variables, several of which are difficult to estimate for low-income countries due to low-quality data.

6. Institutional Definitions. These definitions separate "natural water scarcity" and "adaptive water scarcity". Natural water scarcity occurs through changes in hydrologic processes while adaptive scarcity subsumes various adaptive behaviors that can be expressed through public policies or other institutional means. These definitions refer explicitly to institutions that are in place to alleviate scarcity and the effectiveness of those institutions. They also refer to institutions that are available but not used to attain water management ends in more efficient and or equitable ways (Scoones, et.al, 2014).

Strengths: These definitions often include social, political, cultural factors and technological factors that are neglected by others. The focus on improved management, public policies and other institutional arrangements are not usually present in other definitions.
Weaknesses: Many of the institutional, cultural, social and political factors are difficult to quantify or otherwise specify in terms that can be useful to water managers. Does not always adequately account for circumstances in which areas of consumption and use are separated spatially such that nationally-based data may not capture the realities of scarcity at local levels. Similarly, long-term plans can be confounded by both rapid and long term changes in these variables and by changes in policies.

REFERENCES

Falkenmark, M. and G. Lindh. 1976. Water for a Starving World. Routledge Press (London, England).

Falkenmark, M. and J. Rockstrom. 2004. Balancing Water for Humans and Nature. Earthsccan.

Gleick, P. 2001. Soft Paths: Solution to 21st Century Water Needs. Science. 320. Pp. 1524-1528.

Molden, D. 1997. Accounting for Water Use and Productivity. lwmi. No. 42.

Rijsberman, F. 2006. Water Scarcity: Fact or Fiction. Agricultural Water Management. Vol. 80. Pp. 5-22.

Rosa, L., D. Charelli, M. Rulli, J. Dell'Angelo and P. D'Odorico. 2020. Global Agricultural Water Scarcity. Science Advances 6;eaaz6031. 29 April.

Scoones, I., R. Smalley, R. Hall and D. Tsikata. 2014. Narratives of Scarcity: Understanding the Global Resource Grab (Athens, GA: University of Georgia Press).

Seckler, D., O. Atmasinghe, D. Molden, R. de Silva and R. Barker. 1998. World Water Demand and Supply. 1990 to 2005: Scenarios and Issues. IWMI Research Report 19. Colombo, Sri Lanka.

Seckler, D., D.J. Molden and R. Sakhtivadivel. 2003. The Concept of Efficiency in Water Resources Management in J.W.Kline, R. Barker and D.J. Modlen, Eds. Water Productivity in Agriculture: Limits and Opportunities for Improvement, CABI. Wallingford, UK. Pp. 37-51.

Shiklomanov, I. A. 1998. World Water Resources: An Appraisal for the 21st Century. IHP Report, UNESCO Paris, France.

Vorosmarty, C.J., P. Green, J. Salisbury and . B. Lammers. 2000. Global Water Resources: Vulnerability From Climate Change and Population Growth. Science. 289. Pp. 284-288.

Wichelns, D. 2002. An Economic Perspective on Potential Gains from Improvements in Irrigation Water Water Management. Agricultural Water Management. Vol. 52. Pp. 233-248.

III. Critical Factors Affecting Water Scarcity

There are several variables that influence the ways in which water scarcity is defined and measured and which also may influence the interpretation of various measures of water scarcity. These are listed below together with some elaborating discussion.

1. Availability of water resources. Water supply in the form of precipitation varies significantly in the world. The general circulation of the atmosphere is an important, albeit not the only, determinant of precipitation on the planet. As a result of this circulation, the amount of precipitation is highly dependent on latitude. In tropical latitudes the highest absolute precipitations and the warmest temperatures in the globe are generally registered. The bounds of these circumstances are delimited by the imaginary lines of the Tropic of Cancer in the Northern Hemisphere at 23°27′ N and the Tropic of Capricorn in the Southern Hemisphere at 23°27′ S. This is especially true in latitudes closer to the Equator (known as equatorial regions). However, near the latitudes of the tropical lines in both hemispheres (and close to 30° N and 30° S) there are also zones of high atmospheric subsidence (sinking of air masses) associated with the atmospheric circulation, which inhibits cloud formation and precipitation, resulting in regions with the driest desserts on Earth. For many years, middle-latitudes (located approximately between 35° N and S and the polar circles at approximately at 60° N and S) climates were referred to as climates of the temperate zone. This proves a definitive misnomer, for while the zone contains some of the most equable of climates, it also has some of the most extreme (Giles, 2006). These regions experience a great amount of cyclonic activity. Finally, polar latitudes are generally dry, as cold atmospheres cannot hold much water. Besides the influence of these general atmospheric circulation patterns, there are other factors that control precipitation, such as: distance to the coast (continentality), air mass lifting by mountains that cause high precipitation in the windward face of the mountain, and dry conditions in the leeward face, oceanic currents, land use in the surface and others. Ideally, efforts to index scarcity require that these climatic factors be contrasted with the size of the population demanding the resource. Usually, this is done by dividing the average supply of water from surface and groundwater sources that are renewable each year and by the number of inhabitants of the country. The result is commonly known as the renewable water resources per capita (RWRc). This number will vary signifiantly by country as seen from the estimates of Vargas-Barrantes and Main-Alfaro (2016) for Israel (97 m^3/inh/year, Mexico (3500 m^3/inh/year) and the United States (9000 m^3/inh/year) respectively.

2. Demands for water resources. Demands for water resources can be categorized as non-consumptive or consumptive use. With consumptive uses the water is either transformed from a liquid to a gas or degraded in quality to the point where it is not suitable for other uses. Consumptive uses are defined as uses that make the water unavailable for subsequent use or reuse. By contrast non-consumptive uses are uses of water in which the fundamental properties of the resource remain unimpaired and the water is available for subsequent use or reuse. Non-consumptive uses entail the existence of return flows that run-off to surface water bodies from which they are available for reuse. Waters that deep percolate to underlying aquifers (without significant degradation of quality) constitute an important component of ground water recharge.

Typically, consumptive water demands are categorized in terms of the ultimate use whether industrial, agricultural, domestic or municipal. Figure 1 shows global fresh water use over time since 1900. Virtually all of this use (withdrawals) is consumptive use. Examples of non-consumptive use include navigation, provision of wildlife and fish habitat and environmental amenity uses. There are some uses with characteristics of both consumptive and non-consumptive characteristics. The use of water for industrial cooling purposes is one example.

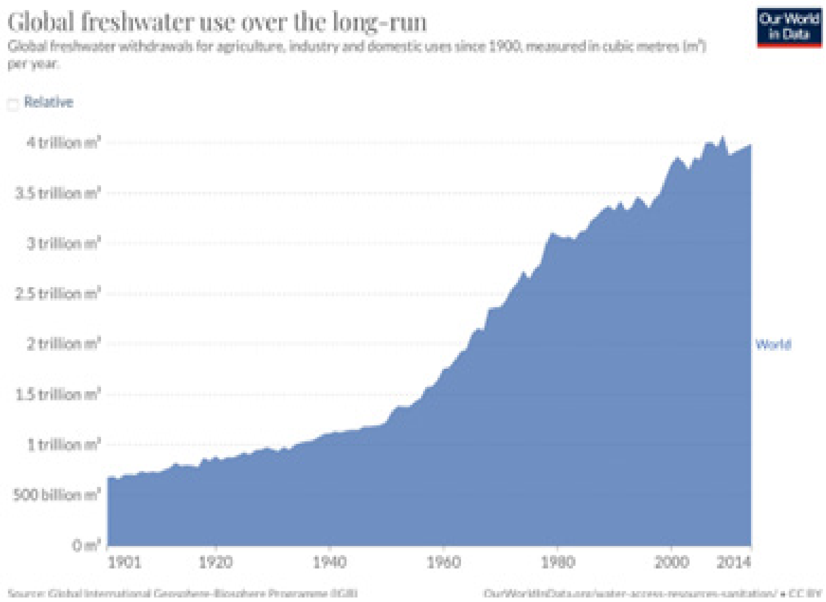

Figure 1. Global Freshwater Use (Our World in Data. https://ourworldindata.org/water-use-stress)

3. Water Balances. A water balance is computed for a watershed, hydrologic basin or other spatially defined area. It is the difference between the quantity of the water input (for example precipitation) and the quantity of the water output (for example evapotranspiration or runoff). Usually, the changes between inputs and outputs are equal to the change in water storage inside the system. Over long time periods – more than a year, for example, the change in the storage can be assumed to be negligible and the balance would have a small closure error. Water balances are usually computed using empirical hydrological data and can be used to verify that closure error is small. Where this is true the quantities of water leaving the basin can be defined as the quantity available to serve new human and environmental demands. A comparison of the availability of water and the potential demands for it can then be interpreted as a measure of the existing scarcity levels in the region, watershed or country in question.

4. Stocks and Flows. With fresh surface waters and recharging ground waters different units become available for use in different time periods. With ground waters that do not recharge the volume of the resource is fixed and the problem of use is identical to that of minerals and other stock resources. Any use of stock resources depletes the stock and by definition increases the intensity of scarcity of resources in the stock. With flow resources it is necessary to separate consumptive and non-consumptive uses since non- consumptive uses are not depleted unless they are qualitatively degraded.

5. Water Quality. Degradation of water quality from both natural and human causes can reduce the availability of water for certain uses, and in the worst cases, for all uses. Thus, return flows that might otherwise be available for reuse used can made unavailable for reuse by virtue of qualitative degradations. In those instances upstream uses that cause such degradations would be considered to be consumptive. Whether that occurs and the extent to which it occurs will depend upon the degree of qualitative degradation and the use to which the return flow would be put. In principle, improvements in water quality of both stocks and flows can attenuate scarcity while qualitative degradation intensifies scarcity. Water quality can be difficult to define because there are a multiplicity of variables, physical, chemical and biological, that affect and determine quality.

6. Seasonality and Interannual climate variability and change (time-scales). The availability of water is frequently determined by timing. Time can be important both inter-annually, as with dry years and wet years, with seasonality and with locales that have wet seasons and dry seasons. For example, the El Nino and Monsoon southern oscillations (as well as other large scale climatic phenomena) have clear influences on atmospheric temperature, humidity and precipitation. Year to year natural variability and anthropogenic climate change also significantly influence the availability of water in many regions of the world and can be the cause of severe and sustained drought as well as increases in the aridity (due to global warming). Thus, measures of water scarcity can vary from year to year or within years depending upon the patterns of rainfall and other sources of fresh supply. This means that any measure of water scarcity must of necessity be expressed in terms of the relevant time frames. Scarcity is commonly expressed in annual terms but this may mask periods of extreme water stress as between wet seasons and dry seasons in places where there is a two season climate. There are regions of the world where the rainy season accumulations are relatively high, but with extensive dry seasons when precipitation is rare. This imposes a challenge for the management of water resources in these regions. Dams and canals can be developed to capture water in wet times and places and transported to drier places and/or in drier times.

7. Spatial Considerations. As mentioned before, the availability of water may vary over different spaces as illustrated by precipitation differences between the windward and leeward sides of mountain ranges. Similarly, the availability of water will vary from river basin to river basin and within river basins depending upon the geographic and hydrologic characteristics of the basin in question. It is very important to be clear about the geographical basis of any measure of scarcity. Commonly such measures are applied to nations whose boundaries do not necessarily conform to the pertinent hydrologic boundaries. Measures of scarcity which are locally based may erroneously count run off waters as consumptive because they are lost to the local users. However, subsequent reuse of those waters is possible by other occupants of the river basin in question and can be captured, stored and transported through man-made geographical modifications such as dams. artificial lakes and canals.

REFERENCES

Giles, B. 2006. Middle-Latitude Climates. In: the Global Climate System Patterns, Processes, and Teleconnections 2006. H.A. Bridgman and J.E. Oliver editors. Cambridge University Press. pp. 96 - 130 DOI: https://doi.org/10.1017/CBO9780511817984.005

Vargas-Barrantes, E. and A. Marín-Alfaro, A. 2016. Costa Rica demanda una gestión integral del recurso hídrico: escenario latinoamericano y la realidad país. InterSedes. 17 (35): 1-18. In Spanish.

IV. Scarcity-related Concepts and Terminology

1. Aridity. State or quality of being without sufficient moisture; parched; dry; barren. It is a numerical indicator of the degree of climate dryness at a given location. It is usually defined as the ratio between precipitation (P) and potential evapotranspiration (PET) as in: A = P/PET. The term is sometimes used to describe areas or regions without sufficient precipitation to support agriculture in the absence of irrigation and is often employed to describe situations in which water is limited or unavailable because of climate. The term is useful as a general descriptor but by itself, lacks reference to metrics or standards that would describe aridity precisely. In most uses it does not, by implication, include water use or consumption in any systematic way though high rates of evapotranspiration are frequently present in arid environments.

2. Water needs. This term is frequently employed to describe water demands. It implies, however, that demands are fixed, urgent and not responsive to price or other variables. The term "water requirements" suffers from the same shortcomings. Typical scientific use of such terms is restricted to the quantities of water that are physiologically imperative for survival.

3. Seasonal Scarcity. In many regions annual precipitation is sufficient or more than sufficient to meet annual demands for use but the occurrence of precipitation is compressed into one or more periods. In these circumstances water scarcity may prevail in "dry seasons or times" but not over longer periods.

4. Environmental Water Scarcity. Such scarcity occurs when water diverted to agriculture, industry and municipal uses such that there is insufficient water remaining to meet the needs of plants, animals and other elements within ecosystems.

5. Irrigation Efficiency. Term used to express, in either physical or economic terms, water used consumptively in irrigation as a proportion of water applied on a field by field basis. It expresses the relationship between the water applied and the proportion of it that is productively utilized by the crop in question. At its simplest this efficiency can be defined as evapotranspiration (from crops and surface evaporation) divided by the quantities of applied water. The term can be expressed in economic terms by examining the price of water and the monetized increment to crop value as a result of irrigation.

6. Basin-wide irrigation efficiency. When irrigation efficiency is measured on a field by field basis there is danger that some water will be counted as consumed by plants when in fact some portion of it may be available for reuse. Water that runs-off the surface of an irrigated field may be available for use downstream and water lost" to percolation that recharges ground water may also be available for reuse. Basin-wide irrigation efficiencies account for waters that can be reused within the basin. They are defined as "consumed" or unavailable for reuse only when they leave the basin or percolate beyond the depths of economically recoverable ground water. It is also important to account for the fact that some waters "lost" to a basin may be captured, stored and transported through man-made geographical modifications such as dams, artificial lakes and canals, thereby becoming available for subsequent use.

7. Water productivity. Water productivity is defined as the ratio between an output linked to a use and a water volume input. It provides a measure of the contribution of water to the product. It is usually expressed in terms of the dollar value of the product or output divided by the dollar value of the water used to generate the product.

8. Economic or allocation efficiency. It refers to the fashion in which resources or other inputs are distributed among alternative uses. Efficient allocation entails the distribution of the resource in way that maximizes the net social benefits for society. When expressed in monetary terms it characterizes the value of of water in alternative uses. Possibilities for improving economic or allocative efficiency include economic instruments and governance arrangements, such as water markets and water rights reallocation, leading to a higher benefit from the use of the available resources. Allocative efficiency concepts have often been applied to municipal/industrial, agricultural and other measurable anthropomorphic uses. Environmental water scarcity refers to the deprivation of water that results from efforts to divert for other uses supplies that are or were previously used in the natural environment. Intensifying water scarcity is often ignored because environmental uses are difficult to define and monetize. Research seeking to value environmental uses suggests that such values may be quite high.

PART II

WATER SCARCITY IN THE AMERICAS AND AFRICA: AN OVERVIEW

The North American Region

Overview

The North American region includes three countries: Canada, Mexico and the United States. As shown in Figure 2, all three are bordered on the west by the Pacific Ocean while in the east Canada and the United States are bordered by the Atlantic Ocean with Mexico bordered by the Caribbean Sea and the Gulf of Mexico. In terms of land area these three nations are among the largest in the Americas with land areas ranging from 9.2 million km² for the United States, 8.9 for Canada and 1.96 million km² for Mexico. In terms of population in 2022 the U.S. is the largest with a population of 337,341,959 followed by Mexico with 129,150,972 and Canada with 38,232,593. The economies of the three countries are generally strong. The U.S. and Canada are well developed with gross domestic products per capita of $US63,359 and $US43, 295 respectively. For Mexico the per capita gross domestic product is $US8,404 and developing rapidly (Central Intelligence Agency, 2020) All three of these countries are faced with intensifying water scarcity as the economies and populations grow. In fact, the management of water scarcity will be among the significant challenges faced by each country in the coming decades and climate change will undoubtedly intensify scarcity related problems.

