CATALYSING SUSTAINABLE WATER SECURITY IN EASTERN AFRICA THROUGH SCIENCE, TECHNOLOGY & INNOVATION

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Foreword

Africa faces a growing water crisis. It is projected that with increasing population and urbanization, at least half of the population may be living in water-stressed areas by 2030 under the current realities of climate change. The Africa Water Vision 2025 offers a context within which water security and sustainable management of water resources can be achieved. Advancing Science, Technology and Innovation (STI) can play instrumental roles in the water security agenda of the continent. STI is already recognised in Africa's Agenda 2063 and the UN Agenda 2030 as an enabler for achieving the developmental priorities of countries. The Science, Technology and Innovation Strategy for Africa (STISA-2024) which is a key component of achieving AU's Agenda 2063 therefore calls for continuous investments in scientific research and development, scientific cooperation and partnership and the adoption of innovative technologies to accelerate and sustain growth in key areas such as the water sector.

Africa is at the Centre of the world's global challenges and one of UNESCO's global priorities. Africa is a global priority not solely because of the challenges it faces but because of its resources and potential which gives the organization the opportunity to be a part of the transformation of a region whose history speaks of the strength and resilience of its people and their outstanding aptitude to use knowledge, technology and innovation to advance its course and humanity.

As a UN body with a mandate in science, UNESCO has over the years provided African countries with guidance in using STI to address daunting water development challenges to enable sustainable development. The UNESCO Intergovernmental Hydrological Programme (IHP) is the only intergovernmental cooperation programme of the UN system dedicated to water research and management, and related education and capacity development. It has been supporting sound, evidence-based water governance and decision-making drawing on transdisciplinary science and technology other knowledge systems in sub-Saharan Africa. The IHP seeks to enable all stakeholders to participate in the creation of a new, sustainable, water culture. The ninth phase of the HP (IHP-IX, 2022-2029) puts science to action for a Water Secure World, in a Changing Environment, with focuses on five interrelated Priority Areas: Scientific research and innovation; Water education in the Fourth Industrial Revolution including sustainability; Bridging the data-knowledge gap; Inclusive water management under conditions of global change; Water governance based on science for mitigation, adaptation, and resilience.

This publication, which analyses and accentuates STI applications in the water sector of Eastern Africa is timely and should help stakeholders define the entry points for developing and scaling up appropriate STI interventions for water security. We are hopeful that the findings will also stimulate policy decisions that drive STI investments in the water sector.

Shamila Nair-Bedouelle,
Assistant Director-General for Natural Sciences,
UNESCO

Preface

Access to safe water remains a great global challenge, which is particularly acute in Sub-Saharan Africa. Whereas there exists international frameworks and national policies to address this challenge, millions of people living in Africa still do not have access to this vital commodity. The situation is further exacerbated by increasing population and rapid urbanization, climate change, pollution from industrial emissions and effluents and agricultural activities. In this context, therefore, it is imperative for players at different levels to evaluate the existing strategies with a view to optimizing access, distribution and utilization of water resources in the continent.

The potential of science, technology and innovation (STI) tools to catalyze sustainable water security in Africa cannot be gainsaid; it provides unlimited opportunities for enhancing utilization and management of water resources. However, effective deployment of these tools must be preceded by the enabling political, institutional and financial frameworks that optimize their utility and promote south-south cooperation and intercountry learning on their application.

This report explores the interplay of integral components underpinning potential of application of best STI practices in managing water resources in Africa. It covers a broad array of issues, key of which include how emerging technologies can be integrated into national water development policies; how political, institutional, and financial frameworks can enhance scaling up of best STI practices; examples of best STI practices currently being deployed in the water sector; and strategies to promote cooperation and intercounty learning on their application.

From the evidence of this report, it is clear that STI will increasingly play a pivotal role in managing water resources in Africa and enhancing its sustainability. However, to achieve the intended purpose, it is important and imperative that all stakeholders in the water sector and other allied sectors be brought on board to help in addressing the identified gaps hindering effective deployment and uptake of these emerging technologies and innovations.

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Executive Director
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We would wish to appreciate all the organizations that provided secondary data used in the generation of these findings. Finally, we would wish to appreciate Dr. Simeon Dulo and Prof. George Krhoda for their scholarly review of the content and the materials presented in this report.

The team of authors led by Prof. Tom M. Ogada, Executive Director ACTS, Dr. Samuel Partey, Program Specialist at UNESCO, Dr. Jayakumar Ramasamy, Chief of UNESCO Science Executive Office, Dr. Joshua Ombaka Owade and Mr. Patrick Obunga all from ACTS would wish to appreciate all the technical personnel that have shaped the material and content of this study. We also appreciate the efforts of the editorial team comprising, Ms. Xinhong Li (UNESCO), Ms. Anne Lilande (UNESCO), and Mr. Alfred Oduor (ACTS).

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Acronyms

4IR	Fourth Industrial Revolution
ACGE	African Centre for a Green Economy
AfDB	African Development Bank
AMCOW	African Ministers' Council on Water
AMI	Advanced Metering Infrastructure
ANN	Artificial Neural Networks
ATM	Automated Teller Machine
AQUASTAT	Food and Agriculture Organization global water database
ASTI	Agricultural Science and Technology Indicators
AU	African Union
AWSB	Athi Water Services Board
BTI	Bertelsmann Stiftung's Transformation Index
CDAs	Community development assistants
COD	Chemical Oxygen Demand
COVID-19	Coronavirus disease
CTCN	Climate Technology Centre and Network
DO	Dissolved Oxygen
DRC	Democratic Republic of Congo
DW	Development Workshop
EAC	East African Community
EEBC	Eritrea-Ethiopia Boundary Commission
EPA	Environmental Protection Agency
EU	European Union
FAO	Food and Agriculture Organisation
FH	Food for the Hungry
GCF	Green Climate Fund
GCWW	Greater Cincinnati Water Works
GDP	Gross Domestic Product
GEF	Global Environment Facility

GIS	Geographic Information System
GOK	Government of Kenya
GRACE	Gravity Recovery and Climate Experiment
GW	Ground Water
GWP	Global Water Partnership
HDI	Human Development Index
IAPS	Integrated Algae Ponding System
IFP-EW	The Initiative for Peacebuilding – Early Warning Analysis to Action
IFPRI	International Food Policy Research Institute
IGAD	Intergovernmental Authority on Development
IGADD	Intergovernmental Authority on Drought and Development
ICA	Infrastructure Consortium for Africa
ICT	Information, Communication, and Technology
IMF	International Monetary Fund
iMoMo	Innovative Monitoring and Modelling
IOC	Indian Ocean Commission
IoT	Internet of Things
ISM	Integrated System Modelling
IT	Information Technology
IWA	International Water Association
IWMI	International Water Management Institute
IWRA	International Water Resources Association
IWRM	Integrated Water Resources Management
i-WSSM	International Centre for Water Security and Sustainable Management
JIP	Joint Programming Initiative
KCCA	Kampala Capital City Authority
KIHBS	Kenya Integrated Household Budget Survey
LDCs	Least Developed Countries
LICs	Low Income Countries
MDG	Millennium Development Goal
MICS	Middle-Income Countries

MWA	Millennium Water Alliance
NASA	National Aeronautics & Space Administration
NASAC	Network of African Science Academies
NCD	Non-Communicable Disease
NCWSC	Nairobi City Water and Sewerage Company
NSAS	Nubian Sandstone Aquifer System
NWIS	National Water Information System
OBA	Output Based Aid
ODI	Overseas Direct Investment Organization
ODF	Open Defecation
OECD	Organization for Economic Co-operation and Development
PSAWEN	Puntland State Authority for Water, Energy and Natural Resources
RAS	Recirculating aquaculture SYSTEMS
RO	Reverse Osmosis
SCADA	Supervisory Control and Data Acquisition
SCP	Social Connections Policy
SDGs	Sustainable Development Goals
SGC	Science Granting Council
SGR	Standard Gauge Railway
SIDS	Small Island Developing States
SIWW	Singapore International Water Week
SMS	Short Message Service
SSA	Sub-Sahara Africa
SSC	South-South Cooperation
STI	Science, Technology, and Innovation
STISA	Science, Technology, and Innovation Strategy for Africa
SNPSF	National Society of the National Posts and Financial Services
SVM	Support Vector Machines
SWM	Smart Water Management
TFAs	Technology Focus Areas
TrC	Triangular Cooperation

TVET	Technical Vocational Education and Training
PoU	Prevalence of Undernourishment
UN	United Nations
UNDP	United Nations Development Programme
UNCTAD	United Nations Conference on Trade and Development
UNICEF	United Nations Children's Fund
UNECA	UN Economic Commission for Africa
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNOSSC	United Nations Office for South-South Cooperation
US	United States
USAID	United States Agency for International Development
WASH	Water, Sanitation and Hygiene
WASREB	Water Services Regulatory Board
WBG	World Bank Group
WFP	World Food Programme
WHO	World Health Organisation
WSNS	Wireless Sensor Networks
WSP	Water Service Provider
WSS	Water Supply and Sanitation
WWF	Worldwide Fund for Nature

Executive Summary

Application of science, technology and innovation can enable the actualization of the water security targets of the Sustainable Development Goals and Africa's Agenda 2063. Understanding the current situation of STI in relation to water security will help advance knowledge and define the entry points for investments and the scaling up of innovations in science and technology in Africa's water sector. With a focus on Eastern Africa, this exploratory study specifically establishes: 1) the status of water resources including climate change impacts; 2) the current and potential application of STI in the water sector; 3) the STI infrastructure for water development and management; 4) the enabling political, institutional and financial environment for promoting and scaling up best STI practices in the water sector; 5) the strategies for promoting south-south cooperation and intercountry learning on the application of STI; and 6) the strategies for mainstreaming best bet STI interventions into national water related development policies.

A combination of desktop reviews and interviews of key experts and institutions in the water sector were used in data collection. The primary and secondary data collected were analysed and synthesized into report, which was then validated by external reviewers.

On the status of water resources, it was found that compared to the western, central, and southern Africa, Eastern Africa has the least water resources, representing about 6.5% of the continent's internal resources. The western part of Eastern Africa has surplus rainfall, while the northern part has large water deficits. Kenya and South Sudan were found to be water-scarce based on the available renewable water sources. Tanzania and Uganda were found to be vulnerable while the remaining countries in Eastern Africa were mostly water-stressed. By 2025, most countries in Eastern Africa are projected to face water scarcity. Groundwater could be used as a major source of water to meet the demand; however, there is limited knowledge and development of groundwater sources in the region as this source of water is the least monitored and understood. Several threats to water resources and security exist. These include pollution from industrial emissions and effluents, agricultural activities, rapid urbanization, increased population growth and climate change. These threats are likely to negatively impact water quality and access if not mitigated. Moreover, climate change will continue to cause increased temperature and variability in precipitation and severe negative effects on water resources availability, food security, tourism, human health, biodiversity and coastal development.

The study found some potential and on-going STI interventions undertaken in the region particularly for enhancing water provision (supply, treatment, quality, and access), sanitation, and agricultural services. Some of the interventions which include real-time monitoring of water quality, quantity, and system performance and digitalization of water systems have been undertaken by private institutions, NGOs, government/public sectors and through public-private initiatives. The study showed that smart technologies such as prepaid water meters, advanced metering systems, water ATMs and mobile money payments widely adopted in Kenya, Rwanda, Uganda, and Tanzania have significantly reduced the non-revenue water, improved technical operation and maintenance, reduced maintenance costs by promoting lean and effective staff establishment, increased revenue collection, and improved water resource management.

For most of the existing smart STI interventions, the study found the adoption rate (considering prevalence use) is however still below 30%. The low adoption is caused by the existing infrastructural challenges including inadequate funding, lack of skilled personnel, inadequate institutional support and network and power problems. For effective adoption and implementation of STI-related smart technologies, all stakeholders should be brought on board including the users and local communities.

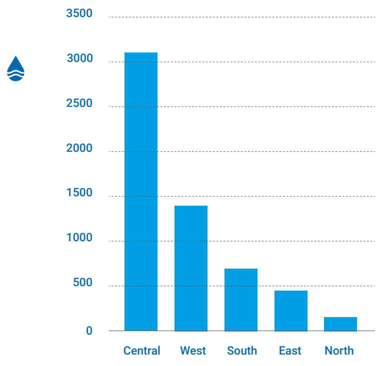
The analysis of strategy for promoting and scaling up the best STI in the water sector found that "starting small", in other words – piloting, could reduce some of the risks that may be difficult to reverse. The success of the STI intervention (pilot project) will then inform the subsequent projects and necessary technology adjustments during scale-up. South-South Cooperation (SSC) and inter-country learning on STI strategies should not be underplayed. Effective SSC in the water sector can be achieved through 1) creating a policy network and knowledge exchange platform, 2) facilitating the creation of partnerships at the local, national, and regional levels, 3) assisting parties' access for better use of funding mechanisms, and 4) recommending actions to enhance country-level support.

1 Introduction

1.1. Background

Africa has a combined population of over 1 billion people, representing about 17% of the global population (UN, 2019). Its water resources are estimated to be nearly 9% of the world's freshwater resources (FAO, 2005). However, these resources are unevenly distributed, with the most water-rich countries in Central and Western Africa holding 54% of the continent's total resources and the 27 most water-poor countries holding only 7% (Table 1 and Figure 1).

Table 1: Distribution of renewable water resources in Africa

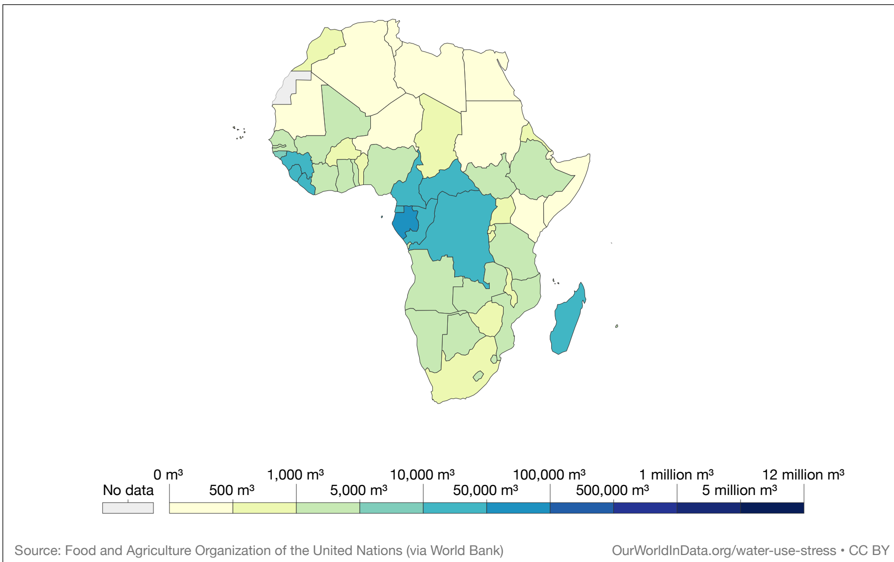


Total renewable water resources per capita (m³/capita/year) 2012

Top 5 Countries	
Congo	200 966
Gabon	106 910
Liberia	56 188
Equatorial Guinea	36 111
Central African Rep	32 182

Bottom 5 Countries	
Libya	109
Algeria	324
Djibouti	331
Tunisia	434
Cape Verde	599

Figure 1: Renewable freshwater resources per capita in Africa, 2014

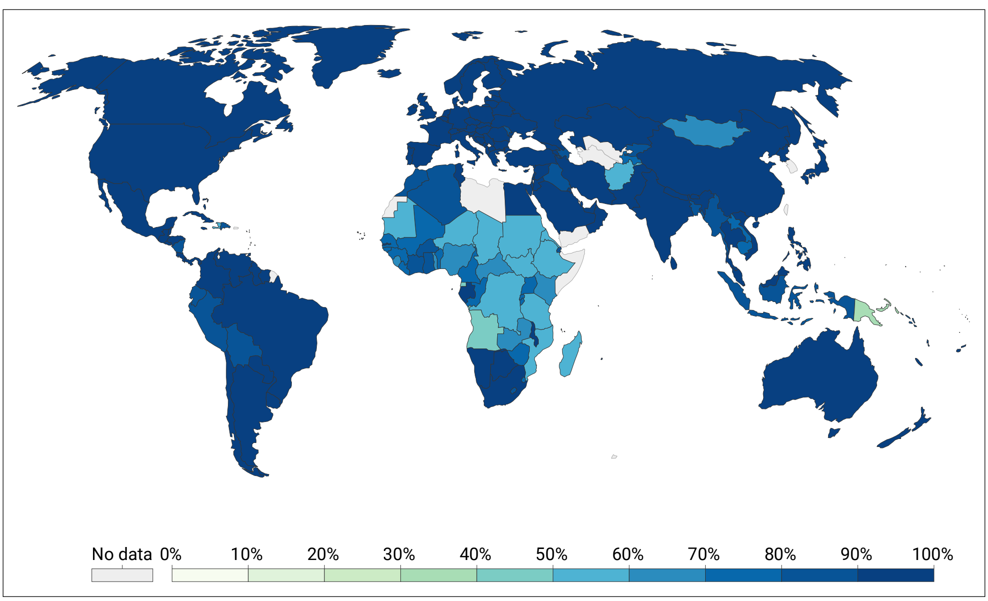


The boundaries and names shown and the designations used on the maps in this publication do not imply official endorsement or acceptance by UNESCO.

This notwithstanding, water security has become an increasingly complex and dynamic challenge for the continent. This is exacerbated by a growing population, a changing and more volatile climate characterised by floods and water shortages in different parts of the continent, demographic changes, urbanization, diminishing supplies of water from aquifers and potential conflict over water resources (Beddington, 2013). In 2017, the United Nations estimated that globally 2.2 billion persons are without safely managed drinking water with 785 million without even basic drinking water and 4.2 billion without safely managed sanitation (sdgs.un.org). A greater proportion of those affected people live in Africa as shown in Figure 2.

In 2004, the AU launched the Africa Water Vision for 2025, which seeks to mitigate threats posed by water security in Africa and create a future with equitable and sustainable use and management of water resources as a means towards poverty alleviation, socio-economic development, regional cooperation, and the environmental conservation. This vision is in tandem with the Africa's masterplan and blueprint for transforming the continent (Agenda 2063) and the United Nations (UN) Sustainable Development Goals (SDGs). Agenda 2063 has a set of seven aspirations each of which has a set of specific goals. Aspiration 1 seeks to create a prosperous Africa through sustainable development and inclusive growth. Goal 7 of Aspiration 1 strives for communities and economies that are sustainable environmentally and climate resilient. This can be achieved by sustainably managing Africa's water resources , enhancing biodiversity, land, forests, and putting in place adaptive measures for mitigating effects of climate change (AU, 2015).

Figure 2: Total population (%) with access to improved drinking water, 2015



Source: ourworldindata.org

The boundaries and names shown and the designations used on the maps in this publication do not imply official endorsement or acceptance by UNESCO.

SDG 6 has eight targets: provision of drinking water (6.1), sanitation and hygiene services (6.2), treatment and reuse of wastewater and ambient water quality (6.3), water-use efficiency and scarcity (6.4), transboundary cooperation (6.5), protecting and restoring water-related ecosystems (6.6), international cooperation and capacity building (6.a), and participation in water and sanitation management (6.b) (UN Water, 2018). The targets and their indicators are shown in Table 2. According to the Network of African Science Academies (NASAC, 2014), the current progress of implementation of SDG 6 in Africa (Table 3), casts doubt on whether SDG 6 relating to water security targets will be achieved by 2030. NASAC notes that only about 27% and 18% of the Sub-Saharan Africa population have access to safely managed drinking water services and improved sanitation respectively.

The Africa Water Vision 2025 offers a context within which water security and sustainable management of water resources can be achieved. Science and technology have long been major drivers for Africa's and global prosperity and have helped meet the ever-increasing demands on the water sector. Agenda 2063 has recognised Science, Technology and Innovation (STI) as tools and enablers necessary for achieving SDGs. Also, Agenda 2063 emphasizes that for sustained growth, economic transformation and competitiveness to be achieved in Africa, there must be continuous investment in new technologies and innovation in key sectors including clean energy, water, health, education and agriculture. Africa is well-placed to ascend to the next level of technological advancement and innovation. The Science, Technology and Innovation Strategy for Africa (STISA-2024) which is a key component of achieving AU's Agenda 2063 (Figure 3) calls for increasing efficiency while eliminating duplications when designing and implementing STI policies nationally and regionally (African Union Commission, 2014).

Table 2: United Nations SDG 6 targets and indicators

6 CLEAN WATER AND SANITATION

Targets	Indicators
6.1. By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1. Proportion of population using safely managed drinking water services'
6.2. By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	6.2.1. Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water
6.3. By 2030, improve water quality by reducing pollution, eliminating dumping, and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally	6.3.1. Proportion of wastewater safely treated. 6.3.2. Proportion of bodies of water with good ambient water quality

6 CLEAN WATER AND SANITATION

Targets	Indicators
6.4. By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1. Change in water-use efficiency over time. 6.4.2. Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5. By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1. Degree of integrated water resources management implementation (0–100) 6.5.2. Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6. By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes	6.6.1. Change in the extent of water-related ecosystems over time
6. A. By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling, and reuse technologies	6. A.1. Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan
6.B. Support and strengthen the participation of local communities in improving water and sanitation management	6. B.1. Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management

Table 3: Snapshot of SDG 6 in Sub-Saharan Africa, 2017

Drinking water	27 % of the population in Sub-Saharan Africa use a safely managed drinking water service (SDG indicator 6.1.1)
Sanitation	18 % of the population in Sub-Saharan Africa use a safely managed sanitation service (SDG indicator 6.2.1a)
Hygiene	25 % of the population in Sub-Saharan Africa has access to a basic handwashing facility (SDG indicator 6.2.1b)
Water stress	6 % of the renewable water resources in Sub-Saharan Africa are being withdrawn, after taking into account environmental flow requirements (SDG indicator 6.4.2 on level of water stress)

Source: https://www.sdg6data.org

1.2. The Role of Science Technology and Innovation

Deploying new technologies, processes and knowledge that can help to make the continental water sector more efficient, innovative and profitable will be even more critical in the future. However, rather than the usual token and uncoordinated efforts - making slow and uneven progress - there is need for a more coordinated strategic approach by international research and innovation actors to address diverse and interrelated challenges. This will require major investments in new platforms for science, policy and enterprise to engage with a portfolio of short, medium and long-term programmes. This will help stimulate investment and support governments to meet environmental and climatic targets as well as social objectives. However, identifying how to invest and maximize the impacts of STI in water security starts with understanding the present use of STI in the water sector, current institutional and decision-support frameworks and financial mechanisms associated with

Figure 3: Role of STI in achieving the AU vision

their use in the context of water security; assessing STI actions already underway and identifying promising STI initiatives for achieving water security. With STI actions varying from location to location, country/region-specific analysis of STI interventions in the water sector is crucial for inter-country learning and cooperation.

In light of the above, the United Nations Educational, Scientific and Cultural Organization (UNESCO), through its International Hydrological Program (IHP), aims to support countries (member states) in achieving water security. This noble objective will be pursued by mobilizing international cooperation with a view to improving knowledge and innovation, facilitating capacity development and strengthening the science-policy interface to enhance sustainable water resource management and governance. UNESCO, meanwhile, has established the Urban Water Management Programme (UWMP) to promote sustainable management of water resources in urban areas. This programme provides a platform for developing and testing new technologies, techniques and methodologies for holistic water resource management and provision of sustainable services amid water scarcity and related challenges - climate change, population growth and water pollution.

1.3. The Aim of this Study

To advance knowledge and define the entry points for developing and scaling up best STI interventions in urban and rural settings for water security in Africa, UNESCO in collaboration with the African Centre for Technology Studies (ACTS), the UN Economic Commission for Africa (UNECA) and the African Ministers' Council on Water (AMCOW) conducted an exploratory study on the use of STI in Africa's water sector. Specifically, the study set out to establish:

1. The status of water resources (surface and groundwater), climate change impacts and water security in Africa;

2. The ongoing and potential scientific and technological innovations in the water sector applicable in rural and urban areas focused on: a) water supply; b) water quality (drinking); c) water access; d) water treatment; e) wastewater treatment/ recycling; f) irrigation; g) water resources management; h) training and research; i) water-related products and services; j) water-related marketing; k) hydropower water resource use efficiency, and l) wastewater treatment and use in irrigation;

3. STI infrastructure for ground and surface water development, utilization, and management; the current infrastructural challenges that may be militating against the adoption of STI in water management, especially in rural communities;

4. The enabling political, institutional, and financial environment for promoting and scaling up best science and technological innovations in the water sector;

5. The strategies for promoting south-south cooperation and intercountry learning on the application of STI in the water sector; and

6. The strategies for mainstreaming best bet STI interventions into national water sector development policies.

1.4. The Study Approach

The research study adopted a combination of both desktop review and interview of key experts and institutions in the water sector. Primary and secondary data was analysed and synthesised into the report which was then reviewed and validated by external reviewers/consultants. The consultants provided independent expert opinion on the content of the report to stakeholders[1] through a webinar. The approved final report following a policy dialogue will be disseminated through UNESCO communication channels.

Although engaging all stakeholders in the water sector proved challenging, this approach is considered more effective as it creates ownership of study findings by stakeholders in the water sector.

1 UNESCO (IHP & PCB) team and other stakeholders – ACTS, AMCOW, AU, EAC, EASTECO, IGAD, IOC, ISC, Ministries in charge of water and STI, National Commissions and Councils of STI, and UNECA

2 General Information about the Region

2.1 Introduction

This section gives general information about the regional blocs and individual countries in Eastern Africa, encompassing geography, demography, economy, politics, human development, food security, livelihoods, education, development challenges, electricity, trade, transport, biodiversity, water security, and climate change.

2.2. Eastern Africa Regional Blocs

Eastern Africa region is composed of three regional blocs (Figure 4): the East Africa Community (EAC), Indian Ocean Commission (IOC) and Intergovernmental Authority on Development (IGAD) (GWP, 2015b). Eastern Africa region has a total population of about 400 million and covers a land area of 6.4 million square kilometers (Table 4).

IGAD

IGAD was formed in 1996 to supplant the Intergovernmental Authority on Drought and Development (IGADD); the latter was formed ten years earlier to address issues of famine, economic hardship and ecological degradation resulting from natural disasters and recurring severe droughts in the region. Ethiopia, Somalia, Djibouti, Sudan, Uganda, and Kenya, through the UN, formed the intergovernmental body. Eritrea and South Sudan joined in 1993 and 2011 respectively after gaining independence. IGAD's major priority areas include economic cooperation, peace, security, environmental protection, regional integration and social development. IGAD possesses major advantages such as strategic location, ecological diversity, size, vast resources and population integrated by transboundary resources and culture (IGAD, 2016).

Figure 4: Regional blocs and member states in Eastern Africa

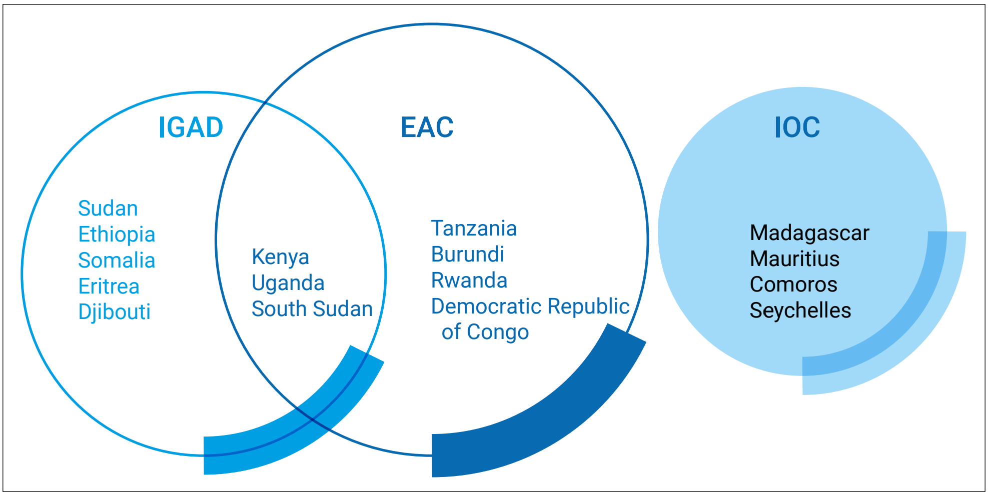


Table 4: Eastern Africa population and size by countries, 2020

Country	Population	Density per km²	Land area km²	Medium age	Urban population
Ethiopia	114,963,588	115	1,000,000	19	21%
Tanzania	59,734,218	67	885,800	18	37%
Kenya	53,771,296	94	569,140	20	28%
Uganda	45,741,007	229	199,810	17	26%
Sudan	43,849,260	25	1,765,048	20	35%
Madagascar	27,691,018	48	581,795	20	39%
Somalia	15,893,222	25	627,340	17	47%
Rwanda	12,952,218	525	24,670	20	18%
Burundi	11,890,784	463	25,680	17	14%
South Sudan	11,193,725	18	610,952	19	25%
Eritrea	3,546,421	35	101,000	19	63%
Mauritius	1,271,768	626	2,030	37	41%
Djibouti	988,000	43	23,180	27	79%
Réunion	895,312	358	2,500	36	100%
Comoros	869,601	467	1,861	20	29%
Seychelles	98,347	214	460	34	56%

Source: www.worldometers.info

EAC

EAC was established through a treaty signed in 1999 and operationalized in 2000. The initial members were Kenya, Uganda and Tanzania. Rwanda and Burundi became full members in 2007, while South Sudan and the Democratic Republic of Congo joined EAC in 2016 and 2022, respectively, bringing the total number of countries to seven. EAC's main aim is to develop programs and policies for promoting cooperation of member states for mutual benefits in several areas such as economic, social, and political affairs, defense, security, and research and technology. The EAC partner states have a Common Market that has liberalized tariffs and goods enhancing free movement of services, goods, capital and labour. The creation of an East African Federation is currently on course to achieve a bloc that is powerful politically and economically (UNCTAD, 2018; EAC, 2007).

IOC

IOC is composed of Comoros, Madagascar, Mauritius, Seychelles, and Réunion, which is an overseas region of France. Mauritius and Seychelles are considered middle-income while Madagascar and Comoros are the least developed in the region and continent. The IOC countries, which are all islands share proximity geographically, relationships (historical and demographic), common development and natural resources. IOC aims to promote sustainable development in the member states, defend members' interests, and promote regional trade, infrastructure, human development, and identity (AfDB, 2012).

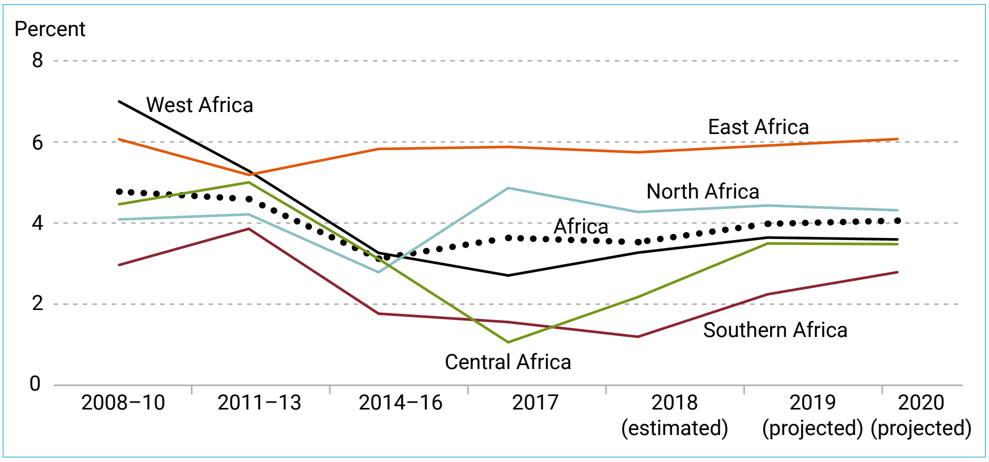
2.3. Eastern Africa Economic Outlook

East African region's GDP grew by an estimated 5.7% in 2018 and was highest among African regions (Figure 5).

Other regions such as North Africa, West Africa, Central Africa and Southern Africa registered economic growths of 4.9%, 3.3%, 2.2%, and 1.2% respectively in 2018 (AfDB, 2019). Economic growth was projected to remain strong at 6.1% in 2020 but may have significantly reduced due to the effects of the COVID-19 pandemic. The structure of the region's economy varies from country to country; Ethiopia, Rwanda, Tanzania, Kenya, and Djibouti have the highest economic growths. Countries such as South Sudan, Burundi, Comoros, and Somalia have reported low growth due to instability, which has disrupted economic activity. Other countries in the region such as Uganda and Seychelles have experienced high economic growth rates (AfDB, 2019).

Eastern Africa's GDP is dominated by the service sector at 59% and agriculture at 25.7%. The industrial sector including construction accounts for about 15.3% of the GDP and is way below Sub-Saharan Africa's average of 27.7% (Table 5).

Figure 5: GDP growth by African regions (2008-2020)



Source: African Development Bank Statistics

Table 5: Structural change, growth, and unemployment in Eastern Africa

Manufactured exports (% of total merchandise trade)		Sectoral share of GDP, 2016 (16%)			Unemployment, 2017		
		Agriculture	Industry	Services	ILO model-based estimate (% population)	Total (% ages 15 and older)	Youth (% ages 15-24)
Burundi	12.8 (2017)	36.5	15.1	48.4	1.6	22.4	49.0
Comoros	21.7 (2013)	33.6	10.8	55.7	4.3	58.8	87.7
Djibouti	-	2.2	15.5	82.3	5.8	44.4	66.5
Ethiopia	12.5 (2015)	34.1	22.9	43.0	6.4	21.8	36.0
Kenya	36.8 (2013)	31.5	17.5	51.0	5.2	42.1	30.5
Rwanda	12.2 (2016)	31.0	15.8	53.3	11.5	15.0	74.8
Seychelles	8.2 (2016)	2.0	11.4	86.7	3.7	35.6	25.9a
Somalia	1.3 (2016)	-	-	-	6.0	56.6	50.8
Sudan	0.5 (2012)	-	-	-	11.5	59.4	80.3
Tanzania	25.0 (2016)	30.5	26.4	67.3	12.718.5	50.1	-
Uganda	25.0 (2016)	30.1	20.0	43.5	2.2	30.8	30.6
Average	14.6	25.7	15.3	59.0	6.4	36.9	48.2

Source: World Bank 2018

Low job creation and industrialization - lack of diversification of the economy and product sophistication and differentiation - characterizes the economic structure and growth patterns of the region. Between 2000 and 2016, the value added by the manufacturing sector grew by just 1.7% and was less than the recorded GDP growth. Manufacturing added about 8.1% value to the GDP as compared to Sub-Saharan Africa which added a value of 10.3% in 2016. Also, the share of manufactured exports in total goods trade (14.6%) shows the lack of structural transformation in the region (AfDB, 2019).

2.4. Human Development and Education in the Eastern Africa Region

The Human Development and Social Progress indices indicate that there is widespread low educational attainment in Sub-Saharan Africa. Secondary enrolment rate is still low in Rwanda, Burundi, Uganda and Tanzania. Kenya has a better enrolment for primary and secondary schools. Other countries of the region including Eritrea, Ethiopia, and Somalia have the highest out of school children rates in the world (IGAD, 2014). Table 6 gives a general overview of the education indicators in the Eastern Africa region.

Table 6: Education indicators in the Eastern Africa region

Country	Estimated adult literacy rate, 2010-17 (% ages 15 and older)			Gross enrolment ratio, primary, 2010-17 (%)		
	Total	Male	Female	Total	Male	Female
Burundi	61.6	69.7	54.7	126.2	126.1	126.2
Comoros	49.2	56.5	42.6	99.4	101.6	97.2
Djibouti	-	-	-	63.9	67.5	60.2
Eritrea	-	-	-	49.4	53.1	45.6
Ethiopia	-	-	-	101.9	106.8	97.0
Kenya	78.7	83.8	74.0	105.3	105.1	105.5
Rwanda	70.8	76.1	66.1	133.4	134.1	132.8
Seychelles	94.0	93.5	94.4	112.8	113.2	112.4
Somalia	-	-	-	-	-	-
South Sudan	-	-	-	66.6	77.8	55.1
Sudan	-	-	-	76.4	78.9	73.9
Tanzania	77.9	83.2	73.1	85.3	84.3	86.2
Uganda	70.2	79.1	62.0	99.0	97.7	100.3
East Africa	74.6	80.9	68.9	95.8	97.7	93.8
Africa	65.5	77.0	62.6	99.5	101.6	97.4

Source: African Development Bank Statistics

North Africa has the highest Human Development Index (HDI) values in the continent and is significantly higher than the African mean of 0.524, and above that of South Asia (Table 7). Eastern Africa region has a HDI value of 0.497 (UNDP, 2016), but with considerable variations within member countries. The IOC nations of Mauritius and Seychelles have the highest indices of 0.796 and 0.801 respectively. Kenya has a HDI of 0.57 followed by Rwanda at 0.536 and Uganda at 0.528. Burundi and South Sudan have the least HDI at 0.423 and 0.413 respectively. Table 8 gives the list of the Eastern Africa countries by HDI between 2017 and 2018 (UNDP, 2019).

Table 7: Average HDI values by sub-regions

Sub region	HDI Value 2014
East Asia and the Pacific	0.71
South Asia	0.607
Africa	0.524
North Africa	0.668
East Africa	0.497
West Africa	0.461
Central Africa	0.507
Southern Africa	0.57

Source: UNDP, 2016

Table 8: Human Development Index (HDI) in the Eastern Africa region

Country	HDI 2017 - 2018
Seychelles	0.801
Mauritius	0.796
Kenya	0.579
Comoros	0.538
Rwanda	0.536
Uganda	0.528
Tanzania	0.528
Madagascar	0.521
Sudan	0.507
Djibouti	0.495
Ethiopia	0.47
Eritrea	0.434
Burundi	0.423
South Sudan	0.413

Source: UNDP Human Development Report 2019

According to the latest HDI, people living in high HDI countries can expect to live 19 years longer, and spend seven more years in school than those living in the group of low human development countries in SSA. A closer look at the HDI's components sheds light on the unequal distribution of outcomes in education, life expectancy and income within Sub-Saharan Africa countries. The Inequality-Adjusted Human Development Index allows one to compare levels of inequality within countries, and the greater the inequality, the more a country's HDI falls.

2.5. Food and Agriculture

Agriculture accounts for about 36% of GDP in the Eastern African economy and contributes up to 80% of livelihoods. The agricultural sector is majorly subsistence with opportunities for large-scale commercial farming. Investment opportunities exist in various sub-sectors including cotton, coffee, livestock, tea, sugar, sisal, tobacco, poultry, cereals, oilseeds and forestry products. The Prevalence of Undernourishment (PoU) indicator by the Food and Agriculture Organisation (FAO) estimates the proportion of a population likely to face insufficient dietary levels from their habitual food consumption. Globally, the prevalence of undernourishment has risen slightly from 10.6 in 2015 to 10.9 percent in 2017. Eastern Africa had the highest undernourishment prevalence of 31.4% in 2017 as compared to other African regions (Table 9). In 2018, up to 25% of Africa's population were undernourished. In Somalia, South Sudan, Burundi, parts of Kenya, and south-eastern Ethiopia, recurrent drought and conflicts have continuously disrupted agricultural production leading to soaring staple food prices (FAO, 2018). About 18 million people mostly in Ethiopia, South Sudan, Kenya, and Somalia are facing food insecurity and require humanitarian assistance. In 2019 up to two million people in Somalia, South Sudan, Ethiopia and Kenya were affected by heavy floods leading to loss of livelihoods, crop losses, outbreak of livestock diseases, and damaged infrastructure (WFP, 2019).

Table 9: Undernourishment prevalence in the world, Africa, and African sub regions

Region/year	2005	2015	2017
World	14.5	10.6	10.9
Africa	21.2	18.6	20.4
Sub-Saharan Africa	24.3	21.1	23.2
Northern Africa	6.2	8	8.5
Central Africa	32.4	24.1	26.1
Eastern Africa	34.3	30.5	31.4
Southern Africa	6.5	7.9	8.4
Western Africa	12.3	11.4	15.1

Source: FAO, 2018

2.6. Water Security and Stress

Water security mainly refers to quality, reliability, quantity, environmental provisioning and equitable access to supplies (ICA, 2014). According to the working definition of UN Water, water security concept (Figure 6) can be defined as: “The capacity of a population to safeguard sustainable access to adequate quantities and acceptable quality of water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability” (UNESCO i-WSSM, 2019).

In 2013, countries in Eastern Africa were characterised by varying degrees of water scarcity and stress. Of the Eastern Africa countries, Eritrea and Djibouti faced the highest water stress index levels with a ratio of water withdrawals to supply more than 80% (Figure 7). The remaining countries had low water stress (less than 10%) except Tanzania with a low to medium stress (10 – 20%). The water stress index was developed for countries, governments, and companies to identify the possible risk of water supply interruptions to businesses, agricultural activities, operations, domestic and industrial use, and other water related activities.