Figure 2: Map of North America

As would be expected of nations of this size the landscapes and climates of all three are quite variable as among regions and locales. Average annual precipitation is 758 mm/yr for Mexico, 715mm/yr for the U.S. and 537 mm/yr for Canada (World Bank Group, 2020). These figures mask significant variations with time - climates with wet and dry seasons -and space – climates that vary from arid, desert climates to lush, tropical climates. Canada has the second largest per capita water endowment of any country in the world but this is deceptive because 90% of the water flows to the north while 90% of the population lives in the south within 100 miles of the U.S. Canadian border (Hipel, Miall and Smith, 2013). By contrast, 77% of the Mexican population is in the northern, north central and northwestern regions which have only 31% of the water supply. Not coincidently, these latter regions account for 87% of the country's gross domestic product (Dominguez, et al., 2013). The precipitation variability in the U.S. varies along a gradient from just outside the western coastal zones to the 100th meridian. Precipitation to the west of that meridian is generally less than 510 mm annually while to the east it is greater than that figure. There is evidence suggesting that the demarcation line is moving eastward as a result of climate change (Seager, et al., 2018)

Recent decades have seen significant internal migration from the more humid east to the arid west (particularly western urban areas) thereby imposing additional stress on already scarce western water supplies (U.S. Geological Survey, 2022). The tendency, present in all three countries, for disproportionate levels of population and economic activity to be located in drier areas makes problems of water scarcity relatively more serious than they would be if population size and economic activity were more tailored to water availability. The impacts of changing climate on precipitation and water supplies are not perfectly clear but available knowledge suggests that levels of precipitation may be reduced in certain regions and that more extreme climatic events will increase in frequency.

Ground Water

All three countries rely on surface water for the majority of their water supplies. However, ground water constitutes an important additional source, accounting for 36% of total supply in Mexico, (Commission Nacional del Agua, 2018), 22% in the U.S. (Vaux, 2013) and around 5% in Canada (Hipel, Miall and Smith, 2013). Even where ground water is a small proportion of total supply it is an important source for several reasons. First, as water scarcity intensifies and additional supplies are sought previously untapped ground water maybe the only available source of additional supply. Second, the availability of ground waters that are recharged tends to be less affected by drought since declines in recharge require time to manifest themselves and on many occasions do not appear until late in the drought period or after the drought is over. The impact of drought on ground water availability is buffered over time. Third, even though groundwater may represent a small percentage of the total, it may serve very important uses. Thus, for example over 30% of the population of Canada relies on ground water as the sole source of their drinking water (Environment Canada, 2020). These three facts assume even more importance in the U.S. and Mexico where ground water is a more significant source of supply. Ground water resources are frequently subject to two different sorts of threats.

Ground water can be classified as either a stock resource or a flow resource depending upon the rates of recharge. In the first case, there is no recharge and all extractive uses are depleting in much the same way that mineral resources are depleted by mining. Water quantities can only be conserved through non-use. By contrast, where recharge occurs different units become available in different time periods and the status of the resource depends upon the balance between extractions and recharge. . Ground water overdraft occurs when extractions exceed recharge. Persistent overdraft results in declining water tables. In these circumstances more energy is required to lift the water from greater depths so that the costs of capture increase. Ultimately, this leads to de facto depletion of the resource - also frequently called economic depletion. In the extreme, the resource can be physically depleted and no longer available. Persistent over draft leads to economic or physical depletion while uncorrected periodic overdraft leads toward economic exhaustion and shortens the life of the aquifer from what is economically optimal. Over drafting of ground water, particularly when it is pumped in an individualistically competitive fashion, is the first of two threats to the resources. The second threat relates to the quality of the ground water. There are circumstances under which ground water salinates "naturally" as salts in the adjacent substrate dissolve. More importantly, improper disposal of contaminants on or below the surface may lead to their migration into and contamination of nearby ground waters. While it is possible to cleanse contaminated ground waters (pump and treat is one technique) the evidence almost always shows that it is cheaper to prevent ground water contamination than it is to clean it up once contamination has occurred. There are management tools available that are capable of addressing both threats. Damaging overdraft can be averted by employing pumping taxes or through command and control measures which impose pumping quotas on interconnected ground water extractors. Both of these techniques require oversight and enforcement regimes which can be expensive (Vaux, 2011). Ground water is an important source of supply in all three countries and the failure to manage ground waters in ways that are both hydrologically and economically sound can intensify water scarcity.

Water Use and Water Infrastructure

Arrayed against the available ground and surface water supplies are the uses that those supplies serve. Consumptive use by sector for the three countries is displayed in Table 1. Several features stand out. 1) The largest consumptive use in each country is for agriculture. This is to be expected in a region where there are significant areas where precipitation is inadequate or seasonal in nature such that irrigation is necessary to ensure and enhance agricultural productivity. 2) Municipal and industrial uses account for about a quarter of consumptive use in Canada and the U.S. The proportion of this use is somewhat lower in Mexico. A large majority of the core urban population has access to safe and healthful water though some suburban and peri urban areas are exceptions. 3) Canada is unique in that consumptive uses associated with hydroelectric and thermal electric generation and for mining and oil and gas production are proportionately large.

TABLE 1
PATTERNS OF CONSUMPTIVE USE IN NORTH AMERICA
(percent of total consumptive use)

Sector	CANADA	MEXICO	USA
Agriculture	44.2	77.0	59.6
Municipal & Industrial	25.95	18.0	28.7
Power Generation	11.0	5.0	4.9
Oil, Gas & Mining	18.85	-	--
Other	3.0	-	6.8

Source: Diagnosis of the Waters of the Americas, 2013

In Canada total water usage is generally balanced with available supplies, and while there are exceptions in the west, ground water overdraft is infrequent. In contrast, there are significant regions of both the United States and Mexico where ground water overdraft is significant and cannot be sustained indefinitely. Developing and implementing effective ground water management schemes will be a critically important in managing scarcity. Persistent overdraft ultimately increases water scarcity at some time in the future. All three countries face growing demands for water as population increases and as economic activity grows and the mix of industries changes. Demands for additional water supplies will occur during periods when there is a likelihood that supplies will remain static or decline. Periods of drought and more intensive drought may become the rule in the future. There is some indication of a prolonged drought in progress in the western U.S. and in northern Mexico. There is a high likelihood that water scarcity will intensify throughout the region in the future and declines in ground water availability will make scarcity more intense than it would be otherwise (Vaux, 2011).

Traditionally, construction of water storage and conveyance facilities, drinking water treatment plants and wastewater treatments plants has been a central response to water scarcity. Today, the adequacy of the resulting infrastructure presents a mixed picture. The most complete and up-to-date water related infrastructure is found in Canada. However, issues remain there. Water related infrastructure supporting indigenous people in indigenous communities is severely lacking and some long term problems of urban flooding and the provision of adequate sanitation are only belatedly being addressed. Long term water supply issues loom, particularly in the west, and are likely to worsen in the face of climate change. Nevertheless, most Canadians have access to healthy drinking water supplies and adequate sanitation. While most of the existing water infrastructure problems are attracting appropriate attention (Hipel, Miall and Smith, 2013), the development of adequate, reliable supplies for indigenous peoples remains a problem.

By contrast the United States can be characterized by the "water paradox of developed nations." At present, virtually the entire U.S. population has access to safe drinking water and adequate sanitation services but the future is characterized by water-related infrastructure problems more typical of countries that lack comprehensive drinking water and sanitation services. Water supply and sanitation infrastructure is aging and there are few plans or financial commitments to replace and or rehabilitate decaying and outmoded facilities (Venkatarman, 2013). Water scarcity grows in response to urban population and economic growth and some existing supplies are declining or unreliable. In addition, many of the available sources are fully allocated so the possibilities for developing new, remote supplies have been essentially exhausted. The specter of climate change makes these circumstances worse. Moreover, where uncommitted supplies do exist, they are very costly to develop and may serve to distract from the need to upgrade existing facilities that have been subject to significant periods of neglect and become increasingly costly maintain in the absence of modernization efforts. Consumers are increasingly unwilling to pay these additional costs and the political leadership needed to educate people about the facts of inadequate water and other infrastructure is absent. The picture that emerges is surprising for a wealthy country (Venkatarman, 2013).

The water infrastructure situation in Mexico is similarly mixed. More than 95% of residents who occupy the core of major urban areas have access to safe drinking water and adequate sanitation. However, residents of peri-urban areas and rural areas do not typically have anything like this level of access. Wastewater treatment facilities nation-wide are not adequate. Many existing facilities in urban areas are old and in need of rehabilitation. In rural areas municipal wastewater treatment is often absent or inadequate and this is also the case for industrial waste waters and, in some instances, wastewaters from irrigated agriculture and agricultural processing facilities. The picture that emerges is that additional investment in wastewater treatment infrastructure is badly needed as are programs of modernization and rehabilitation of many existing facilities. In addition, the areal and demographic coverage provided by existing infrastructure both for the treatment of waste water and to provide healthful water supplies to significant segments of the population is inadequate and significant expansion to unserved and underserved areas is badly needed (Dominguez, et al., 2013; IANAS, 2019).

As a region, North America is better off economically and developmentally than the other regions of the Americas. Yet, throughout much of the region including both the United States, Mexico and some parts of Canada infrastructure for the provision and treatment of water exhibits many of the same characteristics as the water infrastructure in other, less fortunate regions. This means that throughout the region the availability of healthful drinking water is scarcer than it would be otherwise. In addition, the qualitative degradation of water diminishes the availability of it for many uses. Finally, the reliability of water provision and water treatment services is less than satisfactory because there are periods when the services are not available at all or must be substituted for by relying on more costly alternatives. All of these factors combine to accentuate water scarcity no matter how it is defined (IANAS, 2019).

Major Water Scarcity Problems of the Region

With few exceptions water scarcity is pervasive throughout the North American region. It is especially so in large portions of the western areas of Canada and the U.S. and in the north and north central portions of Mexico. It is also present in the moister middle and eastern portions of Canada and the U.S, and in the southern portions of Mexico. Moreover, climate change, population growth and economic growth combined are likely to make water scarcity more intense throughout the region in the coming decades. There are numerous problems of water scarcity both throughout and within the region. Three standout and they are addressed below.

1. Managing Water Scarcity. The problem of managing scarcity remains either partially solved or unsolved everywhere in the region. Historically, the most common approach has been to develop additional supplies in response to growth in demand. Frequently, this has involved the construction of large impoundment facilities to capture water supplies in wet places and canals to transport those supplies to dry places where they are used. Supply augmentation strategies are today significantly less viable than they were historically for several reasons. In many areas available supplies have already been spoken for and those that remain available, if any, tend to be unreliable. The costs of new supplies have also risen for technical reasons and because of competition for funds. It is true that seawater conversion is a potential source in coastal zones but high costs and prospective environmental damages constrain most opportunities (NRC, 2013). The near-exclusive focus on supply augmentation opportunities has resulted in the relative neglect of options that focus on restraining demand. One obvious means is by pricing water at a level approximating its true economic value and avoiding gimmicks that reduce costs but signal that water is less expensive (and less scarce) than it is in actuality. Educating people about the origins of their water supplies and the costs of acquiring them has been shown to restrain collective demands in some areas. Water rationing has also been shown as an effective way to restrain demand, though its effectiveness appears limited to short term situations such as drought. Command and control regimes entailing rules and laws require enforcement that can be expensive. They also tend to be inflexible which is a consideration in areas where uses and circumstances of use vary. Ground water is infrequently managed effectively and overdraft is persistent in many areas despite the importance of ground water in dry areas and as a supplement to surface supplies. Failure to manage ground water well will inevitably lead to physical and/or economic exhaustion of individual ground water bodies (aquifer) and will result in intensified water scarcity. Devising and adopting policies that facilitate the management of water scarcity, including ground water scarcity, will be essential if the water resources of the region are to be protected and maintained.

2. Protection and Enhancement of Water Quality. With very few exceptions water quality is being degraded throughout the North American region. Degradation of water quality almost always results in water that is less suitable for uses to which it could have previously been put. Qualitative degradation of water intensifies scarcity as surely as drought. The number of water contaminants and their sources are numerous. The first imperative of an adequate strategy for managing water quality is an accurate and comprehensive monitoring system. Monitoring is essential if water quality problems are to be identified and for the evaluation of prevention and clean-up efforts. The monitoring efforts of all three countries within the region are far below what is required to support water quality protection programs that are effective. Second, ground water pollution poses special problems both because activities that lead to such pollution can be difficult to detect, the impacts of such activities on ground water quality may not appear for many years and because available research indicates that prevention of ground water contamination is almost always less expensive than clean-up once the contamination has occurred. Third, diffuse sources resist conventional source control efforts because they are diffuse. Yet, pollutants from diffuse sources such as such as sediments from disturbed landscapes, pesticide and fertilizer residues from agriculture and contaminants in drainage waters from abandoned mines are frequently major contaminants of both surface and ground water throughout the region. The means of controlling diffuse or non-point source pollution must be identified and implemented on a broad scale. Fourth, new chemicals are introduced into the environment at rates much greater than the rates at which they can be evaluated for their impacts on health, safety and the environment. Efforts must be made to accelerate the evaluation of such "contaminants of concern" and, where justified, programs to control or eliminate, if necessary, these contaminants must be adopted. The protection and enhancement of water quality represents a key challenge in any effort to address the consequences of water scarcity.

3. Water Governance. Institutions and arrangements for managing water resources are frequently absent, inadequate or outdated. Broadly speaking, all three countries within the region are organized as republics with mixed free enterprise systems in which private and public (governmental) activities co-exist. A significant and common problem within all three is the lack of clarity over how responsibilities for water resources are allocated between the national and the state/provincial governments. In Canada, there is a long history of confusion and conflict over whether the management of water quality rests with national or provincial governments. One consequence is that protection of water quality is done with guidelines and objectives that are not enforceable. In the United States, consumptive uses of water generally fall within the purview of the States while instream, non-consumptive uses rest with the national government. Many state laws governing water allocation were enacted in a different era and need modification to allow for more flexibility in addressing intensifying water scarcity. In Mexico, portions of the country are without water quality regulations with resulting contamination of ground and surface waters. The problems of water scarcity, including declining water quality, appear to require substantial reform to establish clear policies and regulations appropriate for surface waters. Ground water contamination is widespread in all countries and yet there are no effective national policies focused on managing such contamination. There are numerous other issues that require attention and reform. Among them are issues of transparency of and access to the processes of policy making. Environmental justice is rarely considered and environmental uses of water are frequently neglected. Identifying and implementing the governance reforms needed to address water scarcity seems the biggest challenge of all.

REFERENCES

Comision Nacional del Agua. 2018. Estadisticas del Agua en Mexico. Edicion 2016 (Ciudad de Mexico: Government of Mexico. 56-58.

Council of Canadian Academies (CCA). 2009. Sustainable Management of Groundwater in Canada (CCA: Ottawa).

Dominguez, R. et al. 2013. Water Resources in Mexico: Situation and Prospects. In B.l.Jimenez-Cisneros and J. Galiza-Tundisi, eds. Diagnosis of Water in the Americas. InterAmerican Network of Academies of Science (Mexico City: Mexico).

Environment Canada. 2020. Water and the Environment. https://www.canada.cu/en/environment-climate-change/services/water-overview-htm.

Hipel, K., A. Miall and D. Smith. 2013. Water Resources in Canada: A Strategic View Point. In B. Jimenez-Cisneros and J. Galiza-Tundisi, eds. Diagnosis of Water in the Americas. InterAmerican Network of Academies of Science (Mexico City: Mexico)

InterAmerican Network of Academies of Science (IANASA). 2019. Water Quality in the Americas: Risks and Opportunities. IANAS (Mexico City, Mexico).

National Research Council. 2013. Desalination: A National Perspective (Washington, D.C.: The National Academy Press).

Seager, R., N. Lis, J. Feldman and M. Ting. 2018. The Once and Future Physical and Human Geography of America's Arid-Humid Divide. Part 1: The Story So Far. Earth Interactions, Vol. 22, No. 5. 1-22.

U.S. Geological Survey. 2022. U.S.G.S. Water Data for USA. URL: http://waterdata.usgs.gov/nwis

Vaux, H. 2011. Groundwater Under Stress: The Importance of Management. Environmental Earth Sciences. Vol.62. pp. 19-23. DOI https://doi.org/101007/s12665-010-0490-x

Vaux, H., Jr. 2013. The Water Resources of the United States and Their Management in B. Jimenez-Cisneros and J. Galiza-Tundisi. Eds/ Diagnosis of Water in the Americas. IANAS (Mexico City, Mexico)

Vaux, H., K. Vammen, N. Bernex, J. Fabrego, M. Forde and M.L. Torregrosa. 2020. The Challenge of Managing the Urban Waters of the Americas. Environment: Science and Policy for Sustainable Development. Vol. 62. No. 2 14-29. DOI: 10.10800/0011391157.2020.1708170

Ventkatarman, B. 2013. Access to Safe Water: A Paradox in Developed Nations. Environment. Vol. 55. No. 4. July/August. Pp. 24-34

The Caribbean Region

Overview

The Caribbean Region is comprised of both insular and continental states that are proximately situated in the Atlantic Ocean between the North and South American continents. The combined area of the Caribbean Sea and the Gulf of Mexico is approximately 5,326,000 km² (UNEP 2008). While Belize, Guyana, and Suriname are continental countries, for political and historical reasons they are considered part of the Caribbean and classified by the United Nations as being integral members of one of three geographical regions in the world as Small Island Developing States (SIDS)(Figure 2).