Figure 6: Dimensions of water security

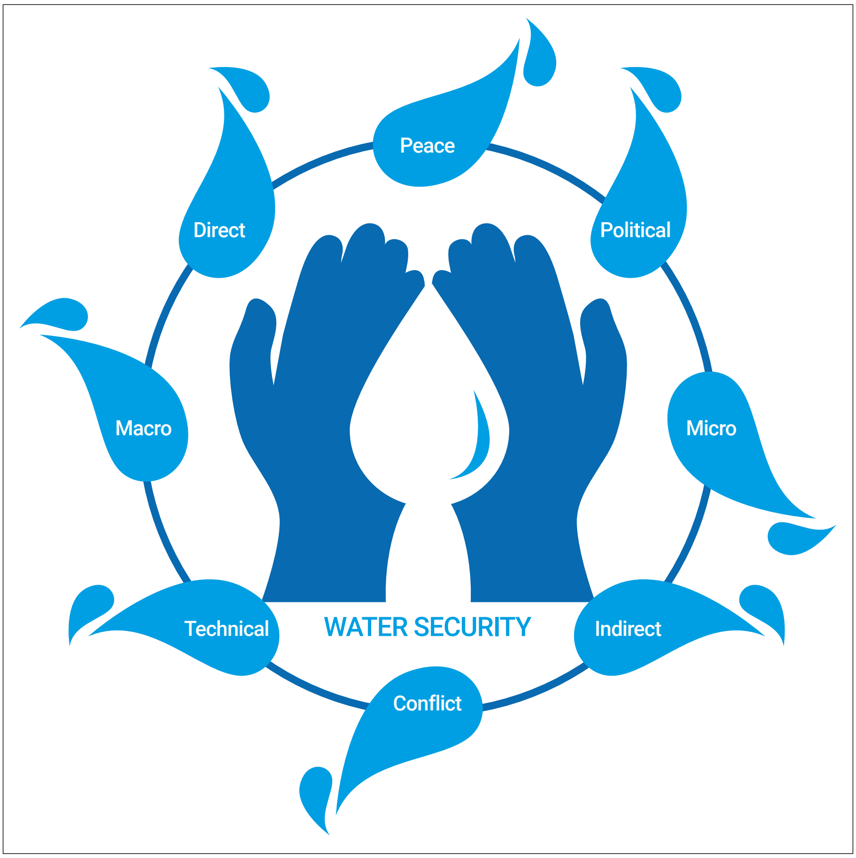
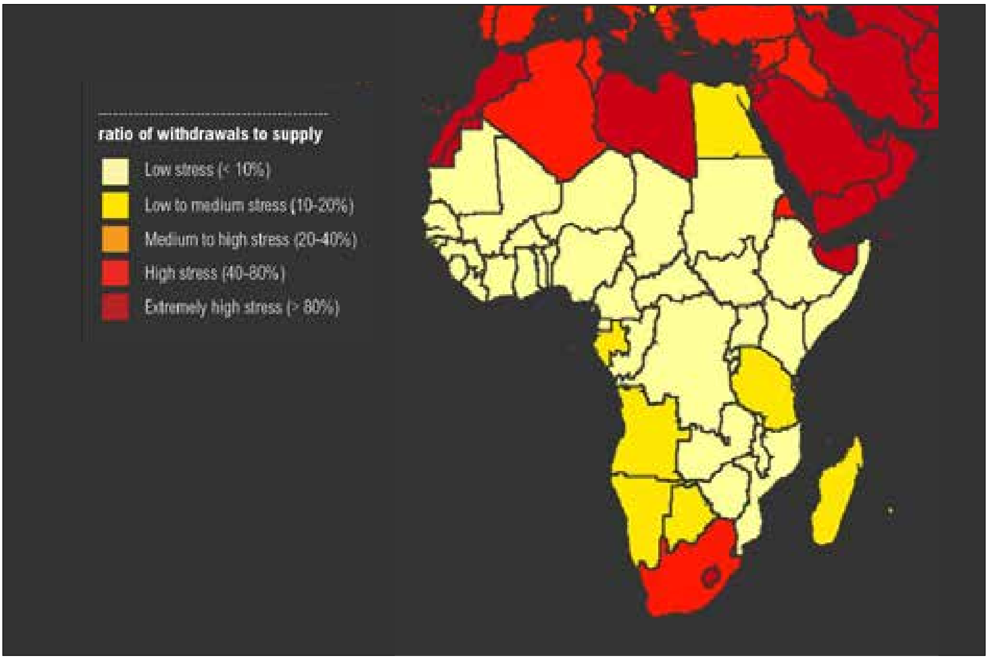


Figure 7: Water stress index, 2013



Source: https://www.huffpost.com/entry/water-stressed-countries_n_4434115?utm_hp_ref=green

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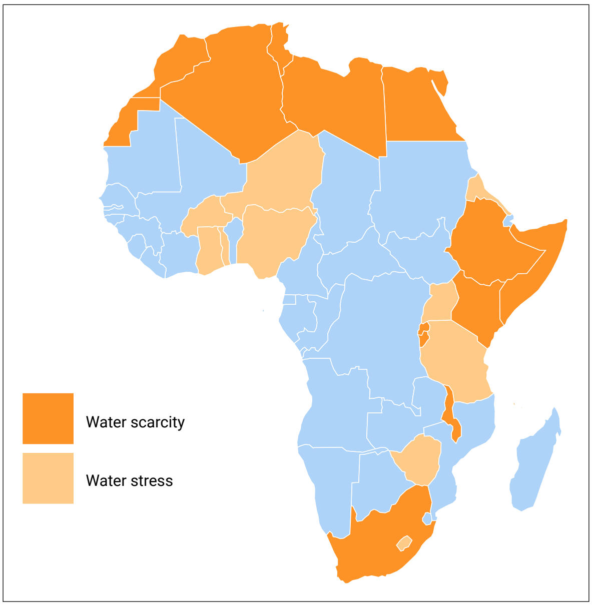
Freshwater sustainability is the most crucial sustainable development challenge since it deals with the most needed and finite resource on earth. Availability of freshwater resources plays an important role in determining the socio-economic development of a country or region. As of 2015, Kenya's and South Sudan's renewable water resources per capita were rated between 500 to 1,000 m^3 (water scarcity). Tanzania and Uganda were rated between 1,700 to 2,500 m^3 (vulnerable) the remaining countries in the East African region were rated between 1,000 to 1,700 m^3 (water-stressed). By 2025, several countries in the Eastern Africa region are projected to face water scarcity or water stress as depicted in Figure 8.

There has been an improvement in access to sanitation and clean drinking water, though the trend will decline given the rapid urbanization and increased degradation of the environment (Table 10). Countries such as Comoros, Mauritius, Seychelles, and Djibouti have the highest access to clean drinking water with more than 90% of the population having access. In Kenya, Burundi, Rwanda, and Uganda, between 60 to 80% of the population can access clean drinking water. Ethiopia, Eritrea, Madagascar, Sudan, South Sudan, and Tanzania all have between 50 to 60% of their population accessing clean drinking water. Somalia has the lowest access in the region at 31.7%.

Figure 8: Projected water scarcity and water stress in Africa in the year 2025



The boundaries and names shown and the designations used on the maps in this publication do not imply official endorsement or acceptance by UNESCO.

Table 10: % of the population with access to clean drinking water in the Eastern Africa region, 2017

Country	Population with access to clean drinking water (%)		
	2007	2012	2017
Burundi	73.8	75.3	75.9
Comoros	90.1	90.1	90.1
Djibouti	87.1	89.9	90
Eritrea	54.8	57.5	57.8
Ethiopia	42.0	51.6	57.3
Kenya	57.7	61.6	63.2
Madagascar	44.0	48.7	51.5
Mauritius	99.6	99.8	90.9
Rwanda	71.1	74.3	76.1
Seychelles	95.7	95.7	95.7
Somalia	-	58.7	31.7
South Sudan	-	55.5	58.7
Sudan	67.7	75.8	55.5
Uganda	54.9	55.4	79
Tanzania	73.8	75.3	55.6

Source: http://www.fao.org/nr/water/aquastat/data

Owing to population growth, climate change, expanded irrigation, improved living standards and increased industrial activities, the gap between water demand and supply has been growing resulting in reduced freshwater availability. Rapid urbanization and expanded irrigation farming (industrial and commercial) are threatening the limited water resources, including freshwater sources. Agriculture is the main economic activity in the region and accounts for up to 87% use of the available water resources. Table 11 gives the renewable water resources in the region by country.

Table 11: Renewable water resources in the Eastern Africa region, 2017

Country	Total internal renewable water resources (10^9 m³/year)	Total internal renewable water resources per capita (m³/person/year)
Burundi	10.06	926
Comoros	1.2	1 474
Djibouti	0.3	313.5
Eritrea	2.8	552.4
Ethiopia	122	1 162
Kenya	20.7	416.5
Madagascar	337	13 179
Mauritius	2.751	2 175
Rwanda	9.5l	778.2
Somalia	6	407
South Sudan	26	2 067
Sudan	4	98.69
Uganda	39	909.9
Tanzania	84	1 466

2.7. Eastern Africa Country Profiles

2.7.1. Kenya

Demographics and economic outlook

Kenya, with a population of about 48 million, is the second largest economy after Ethiopia in the region. It accounts for close to 20% of the region's output and a major driver of regional growth with the capital (Nairobi) serving as a major commercial hub. In 2017, the GDP growth declined to 4.9% against 5.8% in 2016 due to climatic factors such as adverse weather conditions, political interferences and economic factors such as reduced credit growth in the private sector. Agriculture is the largest contributor to Kenya's economy with the traditional tea and coffee cash crop and fresh flowers being major players in the export market. Tourism, which forms part of the service industry, is also a significant driver of economic growth. Kenya mainly imports crude oil, machinery and equipment. Real gross GDP growth will likely decelerate to 1.5% in 2020 from the annual average of 5.7% due to the COVID-19 pandemic (World Bank 2020).

Governance and politics

Kenya is a democratic republic with a presidential system where the president heads both the state and government. Executive power is exercised by the government. Legislative power is vested in both the government and the two legislatures consisting of the National Assembly and the Senate. The political scene has been characterised by relative peace and calm for over 10 years. The ruling coalition - Jubilee - and the opposition have maintained respected relationships (World Bank 2020).

Social and human development

Despite the economic growth experienced in Kenya for the last 10 years, the benefits have not been widespread. The country still has high levels of poverty and disparities as compared to regional partners, inadequate access to basic services, high inequality, and unemployment rates. The youth, women, and vulnerable groups are the most affected by the economic inequalities. According to the 2015/16 household budget survey, relative poverty decreased from 47% in 2006 to 36% in 2015/16; extreme poverty halved to about 9%, and food poverty declined from 46% to 32% in the same period. Whereas 55% of the population belongs to the working group, unemployment including the youth, remains a major concern. According to the KIHBS, in 2015/16 55% of Kenya's population were of working age (KIHBS 2018). In 2018 the unemployment was

7.4%, of which more than 80% of the unemployed were below 35 years of age. Of the total unemployed, 9% had university education, 11% middle level (TVET and colleges), 35% secondary, and 30% primary (UNDP, 2019; KIHBS 2018).

Infrastructure development

By 2030, based on the annual growth rate of 5%, Kenya's GDP is expected to double while the population is expected to increase by 32% thus putting pressure on the demand for infrastructure. Considering the expected developments, the Kenyan Government is increasingly spending on infrastructure with at least 30% of the total budget allocated to development. Dependence on electricity from hydropower continually exposes the country to power shortages during droughts and dry periods. Kenya has a good mix of renewable energy from other sources such as solar, geothermal, and wind. Kenya has over 160,000 km of roads and a rail network consisting of the nine-meter gauge railway and the recently launched standard gauge railway (SGR). Kenya has more than 4 international airports, several domestic airports, and close to 200 airstrips. The Mombasa port is the most important and the leading among several other ports. Kenya's pipeline consists of a network of 1,221 km and a total storage capacity of 286,000 m^3 (AfDB, 2018).

2.7.2. Ethiopia

Demographics and economic outlook

Ethiopia with a population estimated to be over 90 million is the most populous country in the Eastern Africa region and the second most populous in Africa. Ethiopia's youth population is the largest in Sub-Saharan Africa, with 65% under 24-year (AfDB, 2016). The country's demography is shifting to a young and growing population and causing great concern in terms of the country's capacity to its implications for economic development, food security, job creation, and provision of services. Key challenges faced by Ethiopia include poverty reduction, provision of basic services, job creation, ensuring sustainable livelihoods for the big and growing population, and preventing the youths from joining terrorist groups particularly in the Horn of Africa.

Ethiopia's economic growth is one of the fastest in the region, but the country is also one of the poorest based on a per capita income of around $790. By 2025, Ethiopia plans to achieve lower-middle-income status. The country has experienced significant broad-based and strong economic growth averaging around 9.9% annually from 2007 to 2018 with industries, services, and agriculture being the major players. The higher economic growth has led to positive trends in urban and rural poverty reduction with the population living below the poverty line decreasing from 30% in 2011 to 24% in 2016. Through the Growth and Transformation Plan, the government aims to improve the physical infrastructure and transform the country into a manufacturing hub (AfDB, 2016; USAID, 2017a).

Governance and politics

Ethiopia has a federal parliamentary system with the Chief of state being the president and the prime minister as head of government. The government holds the executive power, while the legislative power rests with the Parliament, which consists of upper (House of Federation) and lower (House of Peoples' Representatives) chambers.

Social and human development

Primary school enrolment in Ethiopia has quadrupled, child mortality rates halved, and the percentage of the population with access to clean water doubled since the end of the civil war in 1991. The country has experienced the highest increase in improved sanitation access in the African continent moving to about 26% from 2.5% in 1990. Service delivery has significantly improved leading to the third-highest decline in undernutrition and fertility rates in the continent since 1990 (USAID, 2017). Despite the significant progress, the levels of access to basic services in the country are still some of the lowest globally. Based on the 2015 UNDP HDI, Ethiopia was ranked position 174 out of 188 countries surveyed (USAID, 2017; UNDP, 2019a). In terms of access to clean water and sanitation, the country was ranked 174th and 161st, respectively, out of 186 countries in 2016. Also, Ethiopia's primary education completion rate is one of the lowest globally with half of all enrolled students not reaching the final 8th grade (USAID, 2017).

Infrastructure development

Substantial investments have been made in energy infrastructure over the past 10 years in projects such as Gilgel-gibe III (1,870MW) and the Great Ethiopian Renaissance Dam (6,000MW) hydropower projects, and the Ashegoda and Adama wind power. The energy projects which are renewable will contribute to Ethiopia's green growth plans and earn the country foreign income through electricity exports. Railway network projects include the MekelleHara-Gebeya (268km), Addis Ababa-Djibouti (900km), Awash-KombolchaHara-Gebeya (278km), and Hara-Gebeya-SemeraAssayita (229km) corridors. Ethiopia's road network almost tripled to 120,000km in 2015 from 48,800km in 2010, leading to an increased road density to 109 km/1000 km^2 (AfDB, 2016).

2.7.3. Uganda

Demographics and economic outlook

Uganda's economy is the third largest in the EAC bloc after Tanzania and Kenya. The population is estimated at around 42.7 million of which 24% is urban (BTI, 2020b). Uganda's population is one of the youngest in the world with a rapid population growth of 5.8 children per woman. Unchecked population growth is likely to strain arable land and natural resources availability and overwhelm the government's limited ability to provide employment, food, health care, education, basic services, and housing. Uganda has achieved significant economic growth in the past decades with an average economic growth of 8% between 1992 and 2010. In the same period, the GDP per capita tripled while the poverty rate reduced by half. In 2019, economic growth was estimated at 6.3%, driven by services growth (7.6%), and industrial growth (6.2%) (AfDB, 2020). The impressive growth has been supported by good agricultural performance, public investment, and household consumption. Agriculture is the major sector of the economy accounting for 24.2% of the GDP and employing 70% of the working population. Several factors including the COVID-19 pandemic, the electoral period in 2021, uncertainty linked to oil production, and the complexity of the external context may slow down Uganda's economic growth.

Governance and politics

The president holds executive powers and is the head of state, commander-in-chief of the armed forces, and ensures the implementation of laws passed by

Parliament. The legislative power rests with the National Assembly and the government. The unicameral Parliament has a term of seven years.

Social and human development

The UNDP's 2017 HDI ranked Uganda under low human development (162nd worldwide) with a score of 0.516. Despite economic improvements, poverty is still prevalent with the number of people living below the poverty line increasing from 19.7% in 2013 to 21.4% in 2017 (BTI, 2020). Increased poverty could be due to the high population growth, which is disproportionate to the economic growth experienced. Uganda's degree of inequality is higher than Tanzania and Burundi's, but less than Rwanda's and Kenya's. The youth suffer from inequalities such as access to education, lack of employment, and limited economic opportunities. Primary and secondary education is free and has contributed to a literacy rate of 78.4% as of 2015 and in 2017, gross primary school enrolment of 99% (BTI, 2020). The refugee population has tripled since 2016 and is currently estimated at 1.4 million, making Uganda the largest and third-largest refugee host in Africa and the world, respectively. Uganda's open-door refugee policy is considered most progressive globally with refugees given access to land, work, and social services (WBG, 2018).

Infrastructure development

Uganda's infrastructure is integrated with other member states of East Africa through corridors (Northern and Central). The northern road which links Uganda to South Sudan has been in poor condition but is being improved due to new investments. The road infrastructure comprising of national (10,000 km), urban (4,800 km), and district (27,500 km) roads provides up to 90% of freight and passenger traffic. There is an emerging national power grid with planned regional integration. Power generation is mainly around Lake Victoria. The ICT infrastructure is well developed with the country's global system for mobile communications (GSM) covering almost the entire nation (WBG, 2012).

2.7.4. Rwanda

Demographics and economic outlook

Rwanda, a small and landlocked country in the EAC region is hilly and fertile with an estimated dense population of 12.5 million as of 2018 (World Bank, 2020c). The country borders the Democratic Republic of Congo (DRC), and its EAC neighbors including Uganda, Burundi, and Tanzania. Rwanda has made significant structural reforms, particularly in the economic sector with the help of the IMF and the World Bank leading to sustained growth in the last decade. Rwanda aims to attain Middle Income and High-Income statuses by 2035 and 2050, respectively. A series of seven-year National Strategies for Transformation supported by sectoral strategies in line with SDGs have been put in place. Between 2008 and 2018, Rwanda had robust economic growth and social performances. The annual growth rates averaged at around 7.5%, while GDP per capita had a growth rate of 5% annually (World Bank, 2020c). GDP growth forecasts indicate that Rwanda will outperform several countries in the EAC region in the years to come, reflecting the benefits gained in liberalizing and modernizing the economy (AfDB, 2020).

Rwanda's economy faces several challenges including natural barriers to trade, a narrow economic base, reduced agricultural productivity, public debt, consequences of the genocide, and a low level of human resource development.

Governance and politics

Rwanda has had a stable political system since 1994 when the genocide occurred. In the last parliamentary elections held in September 2018, women filled 64% of the seats, leading to one of the highest female representation in the continent (World Bank, 2020b).

Social and human development

The strong economic growth experienced in Rwanda over the past years has substantially improved the living standards leading to an over 60% drop in child mortality and near-universal enrolment in primary schools. By focusing on homegrown initiatives and policies, Rwanda has significantly improved human development indicators and access to services. The national poverty declined to 55% in 2017 from around 77% in 2001, while the life expectancy (at birth) has almost tripled to 69 in 2019 from around 29 in 1990 (World Bank, 2020c).

Infrastructure development

Rwanda has low but increasing urbanization that is uncoordinated causing employment opportunities and social services to lag. Being a landlocked country, Rwanda is faced with high transportation costs to the ports in Kenyan and Tanzania. Internally, Rwanda has a network of feeder roads that are reliable and safe. Low and expensive electricity supply hinders economic development. Wood, the source of energy, is used by up to 99% of the population leading to deforestation and soil destruction. Imported petroleum and oil products account for more than 40% of foreign exchange (Darvas et al., 2017). Over the last decade, electricity access in Rwanda has increased to 47% from 9% in 2019 (World Bank 2020).

2.7.5. Burundi

Demographics and economic outlook

Burundi is a landlocked country in the EAC region and is considered a low-income economy with 80% of the country's population of 11.6 million working in the agricultural sector. Burundi is densely populated (379 people/km^2) and is one of the leading in the continent (UNICEF, 2020). The country is bordered by Rwanda (to the north), DRC (to the west), Tanzania (to the east), and Lake Tanganyika to the southwest. Burundi's economy has deteriorated since 2015 leading to increased unemployment, reduced purchasing power, and an impoverished population.

The worsening economic outlook has reversed the progress made since 2000 (BTI, 2020a). To improve economic growth and reverse the effects of reduced foreign aid, Burundi's government has turned to the mobilization of domestic resources, which has not been able to meet the high social demand caused by the high population growth. The economic growth slightly increased to 1.8% in 2019 from 1.6% in 2018. There is a slow economic recovery, but in relation to the high population growth has only resulted in a low per capita of approximated $260 as of 2019 (World Bank, 2020a). The economy is dominated by agriculture supporting a majorly subsistence labour force.

Governance and politics

Burundi is a constitutional republic with Gitega, the second largest town selected as the new political capital since 2019. The presidency and the senate are in Gitega, while other major state institutions are still housed in the economic capital of Bujumbura. Burundi has a new Constitution that established a renewable seven-year presidential term and created the offices of the Prime Minister and Vice President. The three offices represent the highest authorities of the country (World Bank, 2020a).

Social and human development

Youth unemployment is very high with about 50% of the unemployed below 30 years of age. Between 2006 and 2016, the child mortality rate reduced significantly by 38%, aided by increased spending on public health. The maternal mortality rate, however, remained high at 500 per 100 000 live births in the same period. There is poor access to basic social services including healthcare, schooling, and sanitation in Burundi (UNICEF, 2020).

Infrastructure development

Burundi's limited transportation infrastructure majorly relies on roads, several of which are not well maintained. There is no railway network and being a landlocked country trade is limited and exports are expensive. Burundi mostly trades with the DRC and uses the port cities of Mombasa and Dar es Salaam for sea exports and imports. Air travel in Burundi is limited and has reduced tourism opportunities. The African Development Bank (AfDB) launched an ambitious Infrastructure Action Plan for Burundi in 2010 aiming to construct new roads (1000 km), pave all existing roads, and establish a national power grid to give at least 40% of the population access to reliable energy by 2030 (AfDB, 2009).

2.7.6. Mauritius

Demographics and economic outlook

The island nation of Mauritius, located on Africa's southeast coast with a population of 1.3 million, has made significant economic developments since 1968. Mauritius is classified as a high-income country. The GDP grew by 3.6% in 2019 majorly driven by banking, ICT, construction, and rebound in agriculture. The services sector (comprising of tourism and financials) accounting for up to 76% of GDP is the most vital for the economy. In 2019, Mauritius had an estimated 1.38 million tourist arrivals. Other sectors of the economy include textile, sugarcane production, and offshore financial activity, while new technologies, outsourcing, and medical tourism are developing sectors. The country has been severely affected by the COVID-19 pandemic which brought the country's tourism industry to a standstill and crumbled the export demand. As a result, the GDP is expected to contract by double digits in 2020, but pick up in 2021 (Mauritius Trade, 2020; World Bank, 2020b).

Governance and politics

Mauritius has a multiparty parliamentary democratic system with the President as the head of state and a Prime Minister with a full executive and head of the government.

Social and human development

The country has significantly progressed in its quest for poverty reduction and social equality. Mauritius's GDP per capita estimated at USD 25,000 in 2019, was the second after Seychelles in Africa. There is relatively low unemployment of 6.7%, though there are significantly fewer women in the labour force as compared to men, while youth unemployment is around 22.5% (Mauritius Trade, 2020).

Infrastructure development

Mauritius has well developed infrastructure consisting of an extensive road network that is paved and in good condition, a major harbor at Port Louis, a modernized telecommunications system, and an international airport. The country has an adequate provision of electricity from hydropower plants, diesel-powered generators, and burning sugarcane residue (bagasse).

2.7.7. Seychelles

Demographics and economic outlook

The nation of Seychelles which lies to the northeast of Madagascar, consists of 115 islands, with a population of about 98,000 of which 75% reside in Mahé, the main island. The country's GDP per capita is the highest in Africa, with an approximated total GDP of USD 1.6 billion as of 2019 (World Bank 2020). Economic growth in Seychelles has been impressive over the past ten years with averages of 5.6%, 4.4%, and 4.9%, between 2011-2015, in 2016, and 2017, respectively. The traditional fisheries and tourism sectors have been the main drivers of growth and are expected to remain so (AfDB, 2019). Increased economic performance has increased the demand for labour leading to an acute shortage of labour. The labour situation is worsened by the small population, limited human resources base, and slow demographic growth. The COVID-19 pandemic is expected to severely affect Seychelles' economy given the strong reliance on international tourism.

Governance and politics

Seychelles has a stable democracy with elections (parliamentary and presidential) held every five years.

Social and human development

Seychelles has eradicated absolute poverty though based on the national standards; poverty still rains high at around 40%. The government is mainly responsible for the provision of social support by advancing financial aid to those on low income and less privileged. Women's representation in decision making and politics is one of the highest in the continent (AfDB, 2019).

Infrastructure development

The country has the leading infrastructure network and services in Africa with over 97% of the population having access to water, electricity, a good road network, and a proper communication system (AfDB, 2019).

2.7.8. Sudan

Demographics and economic outlook

Sudan (differs from the Republic of South Sudan) lies in Africa's north-eastern region and is the third-largest in the continent. As of 2018 Sudan had a total GDP of about USD 30.96 billion and an estimated population of 37.3 million of which about 33% formed the bulk of the working class aged 25 to 54. The country has major rivers including the White and Blue Nile and is blessed with minerals including zinc, petroleum, silver, chromite, uranium, copper, lead, iron, mica, and asbestos (Adesina, 2019). Key domestic challenges faced by Sudan include high unemployment, climate change, external debt, low productivity, and institutional weaknesses.

Governance and politics

Sudan has not been peaceful in the recent past with many civil wars and unrest (Madhist War, Darfur war, Battle of Omdurman, the Second Sudanese Civil war), and coup d'états of 1718, 1971 1989, and 2019 (Adesina, 2019).

Social and human development

In 2018, Sudan's had a HDI of 0.507 putting the country in the low development section and at position 168 out of 189 states. Most recent surveys indicate that about 52% of Sudanese are multidimensionally poor (standard of living, education, and health) while an additional 18% remain vulnerable to multidimensional poverty (UNDP, 2019).

Infrastructure development

In recent years, Sudan has had significant investment in infrastructure with notable achievements such as tripling power generation within two years from 800 MW in 2005 to 2,687 MW in 2007, increased mobile network penetration from 1% in 2000 to 33% in 2009 and doubled road network to 6,200 km from 2000 to 2008. Despite the progress, a good share of the country still lacks roads, while energy remains unreliable (World Bank, 2010).

2.7.9. South Sudan

Demographics and economic outlook

South Sudan's estimated population of 12.2 million and a land area of 644,000 km^2 makes it one of the countries with low population density in the region (UNECA, 2018). Variations in oil production and prices, and political crises, led to fluctuations in the country's economic growth between 2012 and 2016. In 2016 the GPD growth was only 0.3%, a big decline from the 5.1% recorded in 2015. The economy is majorly dependent on oil exports even though more than 80% of the population relies on subsistence agriculture, livestock, and forestry (UNECA, 2018).

Governance and politics

South Sudan's legislative body (the National Legislature of South Sudan) is made up of the Council of States and the National Legislative Assembly. The president heads the executive branch of the government.

Social and human development

The country has high levels of poverty with more than 50% of the population considered poor. Between 2011 and 2015, gross primary enrolment significantly declined by 25%, with about 62% of school-going children out of school by the end of 2015 (UNECA, 2018). Health indicators have been worsened by continued civil war with the country having the highest neonatal mortality rate (39.6% in 2014) in the region (UNECA, 2018).

Infrastructure development

River, road, and air are the three modes of transport used in South Sudan. The railway network has not been in operation due to damaged bridges. River transport is mainly by barge though unresolved conflicts have halted river transport from Sudan thus restricting the remaining small river transport to within South Sudan. The country has two major international airports at Juba and Rumbek (EuropeAid, 2015).

2.7.10. Tanzania

Demographics and economic outlook

Tanzania's real GDP growth was estimated at 6.8% in 2019, down slightly from 7% in 2018. The economic outlook is characterized by private consumption, significant public spending, strong investment growth, and an upturn in exports underpinned the positive outlook. Tourism, mining, services, construction, agriculture, and manufacturing are notable sectors. Growth is projected to be broadly stable at 6.4% in 2020 and 6.6% in 2021, subject to favorable weather, prudent fiscal management, mitigation of financial sector vulnerabilities, and implementation of reforms to improve the business environment (AfDB, 2019). Inflation fell to an estimated 3.3% in 2019 from 3.6% in 2018 due to an improved food supply. The Tanzanian shilling was stable in 2019, exchanging at an average of 2,290 to the dollar, compared with 2,263 in 2018. The fiscal deficit, financed mainly by concessional external debt, stood at 2.0% of GDP in 2019, up from 1.3% in 2018, and is projected to stabilize at 1.9% in 2020 and 2.2% in 2021. External public debt, 63% of it concessional constituted 70.4% of total public debt in 2019. The current account deficit slightly widened to 3.4% of GDP in 2019 from 3.3% in 2018 (AfDB, 2019).

Governance and politics

In October 2015, John Pombe Magufuli was elected the fifth president of the United Republic of Tanzania. Magufuli's Fifth-Phase Government has prioritized efforts to clampdown on corruption, improve public administration and manage public resources for improved social outcomes. The Mo Ibrahim Index of African Governance shows Tanzania has improved in its overall governance indicators between 2015-2018. However, the Worldwide Governance Indicators show Tanzania has either deteriorated or has been stagnant in all governance indicators between 2012 and 2017 (except for control of corruption). The strongest decline has been in voice and accountability, in political stability/violence and rule of law. Tanzania will hold local government elections in November 2019, with presidential and parliamentary elections in October 2020 (World Bank, 2019).

Social and human development

Poverty, inequality, and youth unemployment persist despite recent robust growth. Poverty declined, but at a slower pace of 6.4% between 2012 and 2018 than 18.0% between 2007 and 2012. Youth unemployment increased from 5.7% in 2012 to 7.3% in 2016. Besides, enrollment in secondary education for young people aged between 15–24 declined from 30.0% to 24.7%, calling into question the availability of skills for the job market. Government policy improving the business and investment climate remains a work in progress, particularly in tax policy and administration, access to affordable finance, and government processes. The 2019 Global Competitiveness Report pointed to some key improvements in ICT adoption, macroeconomic stability, financial system, and business dynamism (AfDB, 2019). Despite efforts between 2007 and 2016 that have reduced the country's poverty rate from 34.4% to 26.8%, the absolute number of poor people has held at about 13 million due to high population growth. The most recent poverty measures based on the Household Budget Survey of 2017/18 are still being processed, but it seems likely that the downward trend in the poverty rate continues but has become more gradual. Government efforts to expand access to social services like education, health, and water have been undermined by their declining quality as the population rises faster than the supply of the services (World Bank, 2019).

Infrastructure development

Early signs of slow but steady structural transformation in key sectors include the continued shift of labor from agriculture to services, and even to industry. Employment in agriculture declined from 71.4% of total employment in 2008 to 66.3% in 2018, while employment in industry increased to 7.1% from 5.7% and employment in services to 26.6% from 22.9% (AfDB, 2019). Key challenges in the medium and long term include low total factor productivity growth, a substantial infrastructure deficit, considerable poverty, and a skill mismatch in the labor market. Factor productivity is generally low, particularly in agriculture, where its growth averaged only 0.4% between 2015 and 2017. Tanzania lacks access to the development finance required to bridge the enormous infrastructure gap that comes with its size (AfDB, 2019).

2.7.11. Madagascar

Demographics and economic outlook

Real GDP growth in 2019 is estimated at 5.2%. The primary sector, with 22.4% in 2019, is driven by traditional agriculture, greatly exposed to the effects of climate change (droughts, cyclones). In a shifting environment, exporting companies (extractive industries in an export processing zone) drove the secondary sector's contribution up from 18.5% in 2015 to 21.3% in 2019. There was no significant change in the tertiary sector (growth of 0.8 points), the largest in the economy, with 58% of GDP in 2019, but driven by the least productive sectors, where informal activities are concentrated (trade, transport). Public finances improved with increased tax collection to reach an estimated 12.2% of GDP in 2019, up from 10.5% in 2015. Although public investment spending rose steadily, from 3.5% of GDP in 2015 to 8.3% in 2019, it remains inadequate to meet infrastructure requirements. The 1.5% budget deficit of GDP in 2018, rose to 2.4% in 2019 and is expected to climb to 4.1% in 2020 and 4.9% in 2021. The current account, after a surplus of 0.8% of GDP in 2018, shifted to a deficit of 0.2% in 2019 and is expected to widen to 1.5% in 2020 and 2.4% in 2021. Inflationary pressures remained strong between 2015 and 2019, reaching a high of 8.6% in 2018, and gradually falling to 6.2% in 2019 (AfDB, 2019).

The adverse economic, social, and fiscal impact of the COVID-19 crisis will be very substantial in 2020. Global trade and travel disruptions, as well as domestic containment measures, are expected to result in a sharp deceleration in economic activity in 2020, with gross domestic product (GDP) growth predicted to slow to 1.2%, compared to an estimated growth rate of 5.2% just prior to the outbreak. Vulnerable populations in urban areas are particularly exposed to economic hardship and poverty traps in these circumstances. Sharply declining tax revenues and COVID-19-related spending will widen the fiscal deficit and create a sudden increase in financing needs. These developments emphasize the importance of implementing robust emergency measures to save lives, protect vulnerable populations, and safeguard jobs in the short term as well as accelerate reforms to stimulate investment for long-term recovery, strengthen resilience to future shocks, and maintain public debt at a sustainable course. The World Bank is committed to working with the government to achieve those objectives with a full array of its instruments (World Bank, 2020).

Governance and politics

Presidential elections were held peacefully in January 2019, marking the first political alternation of power in Madagascar. President Rajoelina won 55.6% of the votes and leads the country alongside his Prime Minister, Christian Ntsay, and 24 ministers (World Bank, 2019).

Social and human development

The country's human capital index ranking is among the lowest worldwide, and Madagascar has the world's fourth highest rate of chronic malnutrition, with almost one child in two under five years of age suffering from stunting. An estimated 1.4 million children dropped out of primary school in 2012. Living conditions remain difficult for most of the population, with a low rate of access to electricity (13%) in particular. Madagascar is one of the African countries most severely affected by climate change impacts and experiences an average of three cyclones per year (World Bank, 2019).

Infrastructure development

Between 2015 and 2017, six reforms relating to improvement of the investment climate have been adopted and implemented, tangibly reducing barriers to entrepreneurship and business growth. The total number of direct beneficiaries of the Second Integrated Growth Poles and Corridors Project (PIC2) is estimated at nearly 400,000. In the 77 PIC2 intervention communes, there was an increase of 51% in commune-level revenues between 2015 and end-2016 and an increase of 85% in the number of newly formalized enterprises. Passenger traffic, including tourists traveling by air and sea, increased by 37% in the main PIC2 tourism centers. More than 58,000 hectares of irrigated land were rehabilitated. Rice production yields increased from 2.5 metric tons to close to five metric tons per hectare, bringing direct benefits to more than 76,000 agricultural households. Between 2017 and 2019, almost 100,000 farmers directly benefited from improved irrigation services and agricultural inputs. 300,250 land certificates have been registered since 2006. Annual electricity losses by the national power company, JIRAMA, have dropped by 5%. The proportion of the population with access to electricity increased by 8% because of the grid and off-grid solutions. Total electricity sales per kWh covered by the revenue protection program increased by 23% (World Bank, 2019).

Almost 80% of the population works in agriculture based on subsistence crops (rice, cassava, corn), and jobs in the sector are mainly low paying, with considerable underemployment. The poverty rate in agriculture was 86.4% in 2013. Prior to the COVID-19 pandemic, Madagascar was on an upward growth trajectory. Following a prolonged period of political instability and economic stagnation, growth accelerated over the last five years to reach an estimated 4.8% in 2019, its fastest pace in over a decade. The return to constitutional order and peaceful political transition in the last elections was instrumental to this economic revival, as it contributed to restore investor confidence, reopen access to key export markets, reinstate flows of concessional financing, and encourage structural reforms. These positive trends were also reflected in improved labor market conditions and declining poverty rates, although around 75% of the population was still estimated to live below the international poverty line of $1.90 in 2019, significantly higher than the regional average of 41% (World Bank, 2019).

2.7.12. Djibouti

Demographics and economic outlook

Djibouti is one of the smallest countries in Africa. It covers an area of 23,200 square kilometers and is home to a population of about 865,000 (2011). The size of its economy limits its ability to diversify production and increases its reliance on foreign markets, making it more vulnerable to market downturns and hampering its access to external capital. Djibouti also has less than 1,000 square kilometers of arable land (0.04 percent of its total land area) and an average annual rainfall of only 130 millimeters. It depends almost completely on imports to meet its food needs. Thanks to massive, public debt-financed investments in infrastructure, Djibouti has seen rapid, sustained growth in recent years, with per capita GDP growing at more than 3 percent a year on average and real GDP at 6 percent. Growth is expected to reach 7.5 percent in 2019 (World Bank, 2019).

Social and human development

Because of these investments, the country's debt stands at an estimated 70 percent of GDP. The population living below the international poverty line of US$1.90 per day was estimated at 17.1 percent in 2017 but is expected to decrease if it reaps the benefits of infrastructure investments. Djibouti is not currently engaged in an IMF program but has completed an Article IV review, which was discussed by the Fund's Board of Executive Directors in September 2019 (World Bank, 2019).

Infrastructure development

Djibouti's USD 2 billion city-state economy is driven by a state-of-the-art port complex, among the most sophisticated in the world. Trade through the port is expected to grow rapidly in parallel with the expanding economy of its largest neighbor and main trading partner, Ethiopia. Djibouti has some natural assets that could be used for tourism, untapped marine resources that could support more artisanal fishing, and an infrastructure of undersea telecommunications cables from which it could develop new digital and service industries. Renewable energy could be a source of growth as Djibouti has geothermal, solar, and eolian potential (World Bank, 2019).

The GDP growth is expected to reach 7.5% in 2020 before accelerating to 8.0% in 2021-2023. Growth will remain supported by re-exports by free zone companies and exports of transportation, logistics, and telecommunication services. The gradual emergence of non-traditional exports, mainly light manufacturing from the export-processing zones will increase value-addition. As trade and investment flow to Ethiopia continues to develop, the need for deeper connectivity will drive capital inflows over the medium term and help increase the utilization of existing logistics facilities. The commencement of exploration and production of natural gas in Ethiopia will eventually boost further activities at the same time generation of more revenue at the export terminal in Djibouti (World Bank, 2019).

2.7.13. Comoros

Demographics and economic outlook

Real GDP growth for 2019 was 1.5%, half that in 2018, explained by cyclone Kenneth in April 2019, which caused destruction (power plants, roads, and production capacity) equivalent to 12.5% of GDP. Growth has been driven primarily by electricity and transport on the supply side, and by public investment on the demand side. For 2019, inflation is estimated at 2%, the fiscal deficit at 2.6% of GDP (financed by statutory advances from the central bank to the treasury, loans, and external aid), the current account deficit at 8.9% of GDP, and external debt at 32.4%, up slightly from 2017 (29.3%). The IMF's latest debt sustainability analysis rated the risk of debt distress as moderate (AfDB, 2019).

The COVID-19 health crisis is impacting Comoros' economy through various channels. The slowdown of economic activity due to social distancing measures and the disruption of trade and tourism caused by the pandemic constitutes a threat for Comoros' trade and tourism-related sectors. The expected drop of remittances from the diaspora would substantially reduce households' income, especially the poorer ones. Revenues from trade, which represent the bulk of the government's domestic resources, will decrease significantly raising the fiscal deficit. The fiscal and external financing gaps that the COVID-19 pandemic will create are expected to be covered primarily by donor assistance, given still limited borrowing possibilities, with public debt sustainability remaining at moderate levels despite the shock. However, Comoros' recovery is subject to several vulnerabilities. The current fragile situation of the SNPSF, a money transfer service, could take a sudden turn for the worse and seriously jeopardize financial stability. The possible deterioration of the financial health of state-owned enterprises such as Comoros Telecom could aggravate the fiscal stance. Notwithstanding, the full economic consequences of COVID-19 are still unclear and subject to high uncertainty around the spread of the disease domestically, as well as overseas (World Bank, 2019).

Governance and politics

Absent from the political scene since 2006, Azali Assoumani came back and won the presidential elections in 2016. His government introduced a series of fiscal and structural reforms. The national congress, convened in February 2018 to review 42 years of independence and the Presidential Rotation system among the islands, recommended an overhaul of the system of a rotating presidency. Assoumani's mandate was renewed in 2019 after the yes vote in the July 2018-referendum on constitutional reform that expands the power of the presidency (World Bank, 2019).

Social and human development

The income distribution is highly unequal, and unemployment is high, especially among the young (8.5%). Human and institutional capabilities are weak with almost half of the active population lacking education qualifications. National strategies have not been fully implemented, as with the industrialization strategy (2017), the employment policy (2013), the agricultural policy and the fight against food insecurity (2014), the education sector transition policy (2017), and the national strategy for the blue economy (2013). Poverty (at the national poverty line) affects 44.1% of the population, and the income distribution is unequal, with a Gini coefficient of 0.39. Unemployment is estimated at 3.7% in 2018, and youth unemployment at 8.5% (AfDB, 2019).

Infrastructure development

The post-cyclone cleanup and the support from development partners (for macroeconomic stabilization and sectors affected by the cyclone) are expected to lift GDP growth to 3% in 2020 and 3.2% in 2021. The financing already obtained will be used to re-launch socioeconomic, production, and private sector support infrastructure. Between 2016 and 2018, the real electricity access rate rose from 75.4% to 77.8%, and available capacity increased by 32% (from 19MW to 25MW). The government aims to stabilize the energy sector by implementing decrees to separate water and electricity, create a new electricity company, and review the electricity tariff structure. Structural challenges include vulnerability to climate change, with increasingly frequent and violent cyclones. Labor and capital productivity are low. The diversification of national production and exports (ylang ylang, vanilla, and clove) is weak, market size is small with fewer than 1 million inhabitants, and given the country's isolation, costs are high for international transport. Structural transformation is very slow, with industry's share of the economy stable at 9.6% of GDP. Barriers to the private sector are high, and there was no policy for its development until 2017 (AfDB, 2019).

2.7.14. Eritrea

Demographics and economic outlook

Eritrea's recent growth performance has been marked by significant volatility in part due to its dependence on a predominantly rain-fed agriculture sector, accounting for about one-third of the economy (and which has a significant impact on distribution services which account for around 20% of gross domestic product (GDP) and on a narrow mining sector which also accounts for 20% of the economy.