This classification serves to identify the unique social, economic, and environmental vulnerabilities Caribbean countries experience and contextualizes the range of solutions that can be taken to address any weaknesses found.

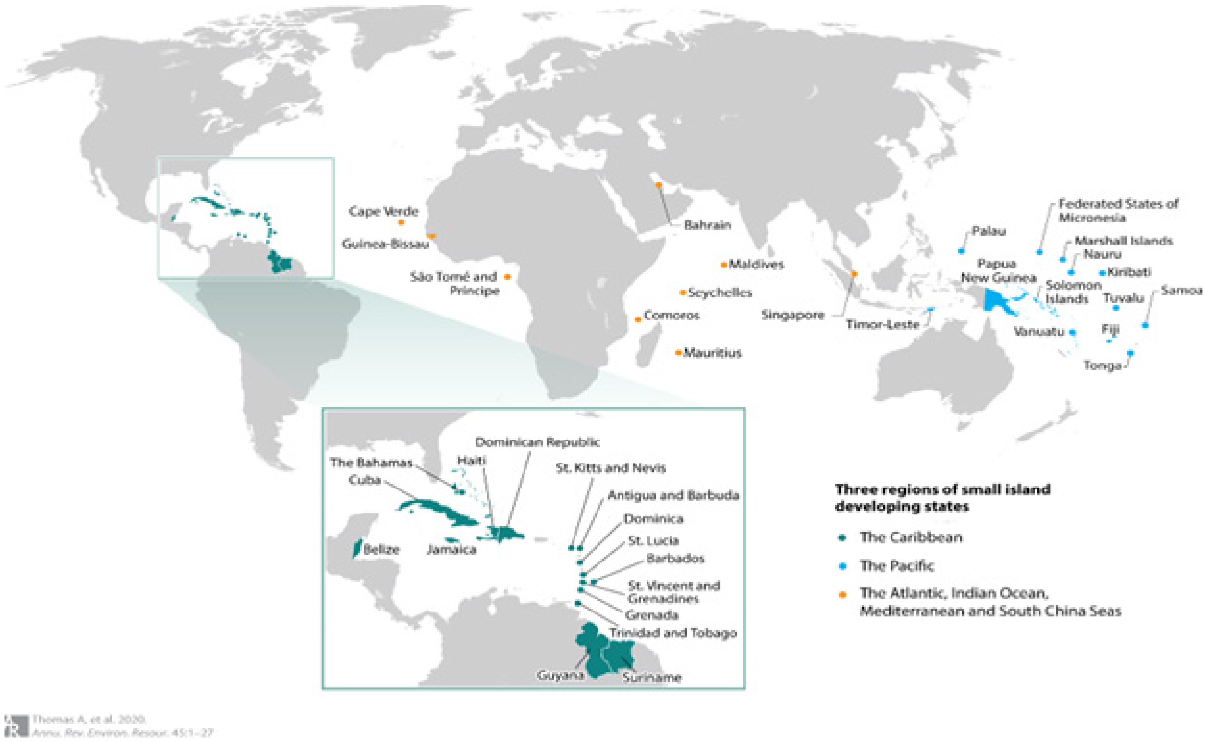

Figure 3: Map of Caribbean Small Island Developing States (SIDS) Thomas, et al, 2020

The countries considered as part of the Caribbean region can be grouped into several subgroups: the coastal continental Caribbean countries (Belize, Guyana, Suriname), the Bahamas, the Greater Antilles (Cuba, Hispaniola, Puerto Rico, Jamaica, and the Cayman Islands) and the Lesser Antilles which can be further subdivided into the Leeward Islands (U.S. Virgins islands in the North all the way down to Dominica in the South) and the Windward Islands (St. Lucia, St. Vincent and the Grenadines, Barbados, Grenada), and the Southern Offshore Islands (Aruba, Bonaire, Curacao, Trinidad and Tobago) (Figure 3).

Figure 4: Map of the Caribbean Region (Source: Wikipedia)

Geographic Features

The geographical features of Caribbean region are markedly variable both in terms of geologic and topographic landforms. Some, such as the Bahamas and Barbados, are characterized as low-lying only a few meters above sea level, whereas others, such the island of Hispaniola, have mountains that reach up to 3,000 meters in height.

The Bahamas is a low-lying archipelagic state comprised of more than 700 islands, cays, and islets encompassing 470,000 km2 of ocean space. Weathering of coralline deposits has created karstic formations with the result that rainfall run-off infiltrates quickly so that there are no freshwater rivers but instead freshwater lenses that sit on top of more saline waters (GWP 2014).

The islands of the Greater Antilles are geologically and topographically more complex with significant surface and ground water sources. Apart from Antigua, Barbuda, and Barbados, which are geologically primarily composed of coral, most of the Lesser Antillean islands—both Leeward and Windward—are predominantly volcanic and sedimentary in origin and are characterized by steep topographies. These islands also have abundant rivers and streams but no significant ground water resources, except for alluvial aquifers associated with river systems (GWP 2014).

The most significant of the Southern Offshore Islands are Trinidad and Tobago which are considered to be geologically part of South America. The island's topography is a mix of mountains and plains with rivers sourced in the mountains tending to disperse in wetland plain areas which have by and large been drained for development purposes.

Demographics

Both the coastal and insular countries of the Caribbean are characterized as having heterogeneous mixes of ethnicities, languages, and cultures which are reflections of their colonial and political histories. Population sizes vary markedly with the small islands inhabited with populations that are typically less than 100,000. In contrast the larger islands such as Cuba and the island of Hispaniola, which hosts the states of Haiti and the Dominican Republic, alone have a combined population of over 31 million inhabitants, 73% of the 44.9 million persons who live in the entire region.

The population in the Caribbean region has grown from 17 million in 1950 to now almost 45 million in 2022 and together with Latin America, the region has been classified as being one of the most urbanized locations on the planet. Rapid and ongoing urban development presents significant challenges to Caribbean governments, from delivering potable water to densely populated communities while simultaneously addressing stormwater and wastewater problems typical of urban environments (GWP, 2014).

Governance

While the term 'Caribbean region' provides a useful and convenient umbrella term to geographically group a number of countries, it masks the highly varied political and governance structures that exist within the region. Guadeloupe, Aruba, and Puerto Rico remain functionally governed by external powers such as the French, Dutch, and United States respectively. The management of water resources in these countries is largely governed by laws, policies and regulations that are, for the most part, determined by their colonial parent. Additionally, for the large Spanish-speaking Caribbean countries, governance structures tend to mirror governance structures that are very similar with those seen in Latin America due to their shared language and cultural heritage.

Caribbean Waterscape

One way to evaluate the presence and degree of water scarcity within the Caribbean region is to look through the lens of supply and demand and focus on the variables that influence the two sides of this equation. There are social factors such as usage patterns and social norms which influence demand whereas the type of available resources, condition of the water provisioning infrastructure, and administrative structures are factors that can materially impact supply (Cashman, 2014). Other factors that can place pressure on water availability and hence water security include uncontrolled urban population growth, extensive land use changes, degradation of water quality, and growing impacts of climate change on the hydrological cycle.

Given the varied ways in which water scarcity can be defined and assessed, a framework utilized by Cashman (2014) which is based on four reviewable elements – Adequacy, Accessibility, Assurance and Affordability – will be used to examine the state of water resources and service provisioning in the Caribbean. A summary of Cashman's assessment based on these four elements buttressed with updated data and information that were available in presented below.

Adequacy of Resources. The Caribbean regions' waterscape varies from being the home to some of the most water-scare nations on the planet, such as Barbados and the Bahamas, to countries that have abundant freshwater resources, such as Guyana and Belize (Table 2, Global Water Partnership, 2014).

Although the overall average annual precipitation in the Caribbean region is over 1,400 millimeters (mm), the annual amounts experienced in different islands from a low of 135 mm for the Cayman Islands to a high of 2,387 mm in Guyana. The amount of precipitation is divided roughly between two distinct seasons: 20 to 25% during a dry season, from January to June, and 75 to 80% during a wet (rainy) season, from July to December, which overlaps with the hurricane season. Further, the amount of precipitation varies spatially as the windward side of an island receives more precipitation than the leeward side. Given that sea level temperatures vary very little throughout the year, this results in evapotranspiration rates exceeding the amount of precipitation for a significant part of the year. Further, notwithstanding the fact that the Caribbean lies in the tropics, island temperatures are strongly elevation-dependent with coastal temperatures varying from a high of 32˚C and low of 24˚C but dropping to as low as 10˚C with increasing elevation.

In 2002, UNEP quantified freshwater resources (internal renewable water resources) in the Caribbean at 2,532 m^3 per capita (UNEP, 2008). However, several islands like Antigua and Barbuda (571.40 m^3/capita/year), the Bahamas (57 m^3/capita/year), and St. Kitts and Nevis (444 m^3/capita/year) fall in the category of water-scarce countries as they fall below UNEP's minimum of 1,000 m^3 per capita per year.

TABLE 2

WATER RESOURCES FOR ENGLISH SPEAKING COUNTIRES

Country	Land area (km^2)	Total average annual rainfall (mm)	Total renewable water resources (mm^3/year)	Municipal water withdrawal (mm^3/year)	Total water withdrawal per capita (m^3/capita/year)	Total renewable water per capita (m^3/capita/year)
Anguilla	91	890	Not given	Not given	Not given	
Antigua and Barbuda	443	1,030	52	5	98	571
The Bahamas	13,880	1,292	20	Not stated	Not stated	57
Barbados	430	1,422	80	20	371	291
Belize	22,966	1,705	16,000	10	Not stated	51,779
British Virgin Islands	153	1,117	Not stated	Not stated	Not stated	Not stated
Cayman Islands	263	135	Not stated	Not stated	Not stated	Not stated
Dominica	751	2,083	Not stated	Not stated	244	Not stated
Grenada	344	2,350	Not stated	Not stated	97	Not stated
Guyana	214,970	2,387	241,000	61	2,222	317,942
Jamaica	10,991	2,051	9,404	275	370	3,406.00
Montserrat	102	1,143	Not stated	Not stated	Not stated	Not stated
Saint Kitts and Nevis	261	1,427	24	Not stated	Not stated	444
Saint Lucia	616	2,301	Not stated	10	98	Not stated
Saint Vincent and the Grenadines	389	1,583	Not stated	Not stated	Not stated	Not stated
Trinidad and Tobago	5,128	2,200	3,840	174	178	2,842
Turks and Caicos	616	559	Not stated	Not stated	Not stated	Not stated

Source: CIA World Factbook (https://www.cia.gov/library/publications/the-world-factbook/); FAO Aquastat database

An engineering review of renewable water adequacy done in 2012 for 17 Caribbean states (Anguilla, Antigua and Barbuda, Bahamas, Barbados, Belize, British Virgin Islands, Caymans Islands, Dominica, Grenada, Guyana, Jamaica, Montserrat, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, and Turks and Caicos Islands) showed a decline in water availability especially in the northern areas of the Caribbean (Cole Engineering Group, 2015). This assessment reported up to a 50% decline in renewable water resources in the Bahamas, Belize, and Antigua and Barbuda with other Caribbean countries except Guyana also experiencing lesser declines. It also determined that a total of 2,811 million liters per day (MLD) was produced in 2012 and sourced primarily from groundwater (1,474 MLD, 52.5%), surface water (1,008 MLD, 35.8%), desalination (327 MLD, 11.6%), and rainwater harvesting (1.5 MLD, < 1%). Due to the lack of adequate freshwater sources desalination accounts for between 85% to 100% of supplies in northern Caribbean countries like Anguilla, Antigua and Barbuda, The Bahamas, British Virgin Islands, Cayman Islands and Turks and Caicos Islands.

For the 17 countries included in this assessment population totals 6,502,580, and per capita water consumption averaged 414 litres per day. (Table 3, Cole Engineering Group, 2015). This level of consumption is very high especially when compared with World Bank identified best performing utilities where a per capita consumption level of 270 litres per day is considered as accepted best practice for Public Water Companies.

TABLE 3
WATER RESOURCES FOR THE ENGLISH SPEAKING CARIBBEAN ISLANDS

Country	Renewable Water % 1968-1972: 2008-2012 % Change	Rainfall % 1960-1990: 1990-2009 % Change	Production MLD	Production l/c/p/d	Water Coverage % of Population	Leakage % UFW	Working Ratio Cost/ Revenue	Tariff US$/M³
Anguilla		-23%	2.5	167	65	60	0.76	3.67
Antigua and Barbuda	-25%	-6%	26.7	300	95	40	0.98	1.70
The Bahamas	-48%	-27%	102	297	98	50	1.32	2.64
Barbados	-14%	+18%	145.4	531	99	49	0.85	1.24
Belize	-60%	-14%	45	131	98	27	0.74	1.82
British Virgin Islands		-24%	18.9	611	81	63	3.33	2.64
Cayman Islands		-35%	18.8	334	85	17	0.90	2.50
Dominica		+2%	45.5	670	90	40	1.07	0.40
Grenada		+4%	43.2	415	97	15-20	1.20	0.78
Guyana	-3%	+46%	340	450	86	25	1.40	0.14
Jamaica	-30%	-35%	855	318	95	66	0.95	0.66
Montserrat		-7%	3.7	616	95	25-30	1.04	0.98
Saint Kitts and Nevis	-17%	-12%	15 (STK) 5 (Nevis)	381	99	50	0.90 0.28	0.63
Saint Lucia		+2%	90	517	92	40-60	2.2	0.37
Saint Vincent and the Grenadines		+4%	27	247	98	20	0.97	0.15
Trinidad and Tobago	-27%	+19%	1025	765	92	51	3.27	0.27
Turks and Caicos		-15%	11.3	293	70	50	1.70	6.60

Source: Cole Engineering Report, 2015

Given increasing demands for water and the predicted negative effects of climate change on the hydrologic cycle, the existing gaps between the demand for potable water and its supply are expected to widen in several Caribbean countries. Barbados is currently using almost 100 percent of its available water resources, St. Lucia has a 35 percent water deficit, in Nevis the deficit is 40 percent, and Trinidad and Tobago has been operating at a deficit since 2000 (Global Water Partnership, 2014). Seasonal water shortages during the dry season are predicted to get worse in Dominica, Grenada, and St Vincent and the Grenadines as demands exceed the water utilities' ability to satisfy from available water resources. In Dominica, the gap in demand-supply may be as much as 50 percent (Global Water Partnership, 2014). The fact that such a shortage should exist in the first place is somewhat paradoxical since as has already been noted in Table 2, the average annual precipitation in these three Caribbean countries exceeds 2,000 mm, however. This supply/demand gap is probably due to the lack of adequate storage infrastructure and/or institutional frameworks and this problem will likely persist and continue to grow.

For the Caribbean region, the tourism sector is the prime driver of economic growth and development. However, it is estimated that tourists consume up to three times as much water as the local population and the supply of water to hotels can account for between 10% and 15% of all water supplied by municipal distribution systems (Cashman, 2013). As the tourism industry continues to grow in many Caribbean jurisdictions, the growing demand for water will continue to pose significant challenges for national water providers.

Access to Services. While access to improved water services exceeds 90% in almost all Caribbean countries, problems related to the quality of service and maintenance of water-related infrastructure continue to beset most islands. The level of daily water consumption depends not only on population size but also on the degree of industrial activity. Thus, heavily industrialized Caribbean islands like Jamaica and Trinidad consume 632,876 m^3/d and 904,110 m^3/d respectively whereas islands like Grenada and St. Kitts and Nevis only 31, 877 m^3/d and 12,600 m^3/d respectively.

High rates of unaccounted for water (UFW) plague most Caribbean countries and vary from a low of 17% in the Cayman Islands to a high of 66% in Jamaica as seen in Table 3. Procuring funding to invest in water main replacement, as well as annual leakage management, remains a constant challenge thus jeopardizing many Caribbean water providers' ability to provide water services reliably and consistently year-round.

Assurance of Supply. Due to the interaction of geographic, climatic, and topographic factors, the availability of water resources in the Caribbean varies both temporally and spatially. Water providers thus face the challenge of developing infrastructure that is both resilient and adaptative enough to cope with current and future needs in a setting where the supply of water is constantly variable.

Climate change is anticipated to exacerbate this challenge as both surface and ground water resources are showing evidence of significant decreases in sustainable yields due to decreases in recharge rates and declines in average annual precipitation throughout the region. The amount of precipitation has generally decreased throughout the region. Simultaneously, there has been an overall decrease in the percentage of renewable water with countries like the Bahamas and Belize experiencing 48% and 60% decreases respectively in the amount of renewable water available receive as noted in Table 3.