Real GDP growth is estimated to have recovered to around 12% in 2018 while averaging -2.7% during 2015-18 on account of frequent droughts and a decline in mining production. Reported inflation has been negative during 2016-18, following the exchange of currency in circulation in November 2015 that resulted in a monetary contraction. Deflation continued in 2018 as increased trade with Ethiopia resulted in further downward pressure on prices (World Bank, 2019).

Governance and politics

Eritrea is a small, coastal country strategically located along the Red Sea in the Horn of Africa, bordered by Sudan, Ethiopia, and Djibouti. Eritrea is divided into six administrative regions called 'zobas', which vary in size, population, and socioeconomic conditions. After long liberation war, Eritrea regained self-rule in 1991 and full independence in 1993. The country enjoyed seven years of stabilization, reconstruction, and development, before the onset of a border war with Ethiopia in 1998. The brunt of hostilities ended in 2000 and a UN Eritrea-Ethiopia Boundary Commission (EEBC) ruled in favor of Eritrea in 2002, but the border zone remained militarized. UN Security Council sanctions were imposed in 2009 and reinforced in 2011. Eritrea remained in a state of mobilization for almost two decades under transitional political arrangements focused on national security with a suspension of traditional checks and balances. The earlier development model was eschewed in favor of greater self-reliance and a more state-led planned economy. Management of national resources – labor, land, and finance – was geared toward maintaining a state of military readiness, alongside efforts to broaden social equity. The private sector was gradually replaced by an extensive state sector geared to marshal scarce resources and increasing restrictions were imposed. An institutional framework was developed to direct labor into an indefinite military and national service. The resulting austerity and extensive controls spurred the migration of people and capital. In mid-2018, Eritrea experienced a turnaround in its external environment. Ethiopia accepted the EEBC decision and signed a peace treaty with Eritrea in July 2018. Eritrea began to normalize relations with neighboring countries. In November 2018, UN Security Council lifted its sanctions on Eritrea. This raised expectations of a re-orientation of Eritrean political and economic arrangements being met with caution from the administration, as evidenced by President Isaias' recent call for a "patient appraisal of the unfolding reality" (World Bank, 2019).

Social and human development

Poverty appears to have remained widespread in Eritrea, but the lack of data limits available quantitative evidence. The most recent available survey data from 1996-97 indicates a 70% poverty rate. The country has seen consistent improvements in life expectancy (rising from 50 years in 1990 to 65 years in 2015) and expected years of schooling (from 3.8 years in 1995 to 5.4 years in 2010) and strong social outcomes in the face of limited resources. Nevertheless, challenges remain. An unfinished maternal and child health agenda is compounded by a significant rise in Non-Communicable Diseases (NCDs). Skilled birth attendance remains low, between 35-60%, maternal mortality ratio high at 485 deaths per 100,000 live births and under-five malnutrition also high with 52% of children underweight (World Bank, 2019).

Infrastructure development

Constraints on starting a business, dealing with construction permits, registering property, obtaining electricity, obtaining credit, and protecting minority investors increase financing costs and reduce returns on investment. Skill mismatches, poor roads, weak domestic finance, and inadequate information and communications technology also reduce the returns on investments and projected growth. The government is addressing skill mismatch by building capacity and developing appropriate curricula for technical and vocational education and training. Eritrea remains low on HDI, ranked 182 of 189 countries. Debt distress could culminate in a drop in the sovereign rating and a rise in interest spreads, constraining growth. Given the dominance of state enterprises and their dependence on state financing, the spill over effects of sovereign debt on these enterprises could reduce output. Dependence on exports of gold and zinc and agricultural raw materials makes the country vulnerable to external shocks. The demand for Eritrea's commodity exports could be reduced by sluggish growth in the global economy, particularly the key trading partners in Europe and the Far East (AfDB, 2019).

2.7.15. Somalia

Demographics and economic outlook

Years of conflict and fragility have left Somalia's economy with a range of challenges, including population growth outstripping economic growth, acute poverty and vulnerability, recurrent external trade, and climate shocks. Weak fiscal space and institutions, active insurgency, and an incomplete political settlement have also affected the country's economic strength. Somalia also has several opportunities, as the economy is transitioning from traditional, rural pastoralism to urban, trade and services. Somalia's economy has remained resilient despite recurrent shocks, including drought and sporadic terror attacks. Driven by increased confidence in the economy, implemented reforms, and political stability, the economy is forecasted to grow at 3.2% in 2020, up from 2.9% in 2019 (World Bank, 2019).

Social and human development

The Somali High Frequency Survey, wave 2, of 2017, indicates that Somalis are among the poorest people in Africa, with a poverty incidence of 69.4% and per capita income of about $400. Poverty among male headed households was about 72%, compared with 66% for female-headed households. A better understanding is needed of the country's poverty dynamics along gender lines.

Youth constitute about 70% of the population, with about 67% of the unemployed. Only 30% of children are enrolled in schools—18% in rural areas. Data are scarce on human development. Low investment, low economic diversification, and low productivity in the informal economy have hamstrung economic dynamism.

At the center is the need to formalize economic activity to provide a base on which the government can mobilize tax revenue, strengthen its public service capacity, and invest in infrastructure. In 2018, the ratio of revenue to GDP was 3.8%, rising marginally in 2019 to an estimated 3.9%. Current revenue does not provide fiscal space to spend on productive investments. Given the global economic slowdown, Somalia's dependence on aid and remittances (about $1.4 billion annually) presents significant risks to growth. These factors, coupled with low skills, low savings, high poverty, insecurity, institutional weaknesses, vulnerability to climate-related shocks, debt distress, and restrictions on borrowing compound the risks (AfDB, 2019).

Infrastructure development

Together with development partners, Somalia is using targeted interventions to help meet its Heavily Indebted Poor Countries (HIPC) debt relief obligations. The support enhances building institutional capacity and providing opportunities for skill development as a catalyst for better public services, including infrastructure. Investments in hard infrastructure such as roads and ports and soft infrastructure such as enhanced skill development, along with increasing formalization of the economy, will boost medium-term growth (AfDB, 2019).

3 Status of Water Resources, Climate Change Impacts, and Water Security

3.1. Introduction

Africa has an estimated annual precipitation of about 20,360 km³ varying from region to region with a continental average of around 678 mm. The northern region with an annual average of 96 mm/year is the driest on the continent. High annual precipitation is mostly recorded in Central Africa and the Indian Ocean island countries including Sao Tome and Principe (3,200 mm/year), Liberia (2,390 mm/year), Sierra Leone (2,526 mm/year), Seychelles (2,330 mm/year), Equatorial Guinea (2,156 mm/year), and Mauritius (2,041 mm/year) (AQUASTAT, 2020). The member countries of the IGAD area of Eastern Africa have precipitation ranging from 282 to 1,180 mm/year and averages about 565.7 mm/year (equivalent to 304 billion m³ of water).

Eastern Africa has limited water resources representing about 6.5% of Africa's internal resources and does not receive significant inflows from outside (Hamed, 2014). Distribution of water resources within the region varies significantly with four aridity zones including moist sub-humid (Uganda, parts of Burundi, and Rwanda), dry sub-humid (western Tanzania and parts of Uganda), semi-arid (parts of Tanzania, Kenya, Ethiopia), and arid (most of Kenya, Somalia, Djibouti, and Eritrea). Western regions of East Africa, including Burundi, Rwanda and Uganda along with the central parts of the continent are considered to have a rain surplus, while large parts of Kenya are considered to have a very large water deficit (UNEP, 2010). Table 12 gives the renewable water resources in the Eastern Africa region by country.

3.2. Surface Water Resources

Freshwater sources in IGAD region are made up of open water bodies, surface water (including dams, Table 13) and groundwater. Also, sizeable wetlands responsible for water storage and filtration of polluted water exist particularly in Sudan, Ethiopia and Uganda. Freshwater availability is one of the most critical ingredients for social and economic development. Ecosystems consisting of freshwater and wetland support several functions such as sanitation, provision of water for drinking, energy generation, agriculture, transport, manufacturing and provision of habitat for species. The IGAD region has not fully maximized its use and management of water resources within its boundaries. A potential exists for attaining an improved supply of water for sanitation and provision of safe potable water, infrastructure services, promote industrialization and enhance agricultural production. Despite sharing the River Nile (one of the greatest rivers in the world) the concerned countries of the IGAD (Ethiopia, Sudan, South Sudan, Kenya and Uganda) still face many inequities over the common resource. It has been shown that there is enough water in the Nile River Basin to sustain the

Table 12: Renewable water resources for the Eastern Africa region, 2017

Country	Long-term average annual precipitation in depth (mm/year)	Total internal renewable water resources (10^9 m³/year)	Total external renewable (10^9 m³/ year)	Total renewable water resources (10^9 m³/ year)	Dependency ratio (%)	Total renewable water resources per capita (m³/person/ year)
Djibouti	220	0.3	0	0.3	0	3,13.5
Eritrea	384	2.8	4.515	7.315	61.72	1,443
Somalia	282	6	8.7	14.7	59.18	997.1
South Sudan	900	26	23.5	49.5	65.79	3,936
Sudan	250	4	33.8	37.8	96.13	932.6
Burundi	1,274	10.06	2.476	12.54	19.75	1,154
Ethiopia	848	122	0	122	0	1,162
Kenya	630	20.7	10	30.7	32.57	617.7
Rwanda	1,212	9.5	3.8	13.3	28.57	1,089
Uganda	1,180	39	21.1	60.1	35.11	1,402
Tanzania	1,071	84	12.27	96.27	12.75	1,680
Comoros	900	1.2	-	1.2	-	1,474
Madagascar	1,513	337	-	337	-	13,179
Mauritius	2,041	2,751	-	2.751	-	2,175
Seychelles	2,330	-	-		-	-

Source: http://www.fao.org/nr/water/aquastat/data

region's population. Moreover, supposing that rainfall over the basin is evenly distributed, the population's per capita water share would be about 10,000 m³ per capita per year, which is much higher (ten times) than the global water scarcity limit (Mwendera, 2010).

The Eastern Africa region is well-endowed with a good supply of freshwater totalling an average renewable volume of 187 km³/year, of which the largest share (39 km³/year) is in Uganda. The available water resources in the EAC region have experienced increased pressure in the recent past such as the degradation of the aquatic resource base leading to an increased struggle in obtaining water. Increased human activities including pollution (domestic and industrial), soil erosion, and deforestation have all led to the degradation and reduced the capacity of the water catchment areas and caused severe flooding and droughts. In addition to the effects of global warming, the region continues to experience declining water availability. The high population growth, dwindling water resources, and increased use of renewable water resources will intensify competition, inequalities, and inadequate development within the region. In the past 30 years, the region has experienced several major droughts including in

1973-74, 1984-85, 1987, 1992-94, and 1999-2000. There is evidence of growing climatic instability in the region, in terms of increasing frequency and intensity of droughts (Mwendera, 2010).

Table 13: Dam capacities in the Eastern Africa region, 2010

Country	Total dam capacity (km³)
Burundi	-
Comoros	-
Djibouti	-
Eritrea	0.0441
Ethiopia	31.48
Kenya	24.79
Madagascar	0.4935
Mauritius	0.0929
Rwanda	-
Seychelles	0.001
Somalia	-
South Sudan	-
Sudan	21.23
Uganda	80
Tanzania	104.2

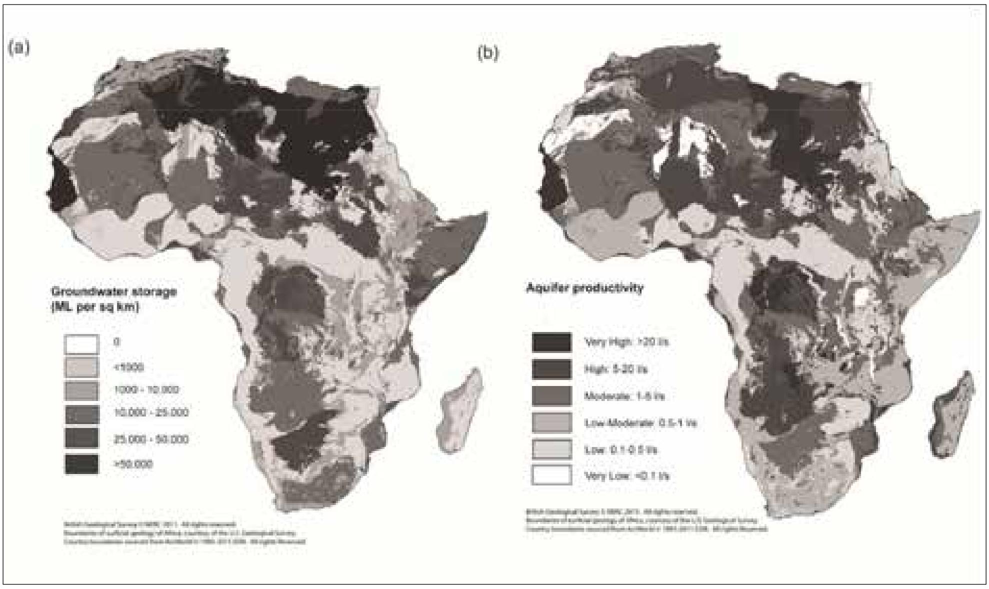
Source: Mwendera, 2010

Rainfall variability and disparities between the abundance of water and population distribution complicate access to freshwater in the IOC nations. Of all the IOC member states, only Madagascar has an abundant freshwater resource internally totalling 337 km^3/year. Given the poor infrastructure development and terrain in Madagascar, the resources are unevenly distributed thus subjecting a large percentage of the population (particularly rural and coastal dwellers) to inadequate water access. Mauritius, the second populous country in the region has about 2.21 km^3/year (1,970 m^3/capita/year) of freshwater resources, which is slightly higher than the threshold for water stress of 1,700 m^3/capita/year (Mwendera, 2010). Most rivers (92 in Mauritius), groundwater resources, and lakes (natural and human-made) in the region have not been exploited or evaluated fully. The wetlands in the region are increasingly facing pressure for land development for industry and housing to sustain the growing tourism sector. Under the Ramsar Convention, Comoros and Mauritius have each declared one Ramsar site (Wetlands of International Importance), while Madagascar has designated two.

3.3. Groundwater Resources

Sub Saharan Africa (SSA), encompassing the eastern part of Africa, uses about 2% of the total available groundwater resource. The significant groundwater resources are not evenly distributed with variable accessibility. Countries in the equatorial region such as Uganda, Tanzania and Ethiopia with rainfall and highest recharge have high amounts of groundwater. On the contrary arid and semi-arid countries where groundwater is needed have the least amounts of renewable groundwater resources (Figure 9 and Table 14). The aquifers found in the countries in the arid areas are not actively charged, thus abstraction will be unsustainable and lead to the depletion of the groundwater resource. Currently, the status of knowledge on groundwater in the African continent is insufficient and should be expanded to enable the full exploitation of the resource to mitigate climate change related water demands. Of all the water resources in Africa, groundwater is the least monitored and understood (World Bank, 2018; Adelana & Macdonald, 2008).

Figure 9: Estimated groundwater storage and aquifer productivity in the Eastern Africa region



Source: (MacDonald, Taylor, & Bonsor, 2013)

Table 14: Groundwater resources and use in the Eastern Africa region

Country	Renewable (km^3/year)	Abstraction (km^3/year)	Used (%)	Recharge/ capita (m^3/ year)	Abstraction/ capita (m^+/ year)
Burundi	7.47	0.16	2.1	346	19.1
Djibouti	0.015	0.02	133.3	85	22.5
Eritrea	0.5	0.09	18	136	17.1
Ethiopia	20	1.49	7.5	531	18
Kenya	3.5	0.62	17.7	662	15.3
Madagascar	55	0.38	0.7	6,124	18.3
Rwanda	7	0.2	2.9	168	18.8
Somalia	3.3	0.28	8.5	649	30
Sudan and S. Sudan	7	0.59	8.4	1,260	13.3
Tanzania	30	0.98	3.3	1,962	21.9
Uganda	29	0.62	2.1	669	18.5

Source: World Bank, 2018

3.4. Transboundary Water Resources in the Eastern Africa Region

3.4.1. Transboundary lakes, aquifers and rivers

Lake Turkana, Jipe, Victoria, and Tanganyika are the major transboundary lakes in the region (Table 15, 16). Several countries in Eastern Africa share groundwater resources. Of the transboundary lakes, Lake Victoria is the largest in the region and Africa; and the second largest world's freshwater lake. Lake Victoria has a large basin covering around 193,000 km^2, spanning four countries: Tanzania (44%), Kenya (22%), Uganda (16%), Rwanda (11%), and Burundi (7%). Given its size, Lake Victoria is a critical determinant of the region's climate and weather. Lake Victoria basin consists of a population of more than 30 million spread across the three major riparian states of Uganda, Tanzania and Kenya.

Lake Jipe, which is the smallest (approximated area of 28 km^2, 3 m deep, 2.5 km wide and 12 km long) lies across the border of Kenya and Tanzania. Lake Jipe receives its major inflows from the Pare Mountains and Mt Kilimanjaro via River Muvulani and River Lumi (passes through Kenya), respectively. Other temporary streams provide minor inflows into Lake Jipe. Lake Turkana shared by Ethiopia and Kenya is in the Great Rift Valley and is the largest permanent desert and alkaline lake in the world. It covers a surface area of about 6,405 km^2, contains 200 km^2 of water and has a basin area of 130,860 km^2.

Table 15: Major transboundary lake and river basins in the Eastern Africa region

River/Lake	Basin area (000 km^2)	States sharing basin
Awash	120.0	Ethiopia, Djibouti
Juba-Shabelli	827.0	Somalia, Ethiopia, Kenya
Lake Jipe	-	Kenya and Tanzania
Lake Turkana	130.86	Ethiopia, Kenya,
Lake Tanganyika	233.0	Tanzania, Zambia, Burundi
Lake Victoria	190.0	Kenya, Tanzania, Uganda
Nile	3,381	Sudan, Ethiopia, Uganda, Kenya, Tanzania, Eritrea, Egypt, Rwanda, Burundi
Pangani	58.8	Tanzania, Kenya

Source: Nanni, 2016

Table 16: Countries and international basins

Country	International river basins
Comoros	-
Eretria	Awash
Ethiopia	Nile, Awash, Juba-Shabelli, Lake Turkana
Kenya	Nile, Juba-Shabelli, Lake Jipe, Lake Turkana, Lake Victoria, Nile, Pangani
Mauritius	-
Seychelles	-
Somalia	Juba-Shabelli
Sudan	Lake Turkana, Nile
Tanzania	Congo, Lake Jipe, Lake Malawi/Niassa/Nyasa, Lake Tanganyika, Lake Victoria, Nile, Pangani, Ruvuma, Zambezi
Uganda	Lake Turkana, Lake Victoria, Nile

Source: Nanni, 2016

Several transboundary aquifer systems and aquifers exist within the East African region with the Nubian Sandstone Aquifer System (NSAS) in the northern part of Sudan being the largest. The Sudd Basin, Merti, Rift Aquifer, Awash Valley and Mt Elgon are the other major aquifer systems in the region (Nanni, 2016). The availability of renewable water resources in the region is shown in Table 17.

Surface water drainage in Eastern Africa is majorly controlled by the Great Rift Valley. The southern and northern part of the valley drains into the Mediterranean Sea and the Indian Ocean respectively. Juba-Shibeli River drains parts of Kenya and Ethiopia reaching the Indian Ocean during the rainy seasons but spreads in sand flats and marshes in the dry seasons. The River Nile drains parts of Uganda, Ethiopia, Kenya, Tanzania, and Rwanda, and other countries ending at the Mediterranean Sea (U. Adhikari, Nejadhashemi, & Herman, 2015).

3.5. Threats to Water Resources and Water Security

Several threats to water resources and security exist including pollution from industrial emissions and effluents, agricultural activities, rapid urbanization, increased population growth and climate change (Ngaira, 2009).

Table 17: Availability of renewable water resources in the Eastern Africa Region

Country	Internal Renewable Water Resources (IRWR) (km^3)				Incoming water from other countries (km^3)		Total Renewable water resources D + E + F
	Surface produced internally	Groundwater recharge	Overlap (shared by surface and groundwater	Total internal renewable water	Surface water	Ground water	
	A	B	C	D = A + (B – C)	E	F	
Comoros	x	1	0	1	0	0	1
Djibouti	x	x	X	0.3	0	2	2.3
Eritrea	x	x	X	2.8	6	0	8.8
Ethiopia	110	40	40	110	x	x	110
Kenya	17.2	3	0	20.2	10	0	30.2
Madagascar	332	55	50	337	0	0	337
Mauritius	2.03	0.68	0.5	2.21	0	0	2.21
Seychelles	x	x	X	x	0	0	x
Somalia	5.7	3	3	5.7	7.5	x	x+13.2
Sudan	28	7	5	30	119	0	149
Tanzania	80	30	28	82	9	0	91
Uganda	39	29	29	39	27	0	66

x: the exact value or quantity could not be established.

Source: http://www.fao.org/nr/water/aquastat/data

- ***Agricultural pollution*** – Rain-fed agriculture being the main economic activity in Eastern Africa region is responsible for the pollution of water resources from pesticides and fertilizers. The exploding population has led to increased large-scale commercial agricultural activities. Agricultural practices (cultivation) can impact ground and surface water quality. Surface water is impacted through erosion and subsequent deposition of topsoil in receiving streams, and nutrients (N and P) runoff from excessive fertilizer use. Pesticide runoff can be locally very relevant when pesticides are applied incorrectly or when rain washes them away (Table 18). For example, the water quality in Lake Naivasha in Kenya has continuously deteriorated as a result of pollution by pesticides and fertilizers used in commercial flower planting in Naivasha. Kenyan flower exports account for up to 25% of the European market (Wang et al, 2014; Loha et al, 2018).

- ***Microbial pollution through Municipal untreated sewage, runoff, and stormwater:*** Direct discharge of municipal untreated effluent into rivers and the lake directly contribute to microbiological pollution. These have contributed to the degradation of river and lake-water quality for habitats and drinking use. Most cities and towns in the region lack proper facilities for wastewater treatment and management, leading to the discharge of wastewater and related effluents into freshwater sources (Edokpayi et al., 2017). Mwanza, a city in Tanzania discharges its effluents directly to Lake Victoria due to a limited sewage supply. The direct discharge contributes to

Table 18: Major water pollutants from agricultural sources

Pollutant category	Indicators/examples
Nutrients	Primarily nitrogen and phosphorus present in chemical and organic fertilizers as well as animal excreta and normally found in water as nitrate, ammonia, or phosphate
Pesticides	Herbicides, insecticides, fungicides, and bactericides, including organophosphates, carbamates, pyrethroids, organochlorine pesticides, and others. Many, such as DDT, are banned in most countries but are still being used illegally and persistently
Salts	Ions of sodium, chloride, potassium, magnesium, sulphate, calcium, and bicarbonate. These are measured in water, either directly as total dissolved solids or indirectly as electric conductivity
Sediment	Measured in water as total suspended solids or nephelometric turbidity units – especially from pond drainage during harvesting
Organic matter	Chemical or biochemical oxygen-demanding substances (e.g., organic materials such as plant matter and livestock excreta), which use up dissolved oxygen in the water
Pathogens	Bacteria and pathogen indicators, e.g., Escherichia coli, total coliforms, faecal coliforms, and enterococci
Metals	Bacteria and pathogen indicators, e.g., Escherichia coli, total coliforms, faecal coliforms, and enterococci
Emerging pollutants	E.g., drug residues, hormones, and feed additives

Source: FAO, 2018b.

the pollution of the lake significantly (Afrik21, 2020).

- ***Lack of awareness of good hygiene practices*** leading direct contamination of beach waters through bathing and washing, and uncontrolled waste disposal around the shorelines and riverbanks.

- ***Industrial pollution*** i.e., beer-brewing, pulp, and paper production, tanning, fish processing, and abattoirs discharge raw/untreated waste to feeder rivers and lakes. In Jinja, Uganda, several industries have been reported to discharge large amounts of raw effluents into the rivers (Kikenyi, Nile, and Walukuba), urban wetlands, and Lake Victoria. The direct discharge leads to nutrient enrichment and the accumulation of toxic organic and inorganic compounds (Oguttu et al., 2008).

- ***The infestation of water bodies by plants*** e.g., water hyacinth infestation of Lake Victoria leading to reduced water quality by increasing the turbidity.

- ***Oil pollution*** particularly in South Sudan where oil exploration and spills have caused contamination of freshwater sources at exploration facilities and around pipelines and disrupted the local hydrology systems. Also, water contamination has resulted from the disposal and release of human waste and solid waste from oil camps. Oil pollution has reportedly poisoned the drinking water used by up to 600,000 people in South Sudan (DW, 2018). In Thar Jath, South Sudan, oil field activities led to increased salinity of water used for drinking, human incompatibilities, and high livestock mortalities. The pollution of the water resource is a result of improper waste disposal by the oil industries (Pragst et al., 2017).

- ***Chemical pollution by agrochemicals*** is increasing in the lake and river basins where there are large-scale farms of coffee, tea, cotton, rice maize, sugar and tobacco.

- ***Extensive deforestation*** leading to severe land erosion causing sedimentation of water bodies and reducing water quality. Sedimentation reduces the effectiveness of the existing infrastructure to improve water security. Reservoirs such as dams for irrigation and drinking water are increasingly losing their capacities due to sedimentation. The capacity of the main water reservoir supplying Addis Ababa in Ethiopia has reduced by up to 2.1 million m^3 between 1979 and 2010. The capacity of the Angereb dam for drinking water also in Ethiopia, has reduced by half since it was built in 1976 (REACH, 2015).

- ***Rapid urbanization*** has led to large volumes of water being extracted from existing sources. The influx of water and human waste has outpaced existing and new wastewater management systems leading to the pollution of natural water bodies. Ethiopia's town of Adama with an estimated population of 350,000 residents spends up to 70% treatment cost for municipal drinking water on the removal of sediments and pollutants originating from upstream urbanization and industrial activities. Also, Ziway, another town in Ethiopia with 50,000 residents, has been forced to shift spring water sources following a high level of pollution of the water from the lake. The springs being further away from the town than the lakes, results in increased higher charges for the water users including the poor (REACH, 2015).

- ***Solid waste pollution*** from huge amounts of municipal solid waste, industrial solid waste, and medical waste thrown into wetlands, lakes, rivers, and open spaces poses a serious threat to water resources and security. For instance, in Addis Ababa, insufficient waste management facilities lead to the piling of waste in open spaces. When it rains, the waste is washed off to rivers and other receiving streams (Wang et al., 2014). The country-specific threats to water security in the Eastern Africa region are given in Appendix A.

Table 19: Threats to water resources and security in Eastern Africa

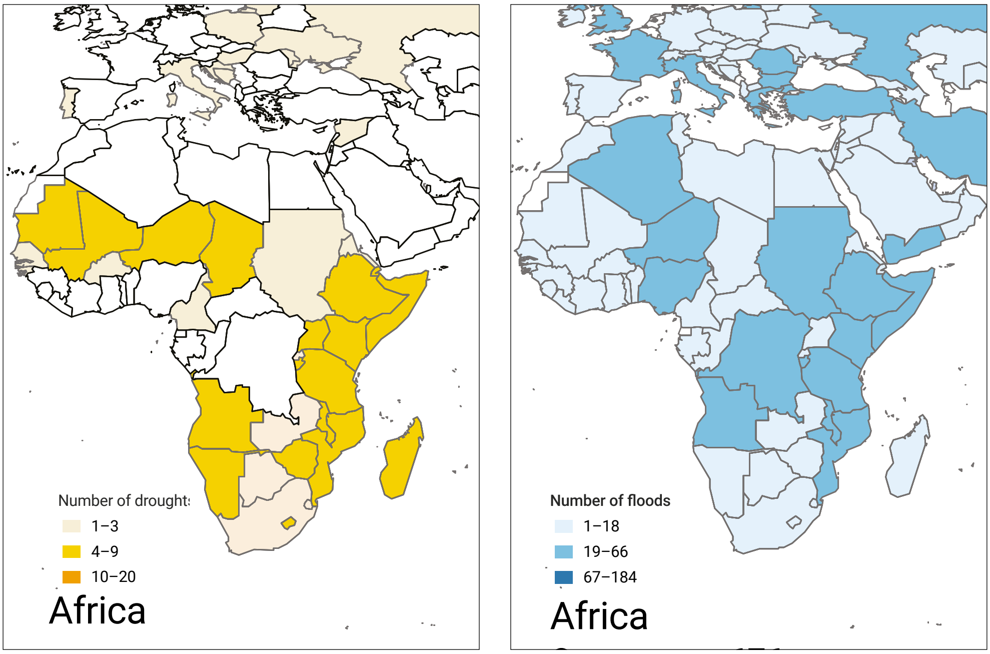
Threats to water resources and water security	Level
Microbial pollution through Municipal untreated sewage	Critical
Deforestation	Critical
Rapid urbanization	Critical
Agricultural activities	Critical
Industrial pollution	Critical
Chemical pollution	Critical
Marine transportation	Critical

3.6. Impacts of Climate Change on Water Security

Climate change manifests through the increased number and magnitude of events including unprecedented rainfalls, heat waves, storm surge, thunderstorms and droughts (UN Water, 2020). In the past 20 years, more than 70% of natural disasters caused by or linked to climate change have been water related. Africa's rise in temperature is projected to be faster than other regions of the world exceeding 2°C by 2050 and 4°C by 2100 (Adhikari et al., 2015). Climate change is expected to lead to increased temperature and variability in precipitation in the Eastern Africa region, and cause severe negative effects on water resources availability, food security, tourism, human health, biodiversity and coastal development. From climate change projections, the region is expected to experience warmer temperatures (up to 20%) increased rainfall between December and February, and decreased rainfall(10%) between June and August by 2050 (WWF, 2006). The non-uniform changes will be unpredictable and occur sporadically. The increased precipitation will most likely occur in the wet seasons thus leading to water management and erosion issues. Also, in the dry season, reduced precipitation is expected to cause frequent and severe droughts.

In the southwest Indian Ocean, warming surface temperatures will affect the rainfall pattern of East African region and is currently linked to change in rainfall across the region's equatorial-subtropical parts. The recent droughts of the 1980s and 2000s experienced in equatorial and subtropical parts of Eastern Africa are believed to have been caused by the warming sea surface. Between 1980 and 2000, several food crises in the region tripled while drought affected water supply leading to reduced crop production (WWF, 2006). Between 2000 and 2018, Eastern Africa region has experienced the highest number of water-related disasters (droughts and floods) resulting from the effects of climate change leading to significant losses in livelihoods and affecting several millions of people (Figure 10). The potential climate change effects on water resources of the countries in Eastern Africa region are summarised in Table 20.

Figure 10: Spatial distributions of droughts and floods in Africa between 2001 and 2018 (UN Water, 2020)



The boundaries and names shown and the designations used on the maps in this publication do not imply official endorsement or acceptance by UNESCO.

Table 20: Effects of climate change on water resources in the Eastern Africa region

Country	Climate change-related effects
Burundi	Flooding, landslides, drought
Comoros	Cyclones possible during the rainy season (December to April); Le Kartala on Grand Comore is an active volcano
Djibouti	Earthquakes; droughts; occasional cyclonic disturbances from the Indian Ocean bring heavy rains and flash floods
Eritrea	Frequent droughts; locust swarms
Ethiopia	Geologically active Great Rift Valley susceptible to earthquakes, volcanic eruptions; frequent droughts
Kenya	Recurring drought; flooding during rainy seasons
Madagascar	Periodic cyclones
Rwanda	Periodic droughts: the volcanic Virunga mountains are in the northwest along the border with the Democratic Republic of the Congo
Somalia	Recurring droughts; frequent dust storms over eastern plains in summer; floods during the rainy season
Sudan	Dust storms and periodic persistent droughts
Seychelles	Lies outside the cyclone belt, so severe storms are rare; short droughts possible
Tanzania	Flooding on the central plateau and south-eastern coastal areas during the rainy season; drought

Source: FAO, 2018b.

3.6.1. Impacts of climate change on surface water

Compared to the rest of Africa, Eastern Africa is expected to experience an increased annual surface runoff (Table 21). By 2050, an estimated increase in annual rainfall of up to 23% will result in 115% increased surface run-off in Kenya's Nzoia catchment area and Lake Victoria basin. Uganda's Sezibwa River will have an increased surface runoff of 60% and 100% by 2050 and 2080 respectively. The upper Nile basin in Ethiopia experience a predicted change in annual run-off ranging from -25% to +30%. The mean discharge of River Nyabarango in Rwanda is expected to slightly decrease by 2021, while Tanzania expects a decrease of up to 10% in Pangani and Ruvu rivers; and an increased 11% run-off in river Rufiji under doubled CO_2 emissions (Adhikari et al., 2015).

The tropical glaciers in Tanzania (Mount Kilimanjaro and Mount Ruwenzori) and Kenya (Mount Kenya), have decreased by up to 90% by the start of the 20th century with a 75% ice cover reduction (Table 22). The ice covers and glaciers are likely to disappear in the next few decades with the initial melting leading to increased and decreased river flows in the short and long term respectively (UNEP, 2013). The ice melt is however an indicator of climate change and may not affect the hydrology which is dominated by forest cover (Adhikari et al., 2015).

Table 23 shows the negative and positive effects climate change is expected to have on the water sector and resources.

Table 21: Expected changes in surface runoff in the East African region

Name of catchment	Country	Year	Change in Runoff
Lake Tana	Ethiopia	2075	-11.3%
Upper Nile	Ethiopia	2050	-25% to +32%
Nzoia	Kenya	2050	+6% to +115%
Sezibwa	Uganda	2100	+47%
Nyangores	Kenya	2100	-27% to +32%
Mitano	Uganda	2100	+14%

Source: Adhikari et al., 2015

Table 22: Glacier and ice cover reductions on Eastern Africa mountains

Mountain	Findings	Period
Mount Kenya	Seven of 18 glaciers and two-thirds of the ice cover disappeared	Past century
	Lewis Glacier area decreased by 90%	Since 1934
Mount Kilimanjaro	Ice cover decreased by 79%	1912-2003
	Ice cover decreased by 85%	1912-2007
	Ice cover may disappear	Within the next two decades
Mount Ruwenzori	Ice cover decrease by 52%	1987-2003
	Ice cover may disappear	Within the next two decades
Mount Kenya, Mount Kilimanjaro, Mount Ruwenzori	Glaciers decrease by 80%	Since 1900
	Glaciers decrease by 82%	1906-2006

Source: Adhikari et al., 2015

Table 23: Expected impacts of climate change on the water sector in the Eastern Africa region without adaptative measures

Phenomenon and direction of the trend	Likelihood of future trends based on projections for 21st century using a special report on emissions scenarios	Examples of major projected phenomenon impacts on water sector
Over most land areas, warmer and fewer cold days and nights warmer and more frequent hot days and nights	Likely	Effect on water towers with snow
The frequency of warm spells increases over most land areas	Very likely	Increased water demand and water quality problems, algal blooms
The frequency of heavy precipitation events increases over most areas	Very likely	Adverse effects on surface and Groundwater quality; contamination of water supply; per capita water might increase
Areas affected by drought increase	Very likely	Widespread water stress

3.6.2. Impacts of climate change on groundwater

Given the large storage capacity, groundwater is less affected by the short-term climate changes as compared to surface water. Long-term climate change poses significant impacts to groundwater directly by affecting the recharge of groundwater and indirectly through groundwater abstractions. Evapotranspiration may increase the salinity of shallow wells and aquifers during dry regions and in some cases dry up during droughts. Groundwater storage, discharge, biogeochemical reactions, and transportation rate of chemical fluxes will be modified by climate change as already experienced in other parts of the world. The changes in quality and quantity of groundwater will be the most noticeable (USAID, 2017b). Quantifying climate change impacts on groundwater is made difficult by the inability of currently developed climate models in providing detailed information particularly in drier climates (Adhikari et al., 2015).

3.7. Conflicts Arising from Water Threats and Security

Climate change, pollution, deforestation, population growth and other threats will lead to a reduced water supply to users, communities and countries. Increased water scarcity creates competition in water withdrawals and uses leading to conflicts. Several types and levels of conflicts resulting from water use family/household, community, regional, national and international levels.

- ***Community-level conflicts*** mostly involve pastoralists who water their animals at neighbouring villages or communities particularly during drought seasons. In some cases, the migration by pastoralists to areas with permanent water supply puts increased pressure on the existing water resource leading to conflicts with the local community. Also, conflicts between local community members and government bodies may arise in cases where people encroach on marginal lands and gazetted/ protected areas (game reserves, national parks, and wetlands) looking for water and pasture. Owing to the increasing water scarcity because of climate change and droughts, many communities have resorted to invading the protected areas. For instance, up to 800 families faced forced evictions from the Serengeti National Park (Tanzania) having invaded the area for water following prolonged droughts. Similar types of evictions have been reported in the Usangu Game Reserve in southern Tanzania (ISS, 2010)..

- ***Conflicts caused by competing livelihood systems*** i.e., different groups of people with different types of economic activities, such as crop cultivation and livestock keeping may compete over resources particularly during droughts. Livestock keepers may sometimes encroach on water and land meant for practicing crop production. Also, crop growers may encroach on the grazing land thus reducing the pasture reserved for the livestock. Upstream and downstream water users experience a similar type of conflict regardless of the economic activity practiced. For example, the downstream users of the Mara River in Tanzania have blamed upstream users on the Kenyan side for excessive water withdrawals for irrigation thereby leaving less water for downstream activities. Also, the downstream users have blamed the upstream users for water pollution given the increased turbidity and colour resulting from riverbank cultivation.

- ***Interstate conflicts*** may result from competition for transboundary water resources shared between countries regarding access and use. The transboundary Mara River is shared by Kenya and Tanzania. The Mara River water is used for different activities at different sections including for farming (livestock and irrigated agriculture), domestic, and environmental, and wildlife maintenance. Access and use of the Mara water will likely cause conflicts between upstream (Kenya) and downstream (Tanzania) users, and between human populations and wildlife. Climate change and land use may lead to reduced water supply in the Mara River. Climate change causes decreased rainfall and temperature rise leading to increased evaporation.

- ***Tribal clashes*** have increased in the Eastern Africa region mainly in the arid areas inhabited by pastoralists. As the water resources shrink, the communities in the northern parts of Kenya, southern parts of Ethiopia, and along with Uganda/Kenya, Kenya/ Ethiopia, and Somalia/ Kenya borders have had increased water-related tribal conflicts (IPSTC, 2010).

3.8. Country by Country Analysis of Water Resources, Climate Change Impacts, and Water Security

3.8.1. Kenya

More than 40% of Kenya's population depend on unimproved water sources including shallow wells, rivers, and ponds, while about 70% cannot access basic sanitation (water.org, 2020). The water and sanitation challenges are prominent in urban slums and rural areas where there is poor infrastructure of piped water. Climate change is causing direct or indirect impacts to all sectors of Kenya's economy and has limited livelihood resources viability, lowered productivity and compromised infrastructural development.

3.8.2. Ethiopia

Climate change poses a serious threat to water resources and services dependent on water. Ethiopia will experience a variable climate resulting in droughts and floods that have historically catalyzed humanitarian crises. Extended droughts may lead to the drying up of hand-dug shallow wells that offer limited storage, while floods can damage infrastructure and spread contamination. The effects of climate change will impact livelihoods, particularly to rural Ethiopians depending overwhelmingly on groundwater resources offering a natural buffer against variations in the climate (ODI, 2013).

3.8.3. Uganda

Uganda has abundant renewable sources of water equivalent to 2085 m^3/year, which is above the 1000 m^3/year global water scarcity limit. The Ugandan water sector is however underdeveloped with only 0.5% of the renewable water withdrawn annually for agricultural (40%), industrial (17%), and municipal (43%) uses. Uganda is a riparian state of the river Nile which is a wide basin of several countries including Kenya, Rwanda, Uganda, Burundi, Sudan, Tanzania, Ethiopia, the Democratic Republic of Congo (DRC), Eritrea, and Egypt. More than 21 million Ugandans do not have access to clean water (IFP-EW, 2011). Whereas much of the country is swampland and open water, the water drawn is undrinkable. Poor management and high demand have led to shortages in clean groundwater. Several facilities in towns and cities are strained while the shallow wells and springs that supply most rural communities are almost used up.

3.8.4. Rwanda

About 52% of Rwanda's population has access to clean drinking water. The daily water consumption of about 8.15 litres per person mostly in rural areas is well below the global 20 litres standard. Rwanda has reserves including lakes, rivers, streams, and favourable precipitation (900 & 1800 mm per year) that could provide enough water for irrigation and consumption. Moreover, the abundant supply of high-altitude water that exists in the western part could provide water by gravity to low lying southern regions facing water shortages (Rwanda Vision 2000).

3.8.5. Burundi

In Burundi, access to basic sanitation in rural areas is higher than in urban areas. Whereas about 81% of the population could access improved drinking water sources in 2017, only 61% could access safe water for drinking within half an hour round-trip from their homes. Main barriers to the provision of basic sanitation include poor sanitation infrastructure quality, poor maintenance practices of the existing infrastructure, and difficulty in community mobilization (UNICEF, 2020).

3.8.6. Mauritius

Piped water network covers the whole island with the entire population having access. About 9.6% of the country's population can access piped water within their homes, with about 85% having the piped water inside their houses

(FRESH WATER, 2004). Climate change has amplified Mauritius's vulnerability to tropical storms and floods that are estimated to lead to up to $ 110 million annual losses (World Bank, 2020b).

3.8.7. Seychelles

Water security is a major concern for Seychelles with a major focus on catchment areas, storage, and other facilities. The country's over-dependence on its water resources for both societal and economic activities causes major problems, particularly during droughts. Limited storage capacity of dams and barrage hinder the country from storing enough water for the dry seasons. Up to 95% of the water from freshwater sources is lost to the sea due to inadequate storage and catchment. Inadequate fresh raw water poses a major threat to the major sectors of the economy including tourism, light manufacturing, and agriculture (AfDB, 2019). The country is vulnerable to the effects of climate change such as rising sea levels and increased cyclones. The coastal infrastructure is prone to erosion and other damages (AfDB, 2019).