Another factor affecting the availability of water supplies in several Caribbean countries is the increasing threat to streamflows due to urban development and poor agricultural practices. For example, the urbanization of the upper watershed areas around Port of Spain in Trinidad and Castries in Saint Lucia have resulted in higher peak flows, downstream flooding, higher sediment loads, and an overall decrease in base stream flows (Edwards, 2011; Williams, 2010).

Affordability. Using the metric based on what people are willing and able to pay, the affordability of water in has been addressed by charging fixed amounts for 10-15 m3 per month, the volumes deemed sufficient to basic water requirements.

For service providers, affordability in providing water services is determined by their ability to source and secure sufficient funding to cover annual operating and maintenance costs, as well as finances for capital works needed to upgrade and improve on water supply services and products. This definition is at variance with the definition of consumer affordability which in the Caribbean is lower than what water providers estimate that they require.

At present, water providers rely on tariffs to cover operating and maintenance costs but need government loans or transfers to execute any proposed capital works. Thus existing water tariffs are generally insufficient to cover the costs of water production. Current tariffs tend to be lowest in countries that have abundant water resources like Guyana ($0.14) and St. Vincent and the Grenadines ($0.15) and highest in countries that rely heavily on desalination such as Anguilla ($3.67), the Bahamas ($2.64), the British Virgin Islands ($2.64), the Cayman Islands ($2.50), and Turks and Caicos Islands ($6.60).

A water provider's ability to recover operating costs from annual revenue can be determined by calculating its working ratio. Given that a working ratio of 0.7 is considered as a good indicator of financial prudence, as seen in Table 3, countries in the Caribbean region are experiencing financial challenges. Caribbean countries like St. Lucia (2.2), Trinidad and Tobago (3.27), and the British Virgin Islands (3.33) all require significant governmental interventions in order to continue operations.

Summary

From an overall regional perspective, it might appear that the Caribbean region is endowed with sufficient water resources that meet the needs of more than 90% of those who live in the region. This review, however, has highlighted that the quality and sustainability of this coverage is not evenly distributed and that significant challenges are being brought to bear on the region's water providers to maintain and increase the supply of water under present and future anticipated demands. If these challenges are not appropriately and expeditiously dealt with, the pockets of water scarcity will become more widespread and pervasive, and the ability of water providers to provide for a broad range of water demands will be greatly diminished.

REFERENCES

Cashman, A. 2013. Water Security and Services in the Caribbean. Inter-American Development Bank.

Cashman, A. 2014. Water Security and Services in the Caribbean. Water, 6, 1187-1203; doi:10.3390/w6051187

Edwards, O. 2011, Method for assessing the potential impact of climate change on streamflow regimes and its implications in Trinidad, using the Maracas/St. Joseph catchment as a case study. Master's thesis. University of the West Indies Centre for Resource Management and Environmental Studies, Barbados.

Fletcher, J. 2018, Regional Process of the Americas World Water Forum 2018: Sub-regional report Caribbean Executive Summary 2018, Caribbean Water and Wastewater Association

Global Water Partnership, 2014. Integrated water resources management in the Caribbean: The challenges facing Small Island Developing States, ISSN: 2001-4023, ISBN: 978-91-87823-01-5

Cole Engineering Group, 2015. Assessment and Analysis of the Water Sector in the Caribbean. Caribbean Development Bank (CDB).

United Nations Economic Commission for Latin America and the Caribbean (ECLAC), 2013. An assessment of the economic and social impacts of climate change on the water sector in the Caribbean (2013), https://www.cepal.org/en/publications/38283-assessment-economic-and-social-impacts-climate-change-water-sector-caribbean

United Nations Environment Programme (UNEP), 2008. Climate Change in the Caribbean and the Challenge of Adaptation, Regional Office for Latin America and the Caribbean.

Thomas A, Baptiste A, Martyr-Koller R, Pringle P, Rhiney K, 2020, Climate change and Small Island Developing States, Annu. Rev. Environ. Resour. 45:1-27

Williams, C, 2010, An investigation of the applicability of hydroinformatics in assessing the impact of flooding on Castries, St. Lucia. Master's thesis. University of the West Indies Centre for Resource Management and Environmental Studies, Barbados.

Central American Region

Overview

The Central American Region includes seven countries: Panama, Costa Rica, Nicaragua, Honduras, El Salvador, Guatemala and Belize. They occupy an area of 532,857 km^2 and with a population of 38.31 million. The Isthmus of Central America is uniquely positioned geographically and possesses both biophysical characteristics and socio-economic conditions that create relatively favorable water supply circumstances. As illustrated in Figure 5 the Isthmus has two coastal areas, one bordering on the Caribbean Sea with a length of 2740 km and the other bordering on the Pacific Ocean with a length of 2380 km. Oceans on both coastal zones have a strong influence on the meteorological conditions that prevail on the Central American land. The occurrence of different extreme events is very common as is the high vulnerability to droughts and floods and climate change phenomena.

The geology is dominated by Cenozoic volcanic rocks especially found on the Pacific side with sedimentary rock and more recent alluvial formations found in coastal valleys and plains. As shown in Figure 4, the mountain regions with 109 volcanoes run from Guatemala through Honduras, El Salvador, Nicaragua and Costa Rica. Sea level plains are found in the coastal areas of northern Guatemala and in the Nicaraguan Graben formation where the two largest Central American lakes are located, Lake Xolotlán (1016km^2), and Lake Cocibolca (8150km^2). All of these features interact to create a relatively abundant water supply for the region.

Figure 5: Topographic Map of Central America with Volcanic Chain.
(NASA/JPL/NIMA, Public domain, via Wikimedia Commons)

Ground water found in large volcanic aquifers is presently the main source of water but surface waters are becoming a larger and more significant source of supply. This trend is projected to continue in the coming years. Surface waters are abundant and characterized by a rich network of rivers divided by the central mountain range. The natural water quality is usually excellent in the volcanic and alluvial aquifers. There are 237 watersheds and 70% of surface waters flow into the Atlantic or Caribbean Sea as shown in Figure 6. It is notable that 36 % of the Central American watersheds are transnational. The largest tropical lake of the Americas, Lake Cocibolca in Nicaragua with a volume of 108 km^3, has a vast potential as reservoir for drinking water supply for the Central American region in the event that growing demands for water over time would ever require it.

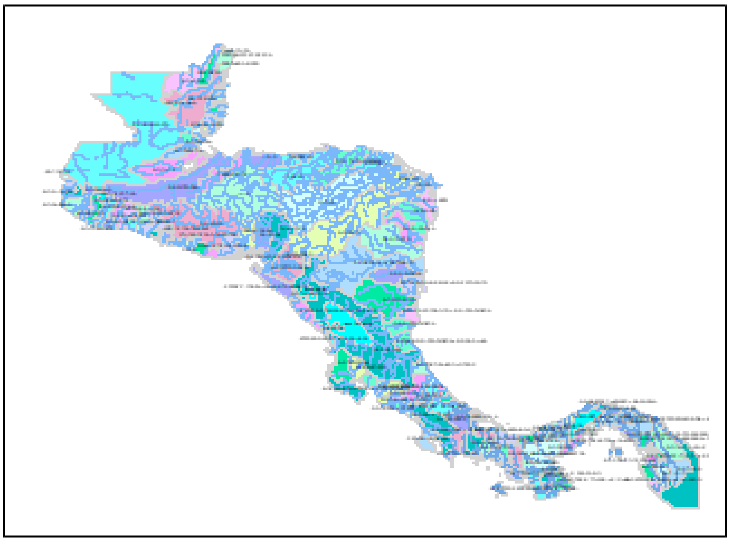

Figure 6. Watersheds and Hydrological Network of Central America. Source: CCAD, 2008

TABLE 4
RENEWABLE RESOURCES PER YEAR IN GLOBAL CONTEXT

Regions	Total Internal Renewable Water Resources (IRWR) m³/capita per year
World	5 829
Oceania	29 225
Americas	19 725
North America	15 845
Mexico	3 220
Central America	13 922
Caribbean-Greater Antilles	2 367
Caribbean-Lesser Antilles and Bahamas	2 071
South America	30 428
Europe	8 895
Africa	3 319
Asia	2 697

Source: FAO/Aquastat, 2022

The climate of Central America is essentially tropical but the two oceanic climates and the geographic diversity creates a precipitation gradient that ranges from semi-desert mostly on the Pacific Coast (400mm precipitation a year) to intensive rainfall and humid tropical conditions in areas on the Caribbean Coast, called the Mosquito Coast (up to 6350 mm per year). There are marked seasons in the Pacific zone with dry season from 4 to 6 months from May to November. The Caribbean zone has wet characteristics usually all year round.

A comparison of the total renewable water resources per capita with different global regions in Table 4 above demonstrates the natural favorable conditions of water resources in Central America. This is also reflected in in the total renewable water resources per capita in the seven Central American countries which ranges from 56,736 to 4,091 m3/capita/year in 2018 as shown in Table 5. The long-term average annual precipitation in volume has been observed from 37.54 to 297.2 ($10^9 m^3$/year). Belize and El Salvador have the least rainfall and more drought phenomena. In the case of Belize, the northern part borders Mexico where the inland is almost desert-like and El Salvador is completely covered by the Central American dry corridor with degrees of dryness valued as mostly high.

TABLE 5

AVERAGE TOTAL RENEWABLE WATER RESOURCES IN CENTRAL AMERICA, LONG-TERM AVERAGE ANNUAL PRECIPITATION, WATER STRESS AND % WITHDRAWAL FOR AGRICULTURE FOR 7 CENTRAL AMERICAN COUNTRIES

Country	Total Renewable water resources per capita 2018 (IRWR- m^3/capita per year)	Long-term average annual precipitation in volume ($10^9 m^3$/year)	SDG 6.4.2 Water Stress	Agricultural water withdrawal as % of total water withdrawal (%)
Belize	56 736	39.16	1.26	67.72
Panama	33 351	220.5	0.9011	36.83
Nicaragua	25 446	297.2	2.692	76.72
Costa Rica	22 603	149.5	5.211	72.03
Honduras	9 613	222.3	4.621	73.3
Guatemala	7 416	217.3	5.742	56.74
El Salvador	4 091	37.54	13.21	67.56

Source of information: FAO/Aquastat, 2022

The majority of water withdrawals supports agricultural activities and extractions range from 37% in Panama to 77% in Nicaragua. The water stress values reflect the availability of water resources and are equal to the quantities of withdrawn by all economic activities divided by the quantities of the total renewable freshwater resources available.

Present Scarcity Problems and Environmental Climatical Changes

Central America has been categorized as a region vulnerable to climate change due both to the frequency of extreme events such as hurricanes and tropical storms and to extended dry periods found mainly in the Pacific and central regions. Temperatures at all seasons are increasing and predictions are for more growth in the future. These higher temperatures bring increases in evapotranspiration and results in higher demand for water from the atmosphere, drier soils and higher aridity impacting agriculture, ecosystems and increasing the potential for forest fires. (Hidalgo, H.G., 2021). In the last decade there have been precipitation deficits in some periods that have been historically more humid. Changes in precipitation regime patterns include increasing intensity and duration and changes in seasonality (Feng et al., 2013). Declines in precipitation along with human activities, such as changes in land use and deforestation, have reduced the extent of forest zones especially in tropical dry forests in the Pacific region of some Central American countries.

Central America has a very pronounced Dry Corridor which extends from Guanacaste in Costa Rica, through the Pacific area of Nicaragua (especially in the north), El Salvador, Honduras and Guatemala where the corridor widens into the central territory. Figure 7 shows the extension of the Central American Dry Corridor which changes for normal (30.3% area of Central America), extreme dry (36.2%) and extreme wet years (21.3%) (Quesada-Hernández et al., 2019).

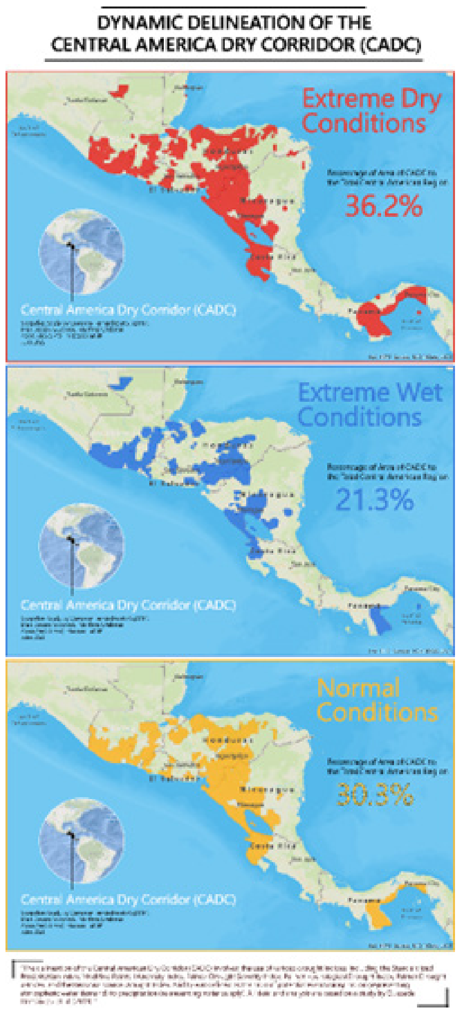

Figure 7: Dry Corridor of Central America (CADC) under 3 different climate conditions.
Source: Quesada et al. (2019)

The population of the corridor is approximately 11 million, almost 25% of the total population of Central America. It is mainly rural and has been characterized for its high vulnerability to climate change. Poverty, together with food insecurity due to the failure of agriculture harvests, has caused frequent waves of human migration.

A significant percentage of land area is used for agriculture in Central America and in some countries agriculture contributes significantly to GNP as seen in Table 6. Yet agriculture has also contributed to water scarcity due to overexploitation of ground water. For example, 74.4% of water used for irrigation in the Pacific Area in Leon.

TABLE 6
PERCENTAGE OF AGRICULTURAL LAND USE AND CONTRIBUTION TO GNP

Country	Agricultural Land % of total land area in 2018	Agricultural portion of GNP (%) in 2017
Guatemala	36.0	13.3
Belize	7.5	--
El Salvador	71.4	12.0
Honduras	30.0	14.2
Nicaragua	42.1	15.5
Costa Rica	34.9	5.5
Panama	30.5	2.4

Sources of %: World Bank, 2018; World Factbook-GNP, 2017

Irrigated with Chinandega, the most intense area of agriculture in Nicaragua, comes from ground water. The quality of these ground water sources has also been adversely impacted by the intensive application of pesticides in the past and present.

Drastic conversions of land use to pastures for cattle breeding and other agricultural purposes has led to significant deforestation. This has led to the loss of many environmental, social and economic benefits of forests in Central America. Such losses include increased rates of erosion and the associated sedimentation of surface waters resulting in loss of potable water supplies and affecting regional climatological conditions. Although Central America has abundant water resources, the constant change in land use from human activity and impacts from climate change specific to this region have led to increases in aridity such that more areas are experiencing water scarcity. This is lowering the prospects for constructive and favorable exploitation of an important natural resource that could contribute to sustainable development of the region. Thus, there is an urgent need for the creation and implementation of improved water management practices to improve the use of regions water resources (Hidalgo, H.G., 2021).

REFERENCES

Comisión Centroamericana de Ambiente y Desarrollo (CCAD), Mapoteca, 2008.

Feng, S. and Q. Fu. 2013. Expansion of global drylands under a warming climate, Atmos. Chem. Phys., 13, 10081–10094, https://doi.org/10.5194/acp-13-10081-2013, 2013.

Food and Agriculture Organization of the United Nations (FAO-AQUASTAT). 2022. Database Query Results, Central America.

Gleick, P.H. 1996. Basic water requirements for human activities: Meeting basic needs. Water International (IWRA), 21, pp. 83-92.

Hidalgo, H., G., Alfaro, E. J., Amador, J. A., & Bastidas, A. 2019. Precursors of quasi-decadal dry-spells in the Central America Dry Corridor. Climate Dynamics, 53(3-4), 1307-1322. https://doi.org/10.1007/s00382-019-04638-y

Hidalgo, H., G. 2021. Climate variability and change in Central America: What does it mean for water managers? Frontiers in Water, 2, 632739. https://doi. org/10.3389/frwa.2020.632739

Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO), Estudio de Caracterización del Corredor Seco Centroamericano. https://reliefweb.int/sites/reliefweb.int/files/resources/tomo_i_corredor_seco.pdf

Quesada-Hernández, L.E., Calvo-Solano, O.D., Hidalgo, H.G., Pérez-Briceño, P.M. and Alfaro, E.J., 2019. Dynamical delimitation of the Central America Dry Corridor (CADC) using drought indices and aridity values. Progress in Physical Geography. DOI: 10.1177/0309133319860224

The World Factbook – GDP- compositions by sector or origin. 2017. https://en.wikipedia.org/wiki/List_of_countries_by_GDP_sector_composition

The World Bank, 2018. Agricultural land (% of land area). https://data.worldbank.org/indicator/AG.LND.AGRI.ZS

South America: Non-Andean Region

Overview

The Non-Andean region of South America encompasses the countries of Argentina, Brazil, Uruguay and Venezuela. Each exhibits heterogeneous landscapes and climate. The largest portion of the region is located in the southern hemisphere but Venezuela and a part of Brazil are located in the northern hemisphere. Venezuela and Argentina have significant extensions of their territories into the Andean region where there are areas with little rainfall as well as areas of dense humid forest with precipitation levels that are among the highest found in the world. Throughout the region there are areas with large temperature variations throughout the year and four season climates are typica. However, in Venezuela and the northern part of Brazil there are only two seasons – rainy and dry.