3.8.8. Sudan

About 85% of Sudan's population do not have access to safe water sources with over 25% relying on surface water and about 60% on boreholes and shallow wells. The reliance on shallow wells and boreholes is one of the highest in the region and poses a big challenge to the country. Sanitation in Sudan is still an issue with only 40% of the population having access to improved latrines, while another 40% practice open defecation (World Bank, 2010).

3.8.9. South Sudan

South Sudan continually experiences warm and dry weather leading to increased evaporation and droughts. Decreasing precipitation accompanied by rapid temperature increases (2.5 times higher than the global average) has caused the normal years to be drier. More people will be at risk given the high population and expansion of farming and pastoralism under the unfavourable climatic regime (Ministry of Foreign Affairs Netherlands, 2018).

3.8.10. Tanzania

It is estimated that forests provide water catchments for over 80 percent of Tanzania's water supplies, which accounts for over 60 percent of Tanzania's generated electricity through hydropower. Despite the importance of forest resources, challenges like inadequate forest extension services, inefficient wood-based industries, and poor infrastructural facilities, lack of stakeholders' participation, outdated legislation, fragmented administration, and outdated or non-existing management plans hamper the development of the sector. Also, unsustainable harvesting of natural resources, water source encroachment, and unchecked cultivation coupled with detrimental effects of global climate change pose increasing challenges to agricultural development (AfDB, 2019). The combination of environmental degradation and climate change effects poses a serious threat to farmers and livestock keepers. Efforts will need to be directed at building the capacity of government and local communities to address this challenge. Within the ASDP/ ASP the issue of early warning and emergency preparedness has not been fully integrated, and the country still has inadequate physical, human, institutional, and financial capacities to deal effectively with the impacts of climate change. This capacity gap hampers adequate crisis prevention, preparedness response, and effective action during emergencies (AfDB, 2019).

3.8.11. Madagascar

In Africa, Madagascar faces the highest risk from cyclones. In the past 20 years, the country has had 35 cyclones, severe droughts (5 times), and 8 floods causing an estimated loss of $1 billion in damages while affecting the quality of life, food security, public health systems, water supply (drinking and irrigation), and environmental management.

3.8.12. Djibouti

The country's main challenges are vulnerability to climate change, reflected in average precipitation barely exceeding 150mm a year across a large part of the country (drought and floods), low factor productivity (labour and capital), little diversification of national production and exports, small domestic market (population of fewer than 1M inhabitants), a longstanding unchanged GDP structure, low purchasing power, unequal distribution of income, high unemployment, and low institutional and human capacities reflected in weak project implementation. (AfDB, 2019).

3.8.13. Comoros

The mean annual rainfall for the islands is 1,000 mm. In Grande Comore, it varies between 1,398 mm and 5,888 mm, in Anjouan between 1,371 mm and 3,000 mm, and Moheli between 1,187 mm and 3,063 mm. Comoros is known for its many microclimates. (Global Security, 2017) Climate change is likely to adversely affect Comoros mainly through changes in rainfall levels and patterns, increased temperatures, sea-level rise (and subsequent salinization of critical coastal aquifers as a result of saltwater intrusion) and an increased frequency of climatic hazards (such as tropical cyclones, droughts, episodes of heavy rainfall and flooding). Forests in Comoros have been the subject of illegal and abusive occupancy since before independence in July 1975 with fuelwood being a dominant energy source (78%). To date, they provide the last frontier for agricultural expansion in the country, placing them at the center of land appropriation dynamics. Forestry exploitation is still of the artisan type and employs few people. (INCC, 2002).

3.8.14. Eritrea

Vulnerability to climate shocks and delayed agricultural transformation have reduced agricultural productivity. Given the size and importance of this sector for food security and employment, lower productivity could constrain the potential contribution of agriculture (now 20% of GDP) (AfDB, 2019).

3.8.15. Somalia

The total available water resources in the entire Somalia are estimated as 14.7 km^3, compared to an estimated annual withdrawal rate of 3.3km^3. About 99% of the estimated total annual water withdrawal is for livestock and agricultural purposes. However, the current water resources in Puntland are not able to meet the increasing demand, and there is need to invest in the development of new sources, especially in the rural areas. The riparian communities use several streams as surface water sources, while distant communities depend largely on rainwater harvesting and groundwater (GW) to meet water demand. The WSS sector is generally driven by a vibrant private sector (PS) with the public sector providing complementary services. With limited available public financial resources, donors and the PS are the main providers of sector financing in both rural and urban communities. Public sector institutions mainly play a facilitative role. The Puntland State Authority for Water, Energy and Natural Resources (PSAWEN) is the key institution responsible for policy, planning, coordination, regulation, and development of available water resources (AfDB, 2015).

According to the World Health Organization (WHO)/United Nations Children's Fund (UNICEF) Joint Monitoring Programme (JMP) 2013 update from 2000 to 2011, the proportion of urban dwellers using improved water supply and sanitation (WSS) facilities increased significantly from 35% in 2000 to 66% in 2011. On the contrary, the proportion of rural dwellers decreased within the same period, with significant decreases in water supply from 15% in 2000 to 7% in 2011. Currently, about 83% of the rural population practices open defecation with serious health implications (WHO/UNICEF, 2013).

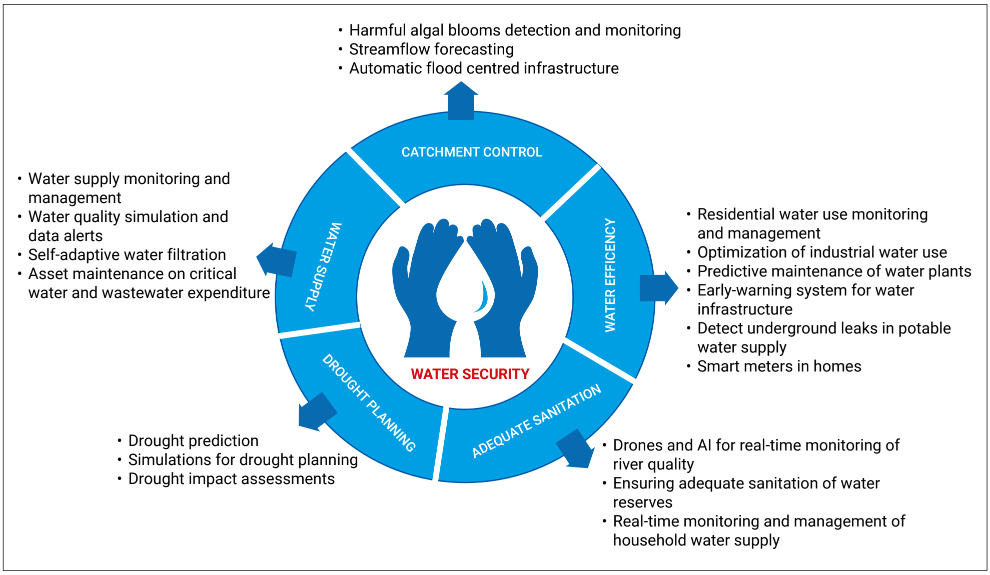
4 Ongoing and Potential Science and Technological Innovations in the Water Sector Applicable in Rural and Urban Environment

4.1 Introduction

Rural areas of Eastern Africa are mostly affected by lack of access to clean drinking water. Residents walk long distances for water - some of which are contaminated - presenting serious health challenges (Water.org, 2020; UNICEF, 2020). Also, sanitation is a major issue where access to toilets and waste disposal methods is still low. In urban areas, existing methods for water treatment and supply are not effective enough. Lack of appropriate plumbing and waste removal causes contamination of water and damage to supply systems. The massive populations in urban areas have also led to high water demands thus putting a strain on the already dwindling water sources.

Agriculture, a leading economic activity in the region, equally strains the water supply and contributes to water pollution. Wetlands, important for filtering water and improving air quality, are increasingly threatened by climate change, pollution, rapid urbanisation and drainage for agricultural use further fuelling water crisis (GWP, 2015a). Despite these challenges, solutions are within reach. Science, Technology and Innovation (STI) - coupled with partnerships, financing and business models for effective implementation - can play an important role in creating sustainable solutions for water security (Figure 11).

Figure 11: Role of STI in promoting water security and sustainable management



The Singapore International Water Week (SIWW) on Technology and Innovation Summit (STIS) of 2016 identified eight key drivers for innovation in the water sector as outlined in Figure 12 (SIWW, 2016). Technology Focus Areas (TFAs) for water (clean and wastewater) aims to address the key drivers based on important areas for investment anchored on by four categories:

(i) High (Low-Hanging Fruit) - Impactful and low effort/lead-time for implementation,

(ii) High Priority (Disruptive) - Potentially impactful but much developmental work needed before implementation,

(iii) Medium Priority - Should be considered based on the availability of resources since the potential impact is less than (i) and (ii), and

(iv) Low Priority - Too much requirement for developmental work but with little potential impact.

The TFAs are classified based on their impacts and investments required for actualization. Figure 13 provides the Global Technology Roadmap developed at SWWI 2016 outlining the 28 TFAs priority levels applicable to clean water treatment and wastewater management or both. These include biological processes and water recovery, sustainable and energy-efficient desalination, water demand and assets management through real-time data collection and mining, sludge management techniques, resilient membrane systems for reverse osmosis (RO) and optimisation of wastewater collection.

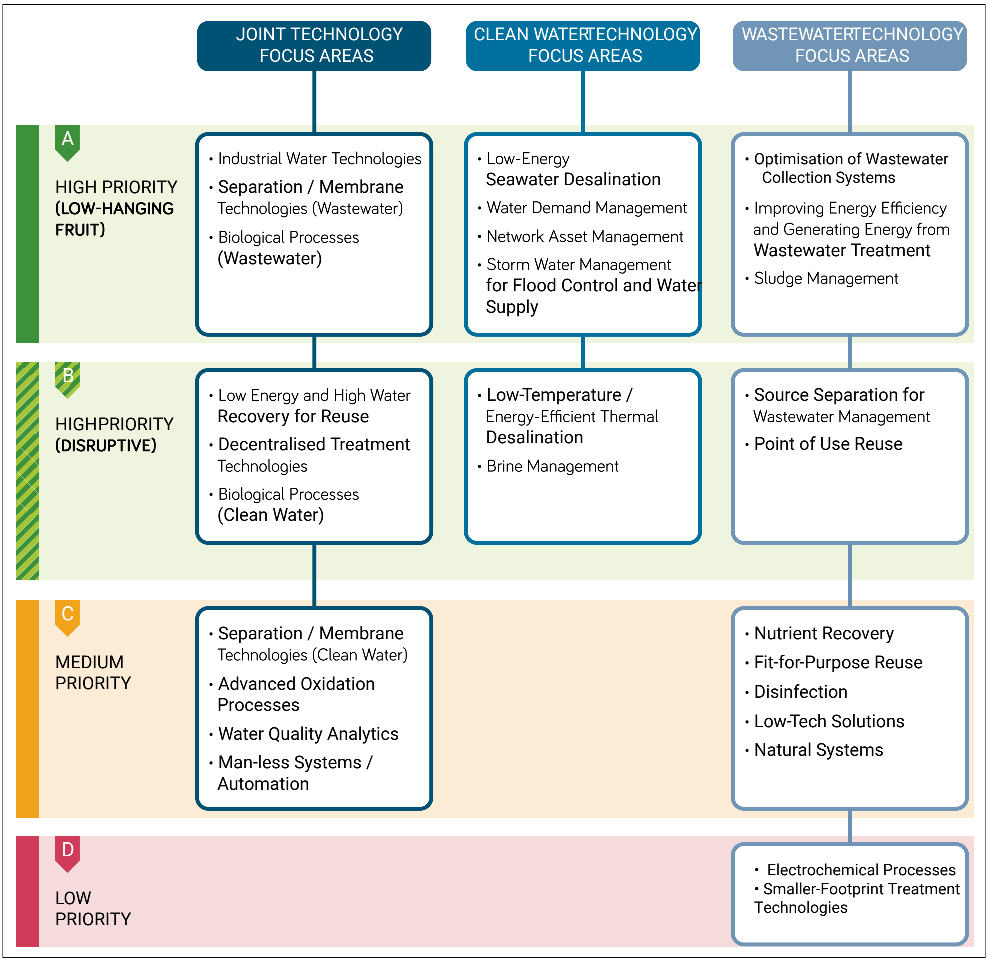
Water technology solutions related to the Fourth Industrial Revolution (4IR) will facilitate uptake of more localized and off-grid solutions for the treatment of water and wastewater management (Figure 14). The 4IR water technologies will also provide strategies for building hybrid decentralized-centralized water systems. Existing centralized water systems currently struggle to cope

Figure 12: Key drivers for innovation in the water sector

8 KEY DRIVERS FOR INNOVATION

1. PROTECTION OF WATER QUALITY
2. CLIMATE CHANGE/EXTREME WEATHER EVENTS
3. DEMAND MANAGEMENT
4. NEED FOR NON-CONVENTIONAL WATER SOURCES
5. WATER-FOOD-ENERGY NEXUS
6. ENVIRONMENTAL SUSTAINABILITY, E.G. WASTE MINIMISATION/ RESOURCE RECOVERY
7. FIT FOR LOCAL CONTEXT
8. GOVERNANCE/LEADERSHIP

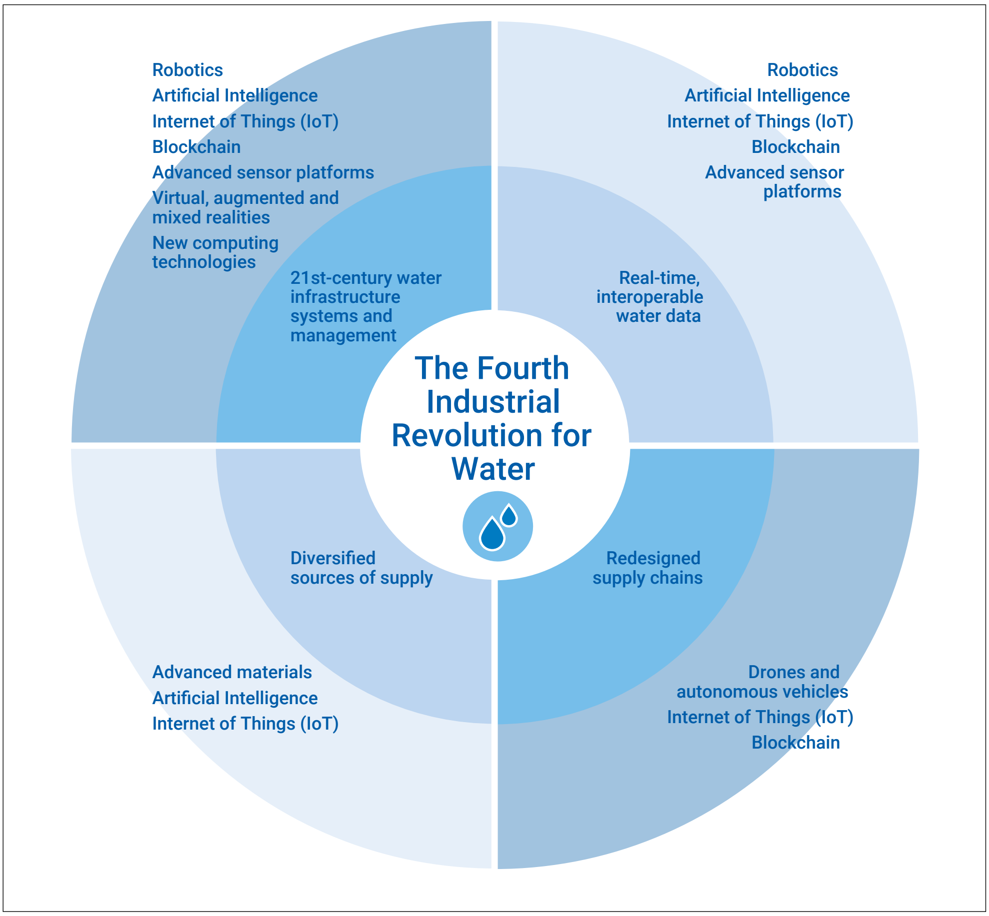
Figure 13: Global technology roadmap, SWWI 2016



with the rapid population growth and urbanization particularly in Africa in addition to limited financing, the effect of climate change, and lack of political will. Shifting to decentralized water network systems will fulfil future water needs and improve urban/city planning and preparedness.

Several innovations such as the adoption of power sector microgrid strategies for water systems are currently in place. Also, the real-time monitoring of water quality, quantity and system performance will significantly increase the adoption of off-grid water systems (World Economic Forum, 2018). Digitalizing water systems will improve the relationship between users and utility providers through real-time technologies for monitoring water quantity (Figure 14). Table 24 shows some of the aspects of water management where the application of 4IR and ICTs tools can improve water resource management in developing countries.

Figure 14: 4IR innovations for water and sanitation



Source: World Economic Forum, 2018

4.2. Wastewater Treatment/ Recycling

Vast amounts of water, valuable energy, and agricultural nutrients could be recovered from the ever-growing volume of municipal wastewater produced from the region. The major nutrients in the wastewater streams include phosphorus (3.0 Tg), nitrogen (16.6 Tg), and potassium (6.3 Tg) annually (Tg = million metric tons). The full energy and nutrient recovery from wastewater could offset up to 13% of the global demand for nutrients in agriculture, reduce overreliance on fossil fuels and minimize eutrophication. Wastewater is no longer considered as waste to be treated and disposed of but as a resource (Qadir et al., 2020). Innovative wastewater treatment technologies and practices - if implemented - will produce water and other by-products for reuse for industrial, agricultural, domestic and recreational purposes. Such technologies need to be appropriate, affordable and sustainable with the additional spin-off benefits of job creation and environmental protection.

Table 24: Key areas of water management for the application of 4IR and ICT tools

Areas for ICTs in water managemet	Examples of ICT tools	Benefits of water management
1. Weather forecasting	Remote sensing satellite systems; in situ terrestrial sensing systems; wire less sensor networks; geographical information systems(GIS)	High-quality and standardised observations of the atmosphere and ocean surface; realtime exchange of meteorological data and information
2. Mapping of water resources	GIS; satellite mapping; water portal systems; supervisory control and data acquisition(SCADA)	Improved understanding of the water resource base; improved knowledge of current levels of water abstractions and use; improved prediction of water resources supply and demand
3.Asset management	IS, buried asset identification and electronic tagging; smart pipes, hand pumps and meters; supervisory control and data acquisition(SCADA)	Improved management of distribution networks; reduced water losses; reduced network damage and deterioration; reduced risk of infection in the water system; shortened response time, reduced maintenance costs
4. Early warning systems	GIS; sensor networks; early warning websites; mobile-phone applications; digital delta	Improved reservoir management; flood mapping; improved data management(quick acquisition, processing, analysis and dissemination to warn the public)
5.Water demand forecasting	IS, ground penetrating radars; optical and pressure sensors; cloud computing; SCADA	Rain/storm water harvesting; managed aquifer recharge; improvements in water resource management
6. Service delivery	e-payment systems; GIS; call centres	Improved service delivery: timely access to water information, operational efficiency of water sector institutions - shortened response time, improved financial management, increasedrevenuecollection
7. Governance and visualisation	Smart mobile-phone applications; websites	Improved public participation, transparency and accountability; improved customer relations

Cities can build smart networks for reclaimed water and use ICT to determine the overall status in real-time. By connecting the systems to a network center, the decision can easily be made to manage supply and demand, stabilise the operation of the treated wastewater network and promote the reuse and recycling of reclaimed wastewater in a manner that is environmentally conducive and socially sustainable.

Innovative technologies applicable for wastewater treatment in the Eastern Africa region include cost-effective measures for algal growth control, low-cost on-site sanitation, biological treatment through a pond and constructed wetland systems and integrated treatment systems. Struvite ($MgNH_4PO_4 \cdot 6H_2O$), which is an important fertiliser for agricultural applications, can be recovered from municipal wastewater

Table 25: Innovative technologies for improved water and wastewater management

Treatment Technology	Drinking water	Waste-water
Cost-effective measures to control algae	√	√
Low energy consumption treatment/solar energy	√	√
Affordable on-site sanitation	×	√
Pond system + biological treatment + constructed wetland	×	√
Proper disinfection	√	√
Groundwater purification	√	√
Water reuse and desalination	√	√
Rainwater treatment	√	×
Harvesting resources and energy from wastewater	×	√

by employing integrated treatment systems. Constructed wetlands can be applied for tertiary wastewater treatment to remove nutrients, prevent eutrophication of receiving streams, and protect ecosystems (Wang et al., 2014). Some of the applicable technologies are shown in Table 25.

Table 26 outlines the sanitation technologies at the household level applicable in the rural, peri-urban, and urban areas.

Energy plays a vital role in water and wastewater treatment and is responsible for the high costs involved. The utilization of renewable energy such as solar or wind to supplement the energy requirement of treatment plants could significantly reduce operational costs. Energy can also be recovered from wastewater or waste activated sludge in the form of biogas. The recovered biogas can be converted to electricity and heat to meet the energy requirement.