The land areas as well as the population densities vary markedly between the four countries (Table 7). Although population densities are relatively modest when compared with other countries in the hemisphere and the rest of world, these figures mask some important features. In Venezuela 80% of the population is concentrated in just 20% of the national territory; in Argentina and Uruguay more than 70% and 90% of the population respectively dwell in urban areas; and in Brazil more than 20 million of inhabitants reside in the semi-arid regions of the northeast (IANAS, 2015). There is a tendency, seen elsewhere in the hemisphere, for populations to be concentrated in areas where water supplies are limited rather than the opposite.

TABLE 7
POPULATION, SURFACE AREA AND POPULATION DENSITY IN NON-ANDEAN COUNTRIES

Country	Population (millions of inhabitants)[1]	Surface (km^2)[2]	Density (inhabitants/ km^2)
Venezuela	29.3	916,445	31.9
Brazil	215.4	8,514,877	25.3
Argentina	45.9	2,792,600	16.4
Uruguay	3.5	176,215	19.9

Sources: World Population Review (2022). 2Cámara Argentina de Comercio y Servicios (2018).

Within each country there are significant variations in climate ranging from hyper hydric (very wet) to those considered xeric (extremely dry) (UNESCO, 2010). Such variations are especially pronounced within Brazil and Argentina due to the size of the respective land masses. Only Uruguay does not have arid areas. Table 8 shows the water deficit defined as the sum of the xeric, hyper-arid, as a percentage of the country area (middle column) and the same fraction, including sub-humid areas in the right hand column. These climatic differences obviously impose limitations on the availability of water. In most locales supplies consist of local and imported surface waters as well as ground water and surface water (IANAS, 2015, 2019).

TABLE 8
PERCENTAGE OF AREAS WITH SURFACE WATER DEFICIT BY COUNTRY

Country	% surface with water deficit	% surface including sub humid areas
Venezuela	4	25
Brazil	8	25
Argentina	57	67
Uruguay	0	0

Source: UNESCO, 2010

Water Extractions for Diverse Purposes

The waters extracted from ground and surface sources are used for diverse purposes. As shown in Table 9 the major purposes are for agricultural and municipal and industrial (M & I) uses. Agricultural uses predominate and range from 58% (in Brazil) to 86.8% (in Uruguay) of total extractions. Municipal uses are fractionally smaller

TABLE 9
WATER EXTRACTED FOR AGRICULTURAL, INDUSTRIAL AND MUNICIPAL USES, 2018

Country	Agricultural use (10^9 m^3/yr)	Industrial use (10^9 m^3/yr)	Municipal use (10^9 m^3/yr)	Total (10^9 m^3/yr)
Venezuela	16.71 (73.8%)	0.79 (3.5%)	5.12 (22.6%)	22.63
Brazil	37.55 (58.1%)	10.18 (15.8%)	16.86 (26.1%)	64.59
Argentina	27.93 (73.9%)	4.00 (10.6%)	5.85 (15.5%)	37.78
Uruguay	3.17 (86.6%)	0.08 (2.2%)	0.41 (11.2%)	3.66

Source: FAO, 2022.

in all four countries but are crucially important because they meet the demands for domestic water and sanitation services. The availability of clean drinking water services is somewhat variable. In Uruguay 100% of the population has access to healthful supplies of drinking water and the comparable figure for Argentina is 82%. In contrast, only 20% of the population of Venezuela has access due to deterioration of water treatment and delivery infrastructure. Moreover, water supplies that do arrive are often of doubtful quality or non-potable (Fundación Agua sin Fronteras et al., 2018; Vaux et al., 2020).

Access to sanitation services ranges from 40% in Argentina to 80% in Venezuela. However, less than 30% is treated in each of the four countries. This results in significant contamination of surface waters from both untreated municipal sanitary wastes and industrial wastewater. It is important to recognize that such contamination reduces the availability of water for M&I and agricultural purposes just as surely as drought and thereby intensifies the degree of physical water scarcity. There are several additional issues which affect the adequacy of water supplies and influence the degree and extent of water scarcity in the region. They must be the focus of improved management practices and effective water policies in the future.

Salinization of Soils

When water is required for irrigation it is usually due to the lack of adequate precipitation to support rainfed agriculture in arid and semi-arid regions. Soil salinization can also be a problem and occurs when soil salts are mobilized or by inadequate drainage of tail water. All waters contain some amount of salt and evapotranspiration can leave salt as a residue in the root zone where drainage is not adequate. The usual solution is to apply additional water to flush the salts from the root zone. Management of salt balances, then, increases the use of water in areas where it is already scarce. This problem is especially evident in Argentina, where drier areas represent two thirds of the country's surface, and in the northeast region of Brazil, where high exploitation or vertical infiltration in poorly sealed wells adversely affects coastal sedimentary aquifers.

Pollution

Pollution of ground and surface water is a serious problem throughout the region and tends to be associated with agricultural and industrial activities. The major pollutants include a wide variety of pesticides and fertilizers, faecal contaminants, industrial solvents, macronutrients, toxic substances, bacteria and viruses. Natural pollutants are also of concern. In Argentina, for example, arsenic and fluorine that originate in the geological substrate are found in groundwater. Boron is found in both surface and groundwaters, often in concentrations that are detrimental to plant growth. In southeast Brazil, natural geochemical anomalies introduce toxic substances such as F, Cr and Ba into the water. There is also an extensive presence of Fe and Mg associated with unconfined sedimentary aquifers.

The petroleum and mining industries are important sources of water pollution. Hydrocarbon production in the Lake Maracaibo area of Venezuela has led to uncontrolled spills which, together with salinity, have modified the chemical composition of the water thereby making it unacceptable for human consumption, irrigation or industrial uses. This same situation has also been observed in waterbodies in Brazil, where the presence of liquid fuels derived from petroleum has also been noted. Mining has caused the degradation and contamination of water across significant areas of the region. For example, in both Brazil and Venezuela high concentrations of mercury have been detected in people living in mining areas in the Orinoco river basin (Venezuela). Elsehwhere, in areas where illegal mining is practiced, high concentrations of mercury have been recorded in sediments, water and fish. In the coastal areas of Montevideo (Uruguay) the presence of high concentrations of heavy metals such as Cr, Pb, Cu and Zn, have been detected. Unhealthy concentrations of copper are reported in some waters of northern Brazil. The fact that most of these contaminants have non-point source origins makes the cleanup and prevention especially challenging. This is also true of solid waste and its associated leachates that generate diffuse sources of pollution that impact surface and ground waters.

Finally emerging contaminants such as pharmaceuticals, cosmetics, antibiotics, hormones, nanomaterials, paints and coatings are of special concern because they are being generated at rates faster than they can be evaluated for potential toxicity in the environment. For example, the evaluation and quantification of the damage to aquatic biota by such contaminants has only recently begun. Such scientific evaluations generally lag far behind the introduction of new materials into the environment.

Deforestation

Argentina, Brazil and Venezuela have experienced significant rates of deforestation that subsequently impact water resources. For example, in Venezuela deforestation associated with extraction activities in the so-called "Orinoco Mining Arc" has adversely impacted large and important water reserves in the country. The conversion of forested lands for agriculture and agro-industrial development as well as urban development has replaced large areas of native forests. This loss of vegetation and the subsequent erosion has reduced the retention of nutrients in drainage basins and mobilized sediments and nutrients that contaminate the waterways which transport them. In addition, deforestation for urban development has generated and introduced debris, chemical compounds, plastic and leachate into pristine environments. Overall of deforestation not only adversely affects water quality but also quantity and timing of water flows. There are few tools available to assess comprehensively the impacts of deforestation in advance of its occurrence. The rate of deforestation is increasing and its magnitude is a major concern. In 2021 Brazil lost 2.90 Mha of natural forests, the highest annual loss ever recorded (Global Forest Watch, 2022). Deforestation is a critical problem that requires early attention.

Eutrophication

Eutrophication of water bodies is the result of "artificial fertilization" from nutrients found in unregulated waste discharges leading to undesirable environmental problems. These include: excessive growth of phytoplankton and macrophytes, proliferation of algae blooms and toxic phytoplankton (some cyanobacteria), fish mortality by suffocation due to the drastic drop in oxygen concentration, the proliferation of suitable habitats for vectors of tropical diseases, deterioration of water quality and loss of biodiversity. Algal blooms associated with some species of cyanobacteria, are particularly costly if the affected water bodies are used for drinking water supply, as removal of the toxins requires advanced treatment processes and inadequate treatment poses serious risks to public health. Problems are also generated in the purification systems due to the need to use higher doses of coagulants-flocculants. Eutrophication is frequently the result of non-point source discharges and therefore presents a significant management challenge.

Health Problems

Polluted waters are the cause of human health problems in both rural and urban areas due to the presence of enteropathogens, bacteria and viruses. Diseases that include dengue, malaria and yellow fever that are spread by mosquitos that are present throughout the region. Schistosomaisis and Leishmaniasis are other examples found in rural areas. Harmful bacteria and viruses are found in wastewaters that have not been treated or are subject to inadequate treatment.

Water Governance

As in other countries in the Americas, institutions and laws related to water resource management are often absent or inadequate and when regulations do exist there is often a lack of enforcement. In Argentina, there are neither national water laws nor are there any regulations regarding the reuse of wastewater. In Brazil, the application of existing laws is often lacking and gives rise to conflicts over improper uses of water. In Uruguay there is a National Water Plan, but it has not been completely implemented. In Venezuela there is an adequate legal framework, but not all its provisions are complied with. It is clear that these problems must be addressed with scientific data playing a strong and important role in developing regulatory policies and the appropriate means of enforcing them.

Climate Change

While many of the impacts of climate change remain uncertain others can be reasonably anticipated including several relating to water scarcity. Four stand out: (UNESCO, 2020)

• Increased frequency and magnitude of extreme events, such as heat waves, precipitation, droughts, storms

and storm surges.
• Negative effects on the water quality due to increased temperatures resulting in declines in the amounts of dissolved oxygen and a consequent loss of a portion of the self-purification capacity of the fresh waters. Flooding and increased concentration of pollutants during droughts will increase the risk of water pollution and pathogenic contamination with clear implications for water scarcity.
• Risks to the environment, particularly for forest and wetland ecosystems. Degradation of these and other ecosystems will lead to a loss of biodiversity and a consequent loss of ecosystem services that depend on water. These include water purification, carbon sequestration and storage, natural protection against floods, as well as the provision of water supplies for agriculture, fishing and recreation.
• Drylands are expected to expand significantly across the globe. Accelerated glacial melting is forecast to adversely affect water resources in mountainous regions and adjacent plains.
• Policies and management systems to meet the challenges and to anticipate climate change generally should be developed in the near future.

REFERENCES

Cámara Argentina de Comercio y Servicios. 2018. América del Sur y la Argentina: Una comparación regional. In: https://www.cac.com.ar/data/documentos/._Am%C3%A9rica%20del%20Sur%20y%20la%20Argentina%20una%20comparaci%C3%B3n%20regional.pdf. Retrieved: May, 14th, 2022.

Food and Agriculture Organization of the United Nations (FAO). 2022. AQUASTAT. In: https://www.fao.org/aquastat/statistics/query/index.html?lang=es. Retrieved: May, 15th, 2022.

Fundación Agua sin Fronteras, Fundación Aguaclara, Clima 21 & Mesas Técnicas del Agua del Municipio Baruta. 2018. Complex Humanitarian Emergency in Venezuela. Right to Water. National Report. Caracas.

Global Forest Watch. 2022. Brazil. https://www.globalforestwatch.org/dashboards/country/BRA. Retrieved: May 15th, 2022.

IANAS. 2019. Water Quality in the Americas: Risks and Opportunities. Inter-American Network of Academies of Sciences (IANAS) & United Nations Educational, Scientific and Cultural Organization (UNESCO). Mexico.

IANAS. 2015. Urban Water Challenges in the Americas. Perspectives from the Academies of Sciences. Inter-American Network of Academies of Sciences (IANAS) – Water Program. ISBN 978-607-8379-12-5. Mexico.

UNESCO, 2010. Atlas de Zonas Áridas de América Latina y el Caribe. Proyecto “Elaboración del Mapa de Zonas Áridas, Semiáridas y Subhúmedas de América Latina y el Caribe”. CAZALAC. Documentos Técnicos del PHI-LAC, N°25.

UNESCO, 2020. Agua y cambio climático. Informe mundial de las Naciones Unidas sobre el desarrollo de los recursos hídricos 2020. Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura. Paris, 243 p.

Vaux Jr., H., K. Vammen, N. Bernex, J. Fábregas, M. Forde, G. Roldán, and M.L.Torregrosa, 2020. The Challenges of Managing the Urban Waters of the Americas. Environment: Science and Policy for Sustainable Development, 62(2): 14-29. DOI: 10.1080/00139157.2020.1708170

World Population Review, 2022. Latin American Countries. In: https://worldpopulationreview.com/country-rankings/latin-american-countries. Retrieved: May 8th, 2022.

South America: Andean Region

Overview

As summarized in Table 10 the population of the Andean Countries is approximately 130 million inhabitants. The countries themselves cover a surface area of 4.6 million km2 (Table 10). Colombia is the most populated country of this region with 38% of the population, followed by Peru with 25%. Ecuador is the most densely populated (52 inhabitants/km2) followed by Colombia (45 inhabitants/km2). Ecuador and Bolivia are the countries with the greatest population growth in the past 20 years.

TABLE 10
POPULATION OF SOUTH AMERICAN ANDEAN REGION BY COUNTRY

	Population 2020 (MM)	Pop. Change (%) 2000-2020	Surface (km^2)	Population Density (inhabitants/km^2)
Colombia	50,88	28,4	1.142.000	45
Ecuador	17,64	39,1	283.560	52
Bolivia	11,67	38,6	1.099.000	11
Peru	32,97	24,6	1.285.216	24
Chile	19,12	24,6	756.950	26
Region	132,28	29	4.566.726	30

Source: World Bank - World Development Indicators and World Bank Open Data

The region has an average precipitation of 9,900 mm/year and average runoff of 5,800 km^3/year as shown in Table 11. Within the global context, the Andean Region could be considered privileged in terms of water resources as its average runoff is 43,000 m^3/person/year, considerably higher than the world average (6,600 m^3/person/year).
However, from a hydrological perspective, the region is one of extremes. Its rivers and aquifers exist in varied geographical settings and are characterized by high spatial variability. For example, annual average runoff ranges from 420 km^3 in Ecuador to 2,000 km^3 in Colombia. Within each country there is also significant variation. In Chile, for instance, in the area north of Santiago arid conditions prevail with average water availability below 800 m^3/person/year, while south of Santiago water availability is exceeds 10,000 m^3/person/year.

TABLE 11
AVAILABLE WATER AND LEVELS OF CONSUMPTION IN ANDEAN REGION BY COUNTRY

	Average annual precipitation (mm)	Geographic variation average annual precipitation (mm)	Average annual runoff (km^3)	Groundwater Recharge (km^3)	Water Use (km^3)	Water infrastructure (Storage capacity Km^3)
Colombia	3240	200-3500	2030	510	11,8	11,28
Ecuador	2274	450-3300	423	134	9,9	7,69
Bolivia	1140	150-6000	547	130	2,1	0,595
Peru	1730	500-2800	1880	303	13,7	5,77
Chile	1520	20-4000	923	140	35,4	13,22
Region	9904	-	5803	1217	72,9	38,555

Source: United Nations (UN, UNESCO, and FAO); World Bank Open Data

Ground water constitutes a significant proportion of the available resources in this region with recharge totaling 1,200 km^3 annually. Rates of recharge within individual countries range 130 km^3 /yr. in Bolivia recharge to 510 km^3 /yr. in Colombia (Table 2). In recent decades ground water has become a more essential water source due to increasing water scarcity as evidenced by the constant increase in the number of pumping wells. In Chile, for example, the number of granted ground water rights increased 4,000% in the last decade. Additionally, there is a limited observation well network and potentially significant volumes of un-gauged groundwater extractions. These hinder the ability of public and private agents to quantify the water balance of groundwater systems. Consequently, hydrogeological knowledge is limited and groundwater governance systems have not been, in general, effective to reconcile sustainable ground water management with changing hydrogeological, technological, economic, environmental, and political circumstances.

Average water storage capacity in the region is 291 m^3/person, a value considerably lower than the world average (3,400 m^3/person/year). Chile has the highest storage capacity (690 m^3/person) followed by Ecuador (435 m^3/person). Bolivia has the lowest storage capacity (50 m^3/person).

Several factors, including population growth, rapid urbanization, and increased water demands due to increased economic growth, are putting considerable pressure on available water resources throughout the region. Average annual water consumption in the region is 551 m^3 per capita. Consumption varies from country to country, ranging from an annual low of 179 m^3 per capita in Bolivia to an annual high in Chile of 1.853 m^3 per capita. It is important to point out that water consumption in all countries of the region has increased along with the development of the economy and the society. Thus, decoupling economic growth from water use has not been an automatic by-product of growth in national incomes.

The increase in consumptive water use has led to important water stress situations that are triggering a greater number of conflicts related to social, economic, and environmental vulnerability. The high levels of water extraction for consumption, have led to important aquatic ecosystem degradation and loss of biological diversity. This will be exacerbated by climate change that is expected to affect the region in a complex fashion. Most climate scenarios predict an increase in the average temperature in all countries but no clear trend in precipitation changes as increases are predicted for some areas while others may experience 30% decrease.

Agriculture is the main user of freshwater. Total irrigated area in the region is around 4,500 hectares. Agricultural water use is generally inefficient due to the predominance of traditional surface irrigation technologies which are found on average on 84% of the irrigated surface. Closed conduit systems, drip and sprinkler, are generally considered to be the most efficient. Chile and Ecuador have the highest rate of use of such systems with 28% and 20% of total irrigated surface respectively. In Andean countries the average irrigation efficiency is 39% with a range varying from 30% to 58%. The global average is 56% so that there is significant potential to increase water productivity in the region by switching to more efficient water application methods.

Each country in the Andean region has undertaken an active process of review and reform of existing legislation in an effort to increase the extent to which healthful drinking water supplies and adequate sanitation facilities are supplied. Currently, all countries have reformulated the pertinent regulatory frameworks. Chile and Colombia approved reforms in 1988 and 1994, respectively. All other countries adopted reforms after the year 2000. Each country exhibits a different degree of reform implementation. Chile and Colombia standout with full implementation while Peru is making substantial progress and Bolivia and Ecuador continue to address the challenges. These differing degrees of progress are expressed by the levels of achievement that the various countries have achieved in improving the extent of availability of healthful drinking water and sanitation services.

The evidence shows that these reforms have resulted in significant advances in the provision of healthful drinking water. Urban areas in the region now average approximately 87% coverage with Chile having universal access and Colombia achieving 97% in recent years. Bolivia and Peru have reached 87% coverage while Ecuador is at 74%. Despite these figures only Chile has continuous coverage with 99% of the suppliers making water available 24 hours a day. All countries are committed to the principle of accessibility which requires that the entire population have access to water (Donoso and Sanin, 2020).

Most countries have experienced more modest advances in providing sanitation services to urban areas. Chile and Colombia have the highest levels of sewage collection with 97% and 92% respectively. Although there have been significant increases in the past decade Peru stands at 83%, Ecuador at 77% and Bolivia has less than 60%. The level of wastewater actually treated is significantly less, however, as only Chile has made significant progress with 98% of wastewater treated. On average, the remaining countries are treating only about 46% of collected urban wastewater (Donoso and Sanin, 2020).

Major Water Problems and Issues

Although the region has made significant progress in addressing water problems that include universal access to drinking water and sanitation, particularly in rural areas, governance, information, drought and flood risk management, water quality and aquatic ecosystem protection numerous challenges remain.
Regional water management problems are strongly influenced by inadequate governance that include lack of coordination of actors, excessive delays in investment studies, lack of knowledge of geographical conditions, as well as lack of data and information. In several countries the challenges of fully implementing reforms persist despite various efforts to improve water policies. The most significant problems and issues that are present in many of the countries of the region are:

1. Lack of a complete and updated national water reporting system of the country's water resources and users.
2. Lack of effective coordination and collaboration between the diverse organizations responsible for water management.
3. Lack of hydrological planning at the national and catchment levels.
4. Lack of stakeholder participation in water resource management.
5. Lack of a stronger presence of regulatory institutions.

Current hydrological and water user data limitations affect the definition of water availability leading to overallocation in many basins with resultant enhancement of water conflicts. An additional weakness is the imprecision in the delimitation and modelling of aquifers that causes incomplete understanding and documentation of groundwater interactions with surface-water. The lack of monitoring remains a serious problem.

Decoupling economic growth from water use is a challenge for sustainable consumption and production and ultimately affecting resource use efficiency. Therefore, dedicated policies to improve water use efficiencies and increasing water re-use are required.

As noted previously, the efficiencies of the existing systems in Andean countries are medium to low so improvements in agricultural wter use efficiencies. Thus, a challenge Andean countries face is the improvement of agricultural water use efficiencies will be essential to increase water and food security as well as protect aquatic ecosystems. These countries must consider water policy changes that provide adequate incentives to use water resources efficiently and ultimately achieve a more sustainable use of water in all sectors.

Water quality is also a challenge for the countries of the region. The hydrogeochemical environments are determined by the interaction between hydrological, hydrodynamic and biogeochemical processes, framed by the Andean geology and a range of socioeconomic activities that include mining, industry, agriculture and urban use. The main water quality issues are the presence of toxic metals and metalloids and the increasing presence of nutrients. The establishment of basic sanitation facilities has significantly increased in the last decade, from 64% of collected wastewater in 2007 to approximately 76% in 2017. However, these figures hide important deficiencies in some countries. In Bolivia, despite significant improvements over the last decade, sewerage coverage in urban areas is less than 60%. The urban sewerage coverage in Ecuador and Peru is 77% and 83%, respectively. The countries with the highest levels of coverage in urban wastewater collection are Chile (97%) and Colombia (92%). Increasing wastewater treatment coverage poses a significant challenge as the regional average of 60% of collected wastewater. There is a significant challenge in increasing water treatment coverage, which at present is on average 60% of the collected wastewater. Chile treats 98% of its collected wastewater while the average in other countries is 46% which when Chile is excluded translates into a general level of coverage of 46%.

The rural sector has historically been characterized by chronic poverty, weak economic integration, and limited political leverage. This combination of factors has resulted in infrastructure which is disproportionately lower than urban centers when compared with metrics such as water and sanitation access. At present, the rural sector presents extremely low coverage of water sanitation and this affects water quality adversely.

Climate change projections indicate an increased frequency of extreme events flooding and droughts. The main challenges the region faces in the issue of floods and droughts are:

- The lack of structural measures and the insufficient capacity to manage extreme events some areas
- Lack of integrated information systems and early warning systems
- Focusing on response to extreme events rather than risk management

REFERENCES

Donoso, G. and M.E. Sanin. 2020. Critical Analysis of the Policies Applied in Latin America in the Water and Sanitation Sector. InterAmerican Development Bank (Washington, DC). DOI:10.18235/0002263

FAO.AQUASTAT: FAO Global Information system on Water in Agriculture. https://www.fao.org/aquastate/es

UNESCO. 2022. Groundwater Making the Invisible Visible. UN World Water Development Report. Division of Water Sciences, UNESCO. http://unesdoc.unesco/org/ark:/48223/pf0000380733

World Bank Open Data, http://data.worldbank.org/.

World Bank. 2022. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators.

Water Scarcity in Africa

Water Scarcity and Water Resources Management within the Context of Climate Change in Africa

Salif Diop and Emmanuel Naah

Overview

The IPCC has recognized that Africa is among the most vulnerable continents to climate change impacts, due to a combination of projected climatic, high poverty levels and the paucity of institutional capacity across the continent (Christensen et al., 2007). This is evident from the ND-Gain index for climate change vulnerability, where the top 5 and 8 out of the 10 most vulnerable countries in the world are in Africa (Notre Dame Global Adaptation Initiative, 2019).

There are two major challenges in addressing climate change impacts in Africa. First, the predicted impacts will add to the existing pressures imposed by limited water resources. Second, climate change pressures will intensify in the face of growing populations and economies. Combined they will place additional stresses on existing water resources and natural ecosystem provisioning services. Thus, the challenge of managing water scarcity and water resources in Africa over the coming decades is both a climate change and development challenge (UNEP, 2009). In this regard, the already-vulnerable rural areas contain the people most at risk from climate change impacts. Any action that increases the resilience of these communities will help respond more effectively to the impacts of climate change, including removing barriers to the integration of climate change adaptation into development planning and decision-making frameworks. This paper provides an overview of the current challenges related to water scarcity and water resource management in the context of climate change faced by most vulnerable areas in Africa and identifies possible options and actions for improved management of water scarcity and water resources.

Africa's Climate and Climate Change

Large parts of Africa are subject to seasonally variable hydrology and geographically uneven distribution of water resources with greater hydrologic variability projected to occur under climate change (Trisos, et al., 2022). This diversity of hydro-climatic zones results in a range of climate risks exists for different economic sectors including agriculture, manufacturing and mining. A study by Distefano and Kelly (2017), reported that water remains a significant obstacle to growth in both developed and developing countries irrespective of their level of water scarcity at present but that efficiency gains from greater investment in technological enhancements could alleviate the problem. However, greater gains through demand management such as reducing use of water intensive goods and services, wastage and shifting activities to regions where existing supply chains are more resilient to the impact of climate changes. Therefore, water security risk mitigation in Africa needs to consider both infrastructure and management responses.

As with other parts of the world, climate change projections for Africa, have a high degree of uncertainty but there is clear evidence of a warming trend across the continent since the 1960s. Nevertheless, it is important to recognize that macro-scale estimations may have significant variations should they be rescaled to the regional or sub-regional level. Under a high Representative Concentration Pathway (RCP), warming projections under medium scenarios estimate that compared to the late 20th century extensive areas of Africa will exceed 2°C by the last two decades of this century. It is likely that land temperatures over Africa will rise faster than the global land average, particularly in the more arid regions. It is also likely that the rate of increase in minimum temperatures will exceed that of maximum temperatures (Niang et al., 2014)

(Figure 8). This warming alone has significant implications for agriculture and the agri-business sector, particularly in relation to increased crop water requirements, changes in growing seasons and impacts on water availability generally.

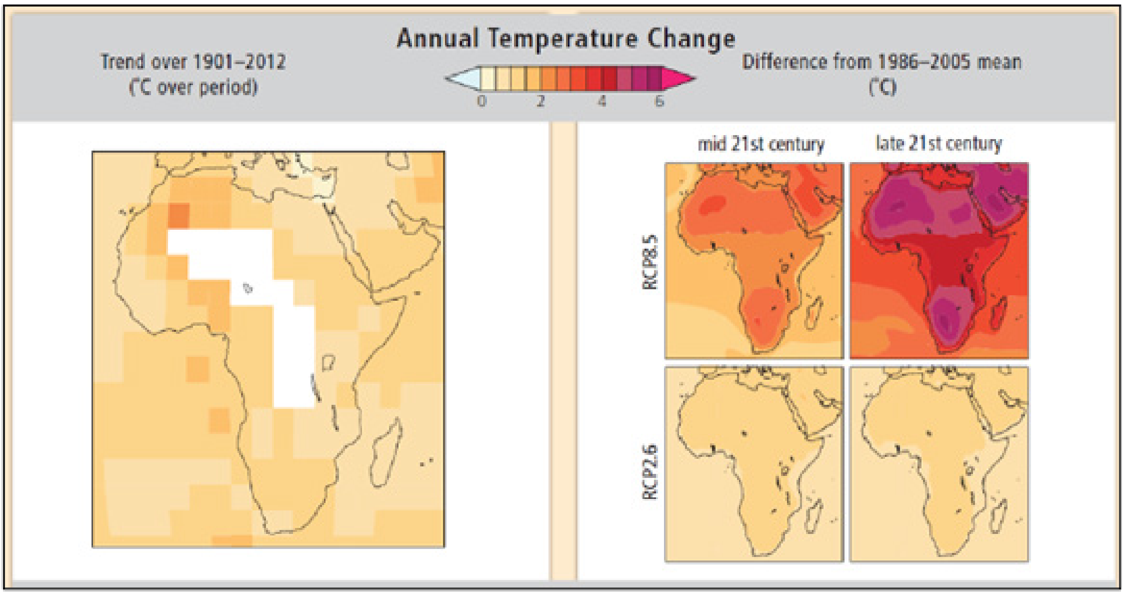

Figure 8. Observed and projected changes in annual average temperature in Africa (Niang et al., 2014)

Understanding the impact of climate change on precipitation in Africa is more difficult. Most areas do not exhibit changes in mean annual precipitation that exceed the baseline variability in more than 66% of the models in either the mid- or late 21st-century periods for RCP2.6 (Niang et al., 2014) (Figure 9). The key findings from the report are:

- It is very likely that mean annual precipitation over southern Africa and the Mediterranean region of northern Africa will decrease in the mid- and late 21st century periods.
- CMIP5 projects likely increases in mean annual precipitation over areas of central and eastern Africa.
- An annual and seasonal decrease in precipitation over the northern African region (including Morocco, Algeria, Libya, Egypt, and Tunisia) is a consistent feature in the 21st century global and the regional climate change projections under the A1B and A2 scenarios.
- Under the A1B scenario, climate models project a significant decrease in the median precipitation as well as the 10th and 90th percentile values during the winter and spring seasons in the northern basins of Tunisia.
- Furthermore, the projection for East Africa is at odds with past precipitation patterns. This is referred to as the East Africa Climate Paradox (Lyon, 2014).

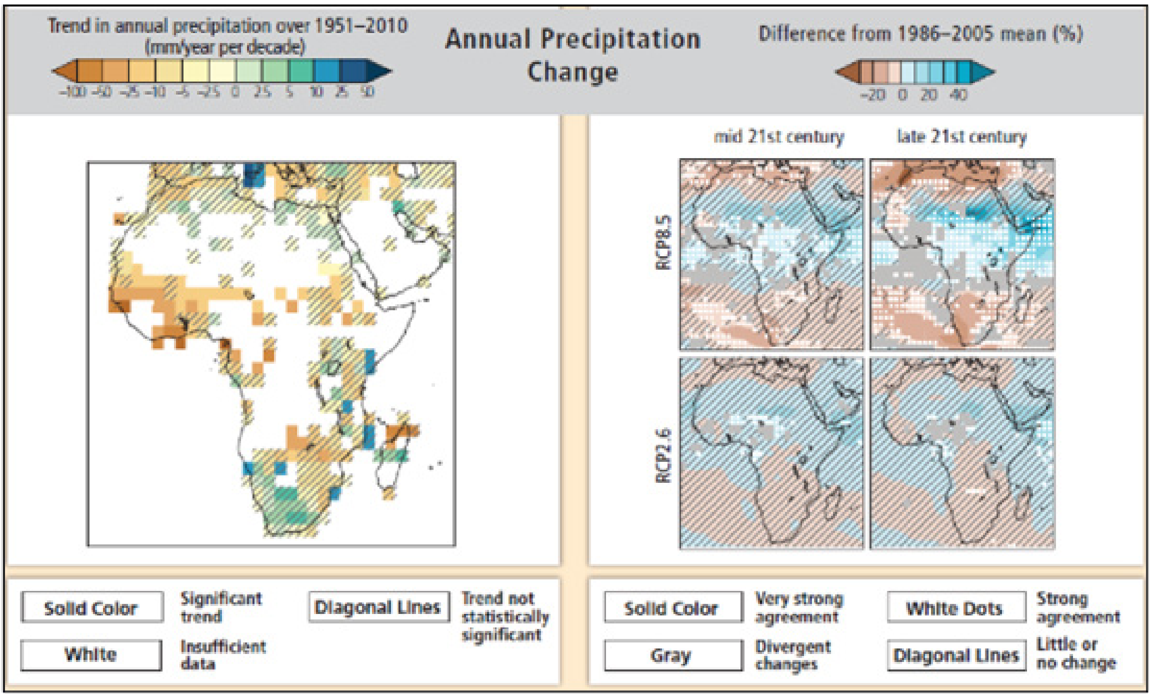

Figure 9. Observed and projected changes in annual average precipitation in Africa (Niang et al., 2014)

Climate projections show a possibility of mixed drought in the horn of Africa due to weather anomaly as well as increased and more intense tropical storm events in the southern Indian Ocean by the end of the century. There will be significant impacts on agricultural production in countries whose weather patterns are impacted by these systems. An increased in extreme weather also has implications for decisions about infrastructure, often requiring larger, more engineered solutions that have greater cost and possibly negative environmental implications. Furthermore, Extreme flood, drought and disease events will increase migration pressures on refugee settlements and urban informal areas. Indeed, it is recognized that adaptation costs will rise rapidly as the planet warms (Trisos et al., 2022), and that it is important to invest early in resilience building in order to save on costs (UNEP, 2021).

Measurement of changes in rainfall associated with climate change is not by itself sufficient to understand related changes in water scarcity and water management since the amount of rain converted into actual streamflow in a river depends on a number of factors, including the nature of the vegetation in the catchment, the level of land degradation and the nature of the soils, slope, and temperature. In South Africa, for example, only around 9% of rainfall ends up as streamflow in rivers flow. IPCC predicts that streamflow will change from -15% to +5% across the continent by 2050. Almost all countries in southern Africa will experience a decline in stream flow but in other areas there is a lack of certainty. Thus, for example the IPPC shows that there is no clear pattern of how streamflow in the Nile will be affected (IPCC, 2022). Changes in streamflow are especially pertinent for sectors such as agriculture, manufacturing and mining. This is because streamflow is often translated into blue water that is dammed, piped and then irrigated or treated for domestic consumption or industrial use. The extent of streamflow changes is also impacted by changes in development and land use within a catchment. Therefore, decisions about the nature and extent of future agriculture, manufacturing, mining and other land uses will impact how much water is available for use.

Climate change and green water use in agriculture poses some risks as well as opportunities. Reduced agricultural production is a likely major impact of climate change in Africa (Trisos et al., 2022). Specific risks for rainfed agriculture caused by climate change could likely increases in erosion. “In Egypt, climate change could reduce crop production by up to 28% for soybeans, and 11% for rice by 2050 and over the same period a 20% reduction in crop growing seasons is projected. Coastal zones and estuaries are particularly at risk from sea level rise, changes in run-off and changing temperatures. A decrease in rainfall, for example, may significantly change the distance salt water penetrates upstream in a river and as a consequence coastal agriculture, including palm oil and coconut plantations in Benin and Cote d'Ivoire, may be adversely affected by inundation and soil salinization. In Kenya, a 1m sea level rise could result in US$500 million loss of income from mangoes, cashew nuts and coconuts" (Pegasys, 2011). However, there may also be positive impacts on agriculture, such as the projected increase in rainfall for some parts of tropical or eastern Africa (Niang et al., 2014).

The blue water use as a result of growing domestic consumption through urbanization is also at risk of climate change. A growing body of literature generated since the AR4 suggests that climate change in Africa will have an overall modest effect on future water scarcity relative to other drivers, such as population growth, urbanization, agricultural growth, and land use change (Niang et al., 2014). In Africa increased urbanization over the next century will also take place through the growth of unplanned settlements that will place increasing strains on already weak infrastructure and management systems. Particular challenges associated with climate change include poor management of storm water in unplanned settlements as this will lead to flash flooding as well as, increased ponding which may increase water related disease.

The Challenges of Water Scarcity and Resource Management in Africa

Climate change in Africa is projected to result in significant changes in the demand for, and availability of, water. Large parts of Africa are already subject to seasonally-variable hydrology, and geographically uneven distribution of water resources. This will increase pressures on Africa's industries and unique ecosystems as demands driven by growing populations and industries intensify (Figures 10 and 11). Despite the fact that Africa is the least polluting and smallest emitter of greenhouse gases (less than 5% of total worldwide emissions, it is projected to be the most heavily impacted continent.

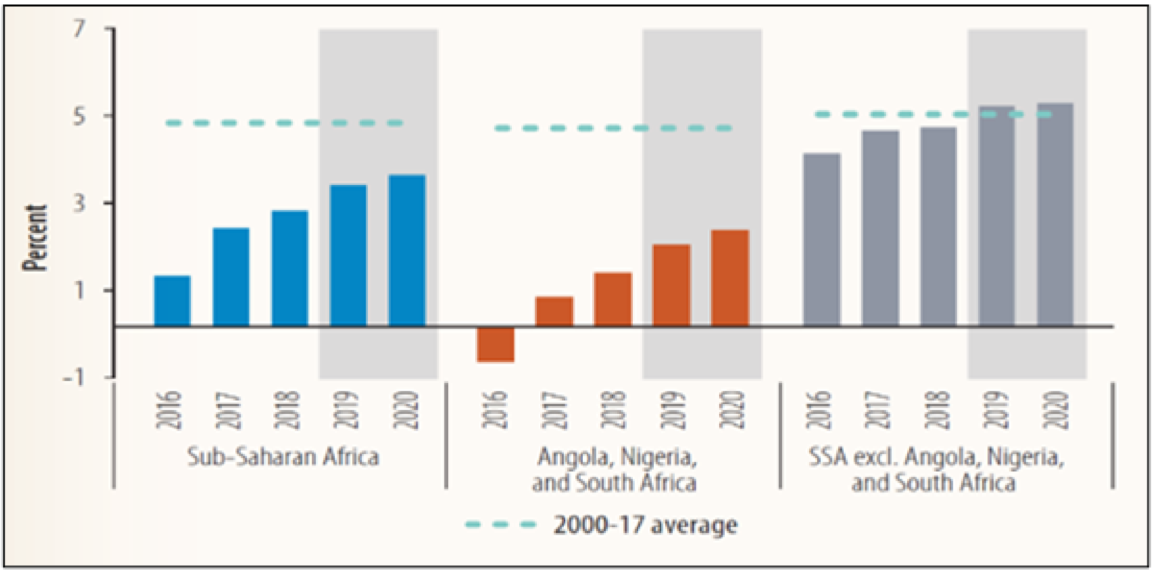

Figure 10. The current and projected average GDP growth in Sub-Saharan Africa.
Period 2016-2018 (source: World Bank, 2018)

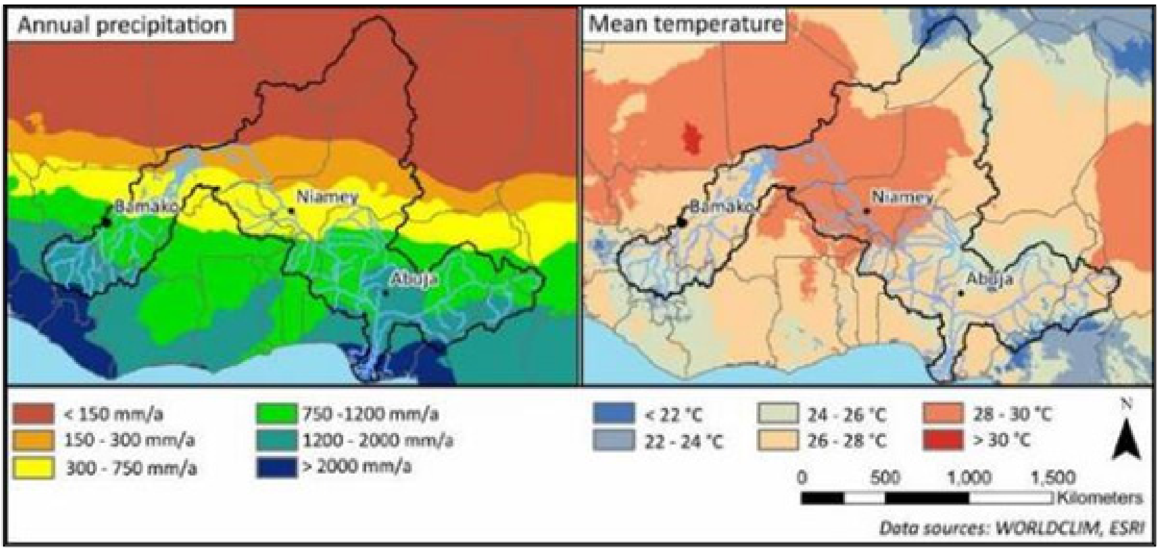

Figure 11. Average annual precipitation and mean temperature in the Niger Basin(source: Aich, 2015)

Climate change is likely to bring more frequent and more intense water-related disasters in many parts of Africa, a continent already prone to floods and droughts. Severe consequences are likely for critical ecosystem goods and services, and, therefore, Africa's population and its development (Terink et al., 2013). Mozambique, South Africa, Malawi and Zimbabwe are already experiencing recurrent floods and droughts and the projected increases in the frequencies and magnitudes of such events, coupled with rising populations suggest a particular vulnerability for water resources and agricultural production. The difficulties of predicting accurately climate change impacts on water systems makes the challenge of ensuring a level of flexibility in planning that facilitates adaptation to changing climate conditions over the long term especially daunting. Indeed, planning under uncertainty is necessary given the projected extremes and associated risks to water -dependent sectors (Trisos et al., 2022).

It should be recognized that the rapidly increasing populations in Africa, together with the associated transitional economic developmental needs, will impose growing demands and pressures on the already stressed freshwater resources. To this end, the proper management of rivers and groundwater resources as well as other readily usable sources such as lakes and reservoirs will be essential. A related concern is the infrastructure for water storage and delivery from these lenticular water systems.

Towards Improved Management of Water Scarcity and Water Resources

While it is important to address the many weaknesses across the continent that may complicate effective responses to climate change, it is equally important to take immediate action to improve the resilience of communities and societies. An overview and synthesis of the key approaches is provided below.

Creating Enabling Policy and Institutional Conditions. Climate change strategies focused on freshwater management strategies will need to ensure that water management plans are aligned with national development and poverty reduction strategies. This would require appropriate legislation, including agreements at the transboundary level, to ensure the existence of effective institutional capacity to manage water resources and services. This will include training well-qualified personnel and ensuring that financial resources and pertinent data are available to develop, operate and maintain the necessary water infrastructure. As human and financial resources are limited in many parts of Africa, it will be important to identify and focus on managing the critical issues in the most vulnerable areas rather than attempting to spread limited resources over too large an area or too many issues. It is also critical that transboundary water resource management is practiced given the large number of transboundary basins that are vulnerable to the impacts of climate change.

Alignment between national development objectives and water availability is of key importance in managing the water-related impacts of climate change. Due to the difficulty of accurately predicting climate change impacts on water management (IPCC, 2014, 2018, 2022), the challenge is to have a sufficiently flexible approach to facilitate adaptation to a changing climate over the years. This will require that water-related development planning departments have access to relevant and up-to-date climate change information. It will also be critical to integrate local resource development and management plans into macro-planning to ensure their systematic consideration, integration and financing. Given that women and children are particularly vulnerable to the impacts of climate change all response plans should proactively address the related issues of gender.

With adaptation as an additional development challenge, substantial increases in financing will be needed to improve rural household land and water management system adaptive capacities and resilience. As the financial resources in African countries are limited, alternative financing options are needed and these should include private sources and public sector funding from developed countries.

Investing in Ecological Infrastructure. As a first line of defense, investments in the protection and rehabilitation of natural aquifers, lakes and reservoirs and wetlands can contribute significantly to increasing resilience to climate change (cf. UNEP, 2021). Vital ecosystem functions and services are already under great pressure from population growth, energy demands, exploitative land-use practices and other pressures, resulting in deforestation and land degradation. Climate change magnifies these challenges. Thus, increasing land and water management resilience requires integrated ecosystem-based approaches, including sustainable land-use management, the designation of water protection areas and the management of natural water storage systems.

It is also vital to secure the vital freshwater ecosystem functions, especially those of groundwater reservoirs and lakes, through appropriate environmental flow and reserve regulation. The objective of this approach is to secure an appropriate flow of rivers and the reserves of other aquatic ecosystems (in particular groundwater reservoirs and lakes). This will require appropriate water allocation decisions and establishment of operating criteria for dam and other storage facilities. The existing and proposed storage facilities in Lesotho ((Dube et al., 2014)) illustrate both the complexity and the importance of integrated operating criteria. Although stakeholders sometimes interpret such approaches as being in direct competition with human development needs, they actually present an opportunity to maintain the important water-related ecosystem services for the overall benefit of society.

Investing in Climate Smart Infrastructure and Technologies. In many areas, climate change is likely result in increases in the frequency of extreme events – droughts and floods. Investment in water management infrastructure and technology to support improved management of droughts floods will be essential. Such investment should focus on the establishment of early warning systems, the rehabilitation of degraded catchment facilities and water conservation efforts. In addition, water supply and sanitation infrastructure may be damaged by flooding, leaving communities vulnerable to poor quality water or lack of drinking water, and lack of functioning sanitation facilities. Thus flood-proofing of water supply and sanitation infrastructure should therefore be considered in vulnerable areas.

In the case of drought, in many parts of Africa, water storage is currently insufficient to disconnect economic growth from prevailing average levels of rainfall. Even in the absence of climate change reality, Africa still requires increased water storage capacity (both large dams and small storage facilities)in order to overcome the impacts of droughts. Finding the financial resources required to develop such infrastructure remains a critical challenge, one that will require participation from African governments, the private sector and international financing agencies.

At the farm level, increased investment and access to information about appropriate irrigation technology, including drip irrigation and rainwater harvesting, is required to improve water use efficiency and productivity. In many areas a shift from rain-fed to irrigated agriculture may be necessary to protect rural livelihoods and food security. Ground water and its governance will be an important target as ground water-specific policies, research and development and financing will all be required if groundwater is to be protected and optimally extracted to support of irrigation in many parts of Africa. Artificial recharge of groundwater sources also presents one potentially important option. Other optionS to developing the buffering function of ground water include the interception and retention of rainfall and runoff for purposes of recharge, the conservation of soil moisture and aquifer storage. However, with increasing impacts of climate change on water resources, it would be unrealistic to expect a substantial increase in groundwater recharge in many parts of Africa (Contribution of Working Group II to the Fourth Assessment Report of IPCC, 2008).

Finally, given that more frequent and more intense water-related disasters are likely, water systems in many parts of Africa will need well-developed early warning systems and post disaster intervention plans. In this regard, artificial intelligence and machine learning hold considerable promise in hydrologic modeling (Gelet et al., 2020) and the development of decision support tools (Srdjevic et al, 2018). These can also be employed to complement and improve environmental monitoring programs for weather, climate, flood forecasting and disaster communication (Sermet and Demir, 2018; UNESCO & UNWater, 2020). Further, it is important that water system infrastructure is well integrated and constructed to optimize systemic interdependences with built-in redundancies and the flexibility to cope with climatic variability and other shocks (UNEP, 2021).

Improved Science and Information. The ability to adapt and mitigate the effects of climate change on water resources depends on the availability of scientific data and the sharing of information particularly across vulnerable shared water basins and aquifers. It is important that the information defines the current state, identifies emerging trends and anticipates possible future paths with the development of models. This requires an appropriate monitoring system that can deliver the necessary information at the appropriate scale. Such systems should extend beyond simply monitoring climate trends to include the monitoring the status of the resource, detect emerging trends and to monitor related environmental variables and processes related to water and to ecosystem-based climate change adaptation. Given the critical role of groundwater, better knowledge and a coherent region-wide information on these resources, is specifically necessary.

Another critical part of an improved information system is development of early-warning systems, particularly for floods. Better forecasting and early warning systems are a prerequisite for adaptation, predicting and limiting the effects of extreme events, planning for planting dates to coincide with the beginning of the rainy season, and predicting whether or not disease outbreaks may occur in areas prone to epidemics. Improved intelligent early warning systems that take advantage of the wide array of remote sensors and observations. The limited institutional capacity in Africa, from both financial and human capacity perspectives, constrains the creation of a continental flood monitoring system that enables exchange of information both within and between countries.in the face of both financial and human capacity constraints. Citizen participation in remote and un-instrumented regions can play a major role in this by providing data and information through internet and social media data streams (Hall, et al, 2014;Wang, et a;, 2018; Sit et al., 2019, UNESCO & UN-Water 2020; and Weeser et al, 2021).

A particular challenge for management of transboundary waters are the complications associated with by high levels of political instability and conflict. A key part of responding to the coming changes will be the ability to learn from one another, to share information and experiences, including indigenous approaches to water management, for the purpose of developing a body of African experience with and knowledge of the impacts of climate change. Another challenge is posed by the lack of models based on scientifically sound information to predict the impact of climate change at the local level. To achieve this goal increased investments in the science of climate change, including understanding its impacts, its trends and its adaptation and remediation methods will be required. One option for achieving this goal would entail the creation of African climate change centers of excellence that would be geared at developing capacity and expertise of Africans to tackle challenges related to climate change. In addition it would be important to build local capacity to monitor water quality, collect data and identify good water management approaches, reinforce traditional adaptation mechanisms and provide early warning systems for local communities.

Working at Different Scales. There is a range of different water allocation systems across Africa, with many parallel formal and customary systems working at different scales. It is important that they are sufficiently flexible to enable water allocation adjustments to climate variability while respecting national development objectives. These systems need also to be sufficiently simple to be effectively implemented and managed within existing capacity constraints.

In the case of transboundary lakes, basins and aquifers, it is particularly important that important that effective transboundary water allocation systems are put in place, supported by accurate, shared data on the status of each source. While some basins have transboundary agreements a large number of basins do not. Even when they do there is often a lack of or institutional capacity at the national or transboundary level to implement and policies that optimize the sharing of water resources.

There is an urgent need to strengthen institutional structures at continental and regional scales for ground water sources that are often neglected even at local scales. This is particularly important when considering development opportunities as climate change is a key driver for expanding regional integration across the continent. In addition, regional integration should be focused more broadly than simply on the water sector. This will aid in the full development of regional public goods, such as transport infrastructure, markets, regional power pools, trade arrangements, and food security responses that can provide substantial benefits in building regional and local resilience to climate change (FAO, 2018).

At the sub-basin or local level there are a range of water allocation systems operating in Africa and it is important that these systems are sufficiently flexible so that adjustments in allocations can be made to manage climatic variability and change. It is also critical that all stakeholders are involved in the water resource management process thereby ensuring that there is full support for the approaches taken. The involvement of stakeholders should also ensure that responses to emerging circumstances are timely, adaptive and optimal. However, the key challenge lies in building the adaptive capacity of such institutions as an effective response to climate change will enable innovation at all levels and creation of flexible and responsive water management systems. Flexible allocation systems that allow changes in water use to adjust to short-term climate variability and longer-term climate change are of critical importance (Claussen et al., 2003).

Decentralized Adaptation. Adaptation takes place at different levels that range from the creation of major storage and flood prevention infrastructure, down to the household level in rural areas (Niang et al., 2014). In this regard, while governments may not be able to extend the necessary services to vulnerable populations, the provision of information itself can assist communities and households to prepare for future changes related to climate. The provision of information and training for rural communities is particularly important because of their high levels of vulnerability and the fact that they are often left out of the information loop. Information could include alternative crops and climate smart production methods, improved livestock management techniques, local water-resource use and protection, and flood protection and warning systems.

For several reason, women are often at great risk from the effects of climate change and thus gender equity especially in areas with high gender disparities, should form a key part of climate change adaptation strategies. Also, it is critical that women be actively involved in decisions relating to investments in infrastructure and technology to ensure that they reflect women's priorities and needs.

As noted earlier, access to groundwater is perhaps the most critical factor enabling both rural and urban, populations to maintain sustainable livelihoods. Despite the fact ground water is often poorly understood, it remain a key resource for local coping strategies. Thus, for example, ground water receives little attention in many Integrated Water Resource Management (IWRM), and Integrated Lake Basin Management (ILBM) approaches and in more general development planning as well. This deficiency needs to be addressed strategically through appropriate regional, sub-regional and national policies, through proper integration into IWRM/ILBM processes, structures and institutions, and through its prioritisation in adaptation initiatives.

Attention to local institutions is critically important when designing adaptation projects and policies. Such institutions are necessary enablers of the capacity of households and social groups to deploy specific adaptation practices. Also, a systematic scaling-up of locally-appropriate solutions is key to ensuring area- and region-wide impacts on poverty alleviation, climate change adaptation and economic development.

Considering the Water/Energy/Food and Health Nexus. It is important to note that several countries depend on hydropower, even though the potential in Africa is still hugely underdeveloped. This energy source is also under threat in some areas from diminishing stream flows or increased flow variability. Further, the high susceptibility of the water-energy-food (WEF) nexus (Ringler et al., 2013)
to climate change as well as the interdependence within WEF itself, amplifies the risks of reduced hydropower revenues and heightened water and food insecurities. Consequently, the 'climate change-proofing' of current infrastructure is an important measure to protect these energy supplies and to protect economic and social development potential while also assuring food and water security (Trisos et al, 2022). Such climate change proofing might include, for example, amended operating rules to consider changing rainfall patterns, the raising of dam walls, or changes to environmental flow releases. At the same time, however, new hydropower development should take place in a manner that ensures it will be able to withstand the impacts of climate change.

It is important to ensure both water and energy security in an integrated manner, across the water-energy-food nexus, at both basin and national levels within the context of climate change. This is particularly important because of the large number of transboundary basins found in Africa and such understanding are needed both levels for effective joint planning across the water-energy-food nexus. Furthermore, and at the core of the 2030 Sustainable Development Goals/SDG's and 2063 African Agenda "The Africa We Want", the water/energy/food/health and ecosystems nexus is increasingly recognized as core to addressing the issue of climate change and securing the wellbeing of the many millions of people in Africa who lack access to basic services such as water and sanitation, energy, food and health.

Conclusions

Based on the findings reported in this section, a number of general conclusions may be drawn. It is evident that vulnerability to climate change risks and impacts, as well as opportunities for adaptation and mitigation in Africa are shaped by complex interactions between land and water resource characteristics, economic conditions and the often highly-diverse livelihood capitals and strategies of individual households. Thus, effective adaptation planning and implementation of land and water management systems are highly context-specific and require an appropriate level of knowledge and understanding of local conditions.

Adaptation should, therefore, be knowledge-based and integrate both scientific and local knowledge. Local knowledge systems for adaptation in many places have evolved from the experiences of generations adapting to changing climate conditions. To be effective, however, short and long-term uncertainties about precipitation and water availability, as well as the impacts, over short- and long-term climate change and its impacts, must be reduced, especially at local levels.

Effective and equitable adaptation actions, furthermore, require that knowledge and information on climate change and adaptation practices in land and water management are shared widely and, in a form, that users can understand. Knowledge and information need to be suitably packaged and appropriately communicated to all decision-makers to scale-up interventions.

REFERENCES

AfDB, 2012. The Cost of Adaptation to Climate Change in Africa. UNECA, Addis Ababa, 41p.

Aich, V., 2015. Floods in the Niger River Basin in the face of Global Change – Analysis, Attribution and Projections. Doctoral dissertation, Mathematisch-Naturwissenschaftlichen Fakultät, Universität Potsdam.

Bradfield, L., 2014. Seasonal Drought in the Greater Horn of Africa and Its Recent Increase during the March May Long Rains. Journal of Climate.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.-T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A., Whetton, 2007. Regional Climate Projections. In: Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.), Climate Change, 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Claussen M., Brovkin V. and Ganopolski A., 2003. Climate change in northern Africa: The past is not the future. Climatic Change 57 (1-2), 99-118.

Distefano T. and Kelly S., 2017. Are we in deep water? Water scarcity and its limits to economic growth. Ecological Economics, 142, 130–147. https://doi.org/10.1016/J.ECOLECON.2017.06.019

Dube, R., Maphosa, B. and Scott-Goldman, J. 2014. The role of local community institutions in the adaptation of rural and urban communities to the impacts of climate change on water access and use. WRC Report No. 1963/1/14.

FAO, 2018. The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. Rome. Licence: CC BY-NC-SA 3.0 IGO. http://www.fao.org/3/i9540en/I9540EN.pdf

Gelete, Gebre, Huseyin Glokcekus, Tagesse Gichamo. 2020. Impact of Climate Change on the Hydrology of the Blue Nile Basin, Ethiopia: A Review. Journal of Water and Climate Change 1 December. 11 (4): 1539-1550. Httpe://doi.org/10.2166/wcc.2018.157.

Hall, J.D., D. Grey, F.Fung, C. Brown, S. j. Dadson, C.W. Sadoff. 2014. Coping with the Curse of Freshwater Variability> Science. Vol. 346, issue6208. Pp. 429-430. doi: 10.1126/science.1257890

IPCC, 2014. Summary for policymakers. 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. and 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 University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

IPCC, 2018. Summary for Policymakers. In: Masson-Delmotte, V., Zhai, P., Pörtner, H. O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (eds.) Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above preindustrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland, 32 pp http://www.ipcc.ch/pdf/special-reports/sr15/sr15_spm_final.pdf).

Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart, Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014)

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P., 2014. Africa. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., 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 B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

Nkem, J., 2016. In “Unpacking Africa’s enigma with INDCs”; Science*Policy*Africa; Quaterly Newsletter of the African Academy of Sciences; PP 14 and 15; Sept. 2016. Nairobi, Kenya.

Notre Dame Global Adaptation Initiative, 2019. https://gain.nd.edu/our-work/country-index/
Pegasys, Water Footprint and Competitive Advantage in the Nile Basin, (2011). https://studylib.net/doc/8684417/water-footprint-and-competitive-advantage-and-trade-in-th...

REDIS (2018). Location and Contracted Capacities of Renewable Energy Projects in South Africa. Vol. 2018. Deparment of Energy, South Africa.

Ringler, C., Bhaduri, A., and Lawford, R. (2013). The nexus across water, energy, land and food (WELF): potential for improved resource use efficiency? Current Opinion in Environmental Sustainability 5, 617-624.

Schulze, R.E., 2011. A 2011 Perspective on Climate Change and the South African Water Sector. Water Research Commission, Pretoria, RSA, WRC Report 1843/2/11. pp 366.

Sermet, Y., I, Demir. 2018. An Intelligent System on Knowledge Generation and Communication. About Flooding, Environmental Modelling & Software, Vol. 108, pp. 41-60. doi.org/10.1016/j.envsoft.201806.003.

Sit, M.A., C. Koylu and I. Demir. 2019. Identifying Disaster-related Tweets and Their Semantic, Spatial and Temporal Context Using Deep Learning Natural Language Processing and Spatial Analysis: A Caase Study of Hurricane Irma. International Journal of Digital Earth. Pp. 1-25. Doi.org/10.1080/17538947.2018.1563219.

Srdjevic, Bojan, Zorica Srdjevic, Milena Lakicevic. 2018. Validating the Importance of Criteria for Assessing Climate Change Scenarios. Journal of Water and Climate Change. 1 September 9(3), 570-583.

doi.https//doi.org/10.2166/wcc.2018.57

Terink, W., W.W. Immerzeel and P. Droogerset, 2013. Climate change projections of precipitation and reference evapotranspiration for the Middle East and Northern Africa until 2050. Intern. J. Clim. (2013). doi:10.1002/joc.3650

Trisos, C.H., I.O. Adelekan, E. Tolin, A. Ayanlade, J.Efitre, A. Gerneda, K. Kalaba, C. Lennard, C. Maseo, Y. MIgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S.Zakieldeen. 2022. Africa. In Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the South Assessment Report of the Intergovernmental Panel on Climate Change. [H.O. Portner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. MMintenbeck, A. Algeria, M. Craig, S. Langsdorf, S. Loschke, V. Moller, A. Okem, B. Rarna {eds.}]. Cambridge University Press. In Press.

UNEP, 2009. Kenya. Atlas of Our Changing Environment, United Nations Environmental Programme, Nairobi, Kenya, pp. 1-39.

United Nations ECA, 2019. Economic Report in Africa 2019 ; Fiscal Policy for Financing Sustainable Development in Africa; 169 p. published in March 2019 by United Nations Economic Commission for Africa P.O. Box 3001 Addis Ababa, Ethiopia.

UNEP. 2021. Future Proofing Infrastructure ro Address Climate Change, Biodiversity and Pollution CrisesUNEP. Nairobi.

UNESCO, UN-WATER, 20220. United Nations Report 2020: Water and Climate Change, Paris, UNESCO

Wang, R.O., H. Mao, Y. Wang, C. Rae, and W. Shaw. 2018b. Hype-resolution Monitoring of Urban Flooding with Social Media and Crowdsourcing Data, Computers & Geosciences. Vol. 111. Pp. 139-147. doi.org/10.1016j.cageo.2017.11.008.

Weeser, B., J. Graf, N.K. Nijue, P. Cerutti, M.C. Rufino, L. Breuer, S.R. Jacobs. 2021. Crowdsources Water Level Monitoring in JKenya's Sondu-Miriu Basin. Who is "The Crowd"? Frontiers in Earth Science. https://doi.org/10.3389feart.2020.602422.

World Bank, 2018. Africa's Pulse (English), Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/881211538485130572/Africas-Pulse

PART III

CONCLUSIONS

The continents of Africa and America are vast with a portion of each in both the northern and southern hemispheres. It is not surprising, then, that the single term, “variable”, applies not only to the patterns and quantities of rainfall across the continents but also to differences that include many features and circumstances, including landscapes, climates, available resources and demographic characteristics. It also describes these differences within the one hundred or so countries on these continents. So what can be learned from a study of water scarcity of two continents so vast and so variable? Are there universal lessons that transcend continental, regional and local variabilities? This brief study by specialists from the two continents suggests that the answer is yes.

Despite the variability of waterscapes, landscapes, climate, governance institutions and personal behavior several common themes and findings emerge from this study. They relate to how water scarcity is defined and measured, some of the consequences of water scarcity and matters that need to be addressed if water is to be effectively managed in the future when various stressors on the resource will intensify. These are summarized in the conclusions below.

1. Care should be taken whenever using the term “water scarcity” to be clear on the definition as well as on the metrics available for measuring it. There are a host of definitions of water scarcity that mean different things to different people and thus have different implications for water policy and water management. Care should also be taken in selecting the metrics used to characterize water scarcity as different metrics require different data. Therefore, when addressing water scarcity it is important to know about the quality the data, as well as the strengths and weaknesses of the assumptions made in the absence of data.

2. Climate change poses threats and uncertainties to virtually every locale in Africa and the Americas. Two threats are frequently mentioned on both continents. The first is that for many places there will be a decline in precipitation from historical levels thereby reducing accustomed levels of water supply. In other locales modelling studies suggest just the opposite. The second is that both the frequency and intensity of adverse climatic events such as floods and droughts will increase. However, there are very few, if any, places on either continent where the precise impact of climate change is clearly understood. This is especially true for Africa. Therefore, adaptive water management and planning is an important and crucial step that must be taken now, and must include flexible approaches in anticipation of the current uncertainties about the timing, impact and extent of climate changes.

3. Develop and implement effective ground water management plans…..everywhere! This study reveals that there are few, if any, examples on either continent where ground water is effectively managed. This is despite the fact that ground water supplies are an increasingly important source of water everywhere as surface waters become fully appropriated and existing surface supplies are diminished because of climate change. Ground water can provide additional sources of supply even in countries that have small endowments of ground water. The sustainability of ground water resources is under threat whenever they are exploited in an individualistically competitive fashion. Effective and enforceable management schemes are needed to avoid persistent and premature decline in water tables and, in some cases, the physical and/ or economic exhaustion of the resource. Effective management schemes are also needed to protect ground water quality. In many locales there is an absence of good data on the characteristics and conditions of local ground waters. Good management will require such data.

4. There is widespread need to protect and enhance water quality. The failure to protect the quality of both ground and surface waters will lead inevitably to a reduction in supplies available for most consumptive and some non-consumptive uses. Thus, there is a need for laws, policies and enforcement mechanisms to enhance and protect water quality though these will vary among regions and locales. Some countries lack enforceable laws and policies altogether while others may have a reasonable array of laws and policies fail that are ineffective because of a lack of monitoring and enforcement. Water quality protection needs to be high on the list of priorities for most nations in the Americas and Africa as a way of protecting existing supplies in the face of adverse changes in climate.

5. Water policies should be based on known water science and scientific research. Accelerated development of water science should be encouraged. Known science should be the basis upon which water policies are devised. At a minimum, policies that contradict available science should be avoided. Simultaneously, higher priority should be accorded to the support of appropriate scientific research on water as a straightforward way to address the water problems of the future. These may be somewhat different than those of the past because of increasing scarcity (by any definition) and the uncertain impacts of climate change. There is a need for adequate monitoring as well as the collection and storage of water quantity and quality data. The making of enlightened water policy depends upon the availability of knowledge about the qualitative and quantitative conditions of the water resources. Without monitoring the making of effective policy is severely constrained.

6. Where possible new economic activity should be steered away from dry lands. There are examples of countries such as Mexico where a majority of the economic activity is currently located in arid zones. In such circumstances, efforts should be made to locate new and expanded activities in more humid areas where the water supply is more generous. Clearly future water management challenges can be more easily addressed if economic activity and other drivers of water use are located where water is relatively plentiful. Such a strategy could be especially important in areas where precipitation will be diminished because of climate change. To the extent possible, actions that create and/or encourage economic and population growth in areas where drought is localized and permanent should be avoided.

7. Make efforts to disconnect water and economic growth. Historically, economic growth and population growth have been considered major drivers of the growth of water demands. There is some evidence that emerges from the southwestern United States that water and economic growth can be disconnected. This may be a short term phenomenon because much water has been freed up by water conservation practices. Such efforts cannot go on indefinitely because there are ultimately minimum quantities of water that must be devoted to agricultural and urban activities if they are to continue at all. Nevertheless, even if limited to the short term water can be freed up through conservation to serve population and economic growth as well as existing activities.

8. Water Governance. Effective water governance is essential if scarcity is to be addressed. Such governance is inadequate in virtually every setting in Africa and the Americas. Where it does exist it relates to current circumstances and lacks the flexibility to respond to future conditions that are likely to be far more constraining and challenging than those of today. Therefore, it is essential that appropriate water governance institutions are established to ensure that flexible and adaptive water policies are devised and implemented.