4.2.1. Recirculating aquaculture systems (RAS)

Recirculating aquaculture systems (RAS) use a fraction of water to produce fish of the same quantity compared to traditional fishponds,. The RAS can be improved and made more sustainable by supplying it with treated domestic wastewater. A pilot plant in Kisumu, Kenya situated close to a stabilization pond for wastewater, combines the RAS system with an innovative membrane bioreactor to recirculates up to 95% of its water volume. The two systems (RAS and MBR) are integrated with renewable energy sources and smart technologies for monitoring. The treated water from the MBR is used to irrigate local vegetables while the natural by-products are applied as fertilizers in farms (EU, 2020).

Table 26: Innovative household centered sanitation technologies

Technology	Description	Application
Single Pit System	This system is based on the use of a single pit technology to collect and store Excreta. The system can be used with or without Flushwater, depending on the User Interface. Inputs to the system can include Urine, Faeces, Anal Cleansing Water, Flushwater and Dry Cleansing Materials.	Best suited to rural and peri-urban areas. Not recommended for areas prone to flooding, which may cause pits to overflow.
Waterless Pit System without Sludge Production	Designed to produce a solid, earth- like material by using alternating pits or a Composting Chamber. Inputs to the system can include Urine, Faeces, Organics, Anal Cleansing Water, and Dry Cleansing Materials. There is no use of Flushwater.	Appropriate for water-scarce areas and where there is an opportunity to use the humic product as soil conditioner.
Pour Flush Pit System without Sludge Production	A water-based system utilizing the Pour Flush Toilet (pedestal or squat pan) and Twin Pits to produce a partially digested, humus-like product, that can be used as a soil amendment. Inputs to the system can include Faeces, Urine, Flushwater, Anal Cleansing Water, Dry Cleansing Materials and Greywater. The	Rural and peri-urban areas with appropriate soil that can continually and adequately absorb the leachate.
Waterless System with Urine Diversion	Designed to separate Urine and Faeces to allow the Faeces to dehydrate and/or recover the Urine for beneficial use. Inputs to the system can include Faeces, Urine, Anal Cleansing Water and Dry Cleansing Materials.	Appropriate for rocky areas where digging is difficult, where there is a high groundwater table, or in water-scarce regions.
Biogas system	Based on the use of a Biogas Reactor to collect, store and treat the Excreta. Addition- ally, the Biogas Reactor produces Biogas which can be burned for cooking, lighting or electricity generation.	Best suited to rural and peri-urban areas where there is appropriate space, a regular source of organic substrate for the Biogas Reactor and a use for the digestate and Bio- gas.
Blackwater Treatment System with Infiltration	A water-based system that requires a flush toilet and a Collection and Storage/ Treatment technology that is appropriate for receiving large quantities of water. Inputs	Only appropriate in areas where desludging services are available and affordable and where there is an appropriate way to dis- pose of the Sludge. For
Blackwater Treatment System with Effluent Transport	Characterized by the use of a house- hold- level technology to remove and digest settleable solids from the Blackwater, and a Simplified or Solids-Free Sewer system to transport the Effluent to a (Semi-) Centralized Treatment facility.	Appropriate for urban settlements where the soil is not suitable for the infiltration of Effluent.
Sewerage System with Urine Diversion	A water-based system that requires a Urine-Diverting Flush Toilet (UDFT) and a sewer. The UDFT is a special User Interface that allows for the separate collection of Urine without water, although it uses water to flush Faeces.	Only appropriate when there is a need for the separated Urine and/ or when there is a desire to limit water consumption.

Source: (IWA, 2008)

4.2.2. Integrated algae ponding system

The use of algae-based wastewater treatment technology is recently attracting attention since microalgae can remove CO_2, which is a major greenhouse gas (Jimoh and Cowan, 2017). Algae-based treatment for municipal wastewater can help in the fight against waterborne diseases, infections, poor sanitation and contamination of water sources. In addition to water recovery for re-use, methane, algal biomass and nutrients are other products of algal treatment (Chong et al., 2019). These products are mostly desired by primary industries including agriculture thus positioning algae-based sewage treatment at the water-energy-food nexus particularly in the peri-urban space. Just like activated sludge is produced from the conventional activated sludge treatment systems, the algal ponds produce the residual algal biomass, which requires further processing and disposal. Algal biomass is nowadays considered as a resource for bioenergy and bioproducts in the context of a circular economy (Solé-Bundó, Garfí, & Ferrer, 2020).

The integrated algae ponding system (IAPS), which is derived from algal-based technology, has been successful in Grahamstown, South Africa. The IAPS has a primary facultative pond (with an anaerobic pit) which is followed by high-rate algae ponds. Unlike other wastewater systems, IAPS does not consist of pre-treatment, trickling filters and stabilisation ponds. The suspended matter in wastewater is degraded anaerobically in the facultative pond (ACGE, 2018).

4.2.3. Wastewater collection optimisation

In developing countries such as those in Eastern Africa, wastewater networks are often in poor shape and require expansion to match up with the rapid urbanisation, making wastewater collection optimisation crucial. Optimisation of wastewater networks can employ Integrated System Modelling (ISM) including data analysis, modern sensors and algorithms for designing treatment trains for water recycling (SIWW, 2016). To deal with extreme events such as flooding and other climate change related impacts, system resilience should be addressed. Other areas of consideration include:

- Designing wastewater network systems that flow efficiently thus avoiding clogging and hydrogen sulphide production;
- Optimizing the distance between treatment plans and wastewater sources to minimise wastewater transfer costs;
- Using long-lasting pipes that are leakage resistant.

4.3. Water Supply

Digitalization and connectivity are two new technologies that could play an important role in promoting sustainable development in almost all countries. The rapid connection of Eastern Africa's population through mobile phones and the internet presents an opportunity for exploiting digitally-enabled technologies for sustainable water management. The production and efficient distribution of water can be facilitated by advances in ICTs. Internet of Things (IoT) devices including sensors, mobile phones and meters can be used to improve water management (Table 27). The wireless sensor network can be used to monitor water supply and quality (United Nations, 2015).

The application of Geospatial technology for managing water infrastructure can significantly improve water supply and reduce water losses. Pipes, pumps, valves, nodes and tanks for storage are all important parts of the water supply. Integration of GIS with the water infrastructure network can help establish an efficient and continuously maintained water supply. All relevant stakeholders including the private sector, civil societies, and water administrators can use GIS technology for the planning and management of water supply infrastructure (UN-Water, 2011). The GIS technology when integrated with the water supply network allows for spatial network data analysis in the form of water pipe parameters including diameter, length, coefficients and roughness. Improved water infrastructure network enhances asset factor productivity, and tasks automation such as pressure management, leak detection, technical maintenance, and improved water quality control (Figure 15, 16).

In South Africa, municipalities are turning to advanced metering infrastructure to give accurate data in real-time thus reducing non-revenue water losses and achieving accurate billing. Advanced Metering Infrastructure (AMI) consists of an integrated system of communication networks, smart meters and data management enabling two-way communication involving customers and utilities. The communication enables the smart meters to be controlled remotely and managed on a fixed network over a private network or through cloud computing. The prepaid meters allow the consumers to have financial control and accurate billing by municipalities. Moreover, some of the systems allow for free daily basic water provision with a top-up option for consumers wishing to purchase additional water over and above the daily allocation (INTELLIGENT CIO, 2019).

Table 27: Major areas for the Internet of Things devices in water management Mapping

Mapping of water resources and weather forecasting • Remote sensing from satellites • In-situ terrestrial sensing systems • Geographical Information Systems • Sensor networks and the Internet	**Asset management for the water distribution network** • Buried asset identification and electronic tagging • Smart pipes • Just-in-time repairs/real-time risk assessment
Setting up early warning systems and meeting water demand in cities of the future • Rain/stormwater harvesting • Flood management • Managed aquifer recharge • Smart metering • Process knowledge systems	**Just-in-time irrigation in agriculture and landscaping** • Geographical Information Systems • Sensors networks and the Internet

Figure 15: Application of GIS in water supply

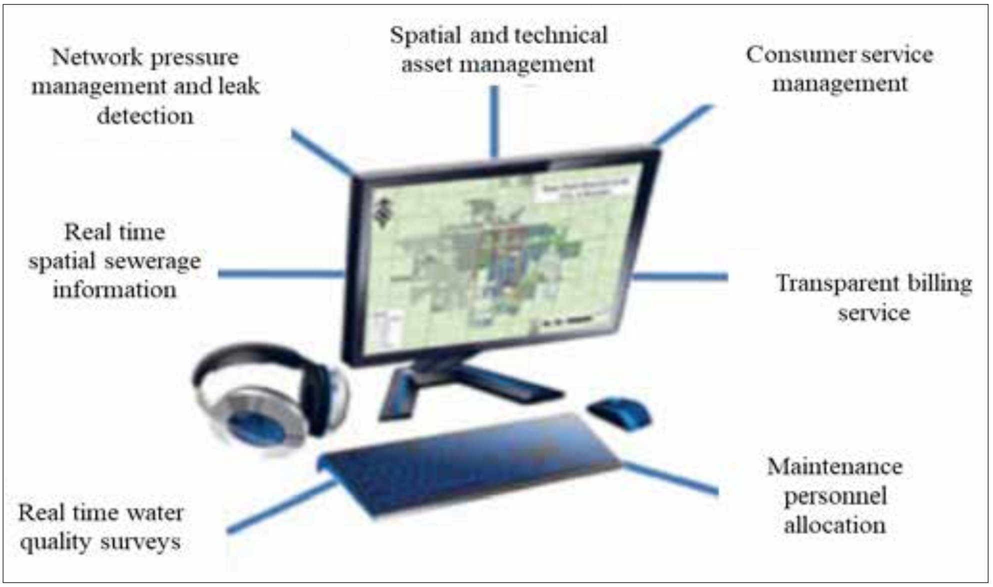
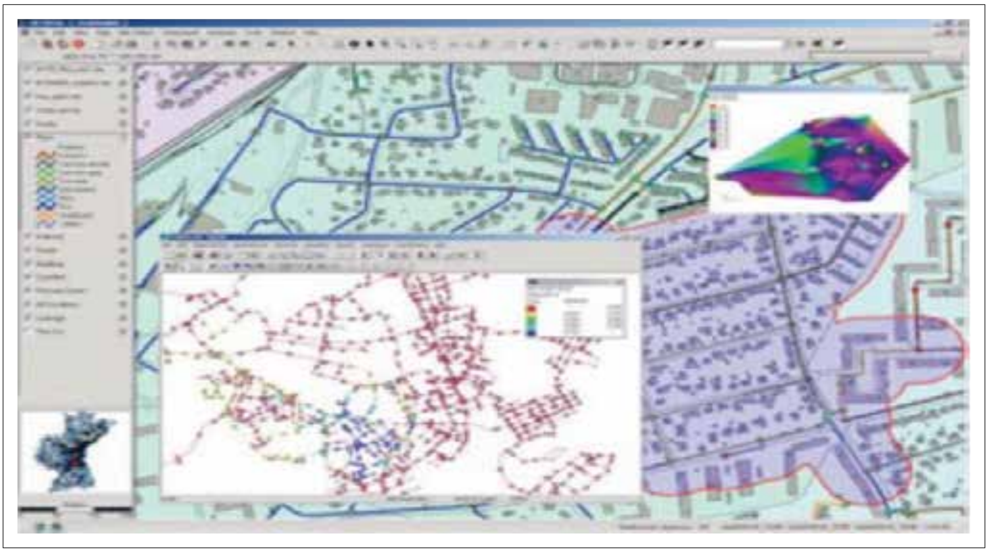


Figure 16: Water supply network managed by GIS



4.4. Novel Technologies in Rainwater Harvesting and Purification

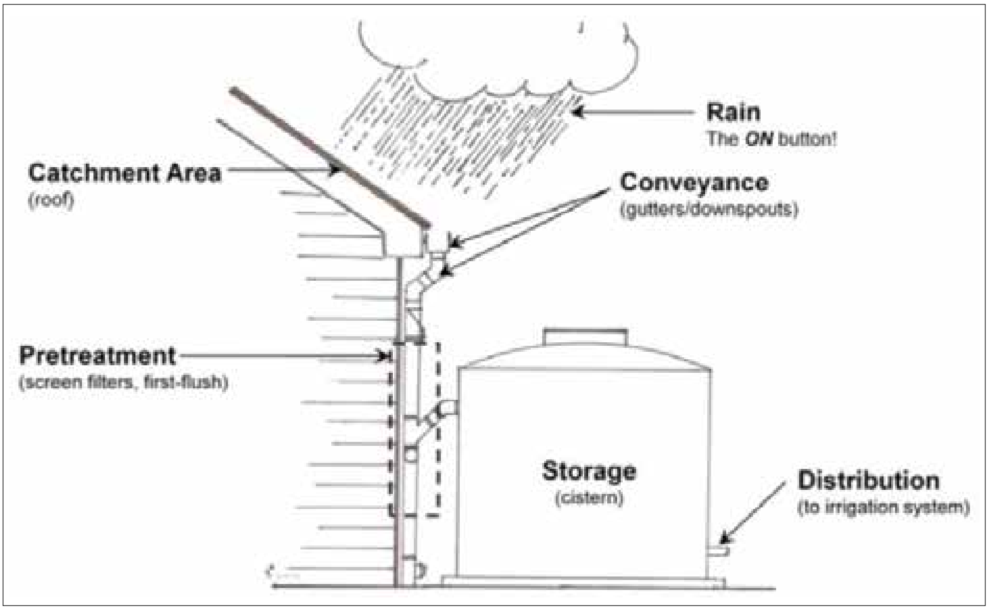
Rainwater harvesting comprises the collection and storage of rainwater. Rainwater is collected from different basements including rooftops of buildings, rock catchments and ground surface. Figure 17 illustrates a system harvesting rainwater including the basic components such as catchment, collection and conveyance. Harvested rainwater from well-maintained rooftops and storage tanks in most cases is pure and can be consumed directly without further treatment. However, for the rainwater collected from ground catchments, the quality may be poor due to various contaminations including bacteriological, physical, and chemical. The quality of water collected from dirty surfaces can be improved through physical and chemical treatments (Patients et al., 2012).

The GIS technology can be used to support water management by using GIS and Landsat data. A study carried out by the International Water Management Institute (IWMI) reported that up to 6,000 traditional water tanks could be restored to capture about 15 to 20% of the local rainfall. The restoration could lead to the capture of 1.7 km^3 of water enough for irrigation expansion by 50% and significantly reduce the cost per hectare by 75% as compared to the construction of a typical dam for irrigation (UNCTAD, 2011).

4.4.1. Rooftop rainwater harvesting

Rooftop rainwater harvesting and storage system is simple and cost-effective. The rooftops, which act as the catchment surface collects the rainwater and directs it to artificial recharge systems or storage tanks via conveyance. The collected water can be subjected to

Figure 17: Rainwater harvesting system



filtration to remove contaminants before storage to make it safe for use. The contaminants which need to be removed include volatile organic chemicals (VOCs) mostly in town centres and cities, metal particles, and organic debris.

4.4.2. Stormwater collection

Stormwater is collected from a drain usually located in the subsurface to collect the rainwater sipping into the subsoil. The collected rainwater can be stored above ground or in underground systems.

4.4.3. Subsurface dam and sand dam

The sub-surface dam and sand dam reservoirs are like concrete, stone, or mud dams. Sub-surface dams consist of hand-dug wells and horizontally placed inflow pipes for water mining. The sub-surface and sand dams (Figure 18) can function effectively in the dry and arid areas with varying rainfall from 200 - 750 mm. The water harvested in the dams is mainly used by the communities for domestic, kitchen gardening, and livestock purposes (Patients et al., 2012).

4.5. Irrigation

Agriculture is the major economic activity and source of livelihoods for most of Africa's population, most of whom are poor and living in the rural areas. Of the total cultivated area in Africa, more than 80% (about 271 million ha) is in SSA. The SSA region is the least productive agriculturally in the world. Several smallholder farmers rely on rain for irrigation and are usually faced with low yields given the erratic rainfall patterns and water scarcity caused by dry spells. Rainfed agriculture accounts for up to 58% of the total food produced (99% for the main cereals including millet, maize, and sorghum). For improved yields, irrigation using innovative technologies that are climate resilient should be adopted (African Union, 2020). Most areas under irrigation in Africa rely on improvised or basic irrigation techniques such as the use of wetlands, flood recession and spate irrigation. The basic techniques are not reliable and lead to low production as compared to modern innovative techniques. Applicable innovative technologies include irrigation scheduling, automated drip irrigation and monitoring information on soil moisture

Figure 18: Picture of a dam

and evapotranspiration (Nair & Landani, 2020). Table 28 outlines some of the innovative irrigation technologies.

4.6. Water Resources Management

Increased urbanisation and expanding irrigation and industrial growth are increasingly posing a major threat to the limited freshwater resources in Eastern Africa. To overcome the water challenges, governments in the region have adopted integrated water resources management (IWRM). Each country has taken a different IWRM approach reflective of their unique nature including socio-economic and natural resources statutes. Components of IWRM such as reforms aimed at institutional, legal, and policy frameworks; action plans and strategies development; and operationalisation of governance and management instruments are at different stages. The IWRM approach emphasises that the water resource is vulnerable and limited public utility, women should play a central role in water management, and, therefore, management of water should be sustainable, equitable and efficient (GWP, 2015; Mapani et al., 2019).

The significance of IWRM is captured by SDG6 (By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate) and indicators 6.5.1. (Degree of integrated water resources management implementation) and 6.5.2. (Proportion of transboundary basin area with an operational

Table 28: Innovative irrigation technologies

Technology	Gravity-fed drip irrigation	Centre-pivot	Floppy Sprinkler
Type	Irrigation	Irrigation	Irrigation
Main user and suitability	Small-scale farming	Medium to large- scale	Small, medium, large-scale.
Advantages	• Low initial and maintenance costs • Locally available materials • Efficient water use • Can be combined with different water lifting systems	• Efficient system • Can be managed remotely	• Efficient system • Can be managed remotely
Disadvantages	• Only suitable if there are gravity differences, e.g. through slopes • Takes a long time for irrigation, depending on the pressure created by gravity • Pipes are prone to insect damage	• Only suitable for medium-size plots and bigger • Very high investment costs • Requires efficient water supply • High loss of potential yield through round irrigation shape	• Very high investment costs • Requires efficient water supply

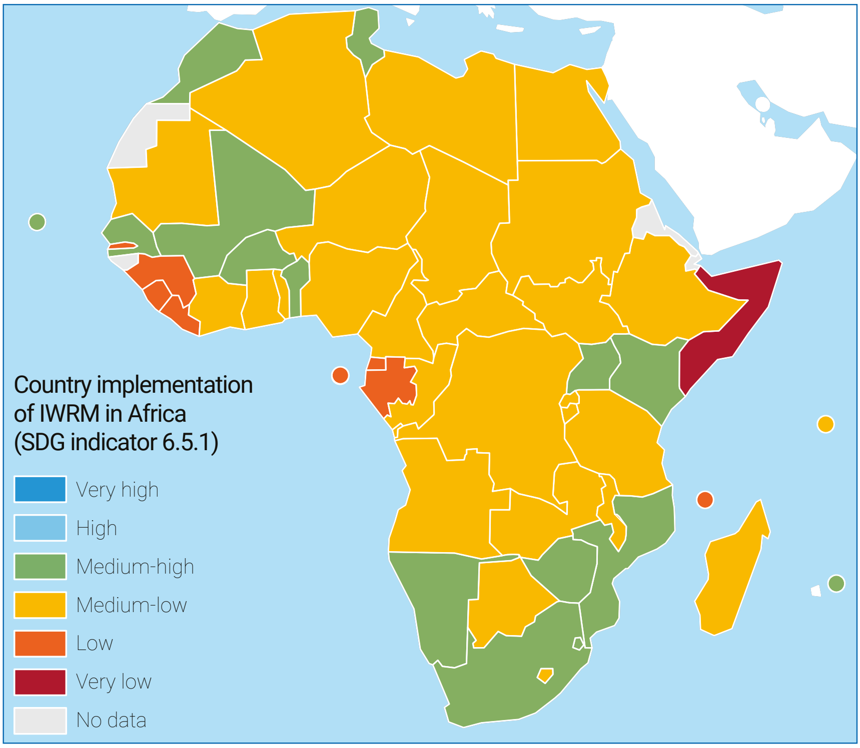
arrangement for water cooperation). Implementing IWRM supports targets not only for water security but also energy production, sustainable agriculture, smart cities and towns, gender equality and health (AMCOW, 2018). The implementation of IWRM is highest in Southern and Northern regions followed by the Eastern region of Africa Figure 19. Several states in Eastern Africa have passed legislation aimed at promoting integrated water resources management (Table 29) based on the IWRM principles (Figure 20). The adoption of integrated water resource management has some commonalities including (GWP 2015):

- Enhanced coordination among sectors and particularly countries in management approaches for shared basins.
- Setting up a regulatory framework for transboundary water resources.
- Participation of stakeholders in governance and management of water resources at all levels.
- Established water resource management legal framework including service provision, policies, resource management, and regulation.

4.7. Water Treatment

Safe water Africa is an autonomous water treatment system for the removal of pathogens and organic pollutants such as pesticides. The water cleaning process begins with a pre-treatment to remove suspended organic particles

Figure 19: Progress of implementation of integrated water resource management (IWRM) in Africa



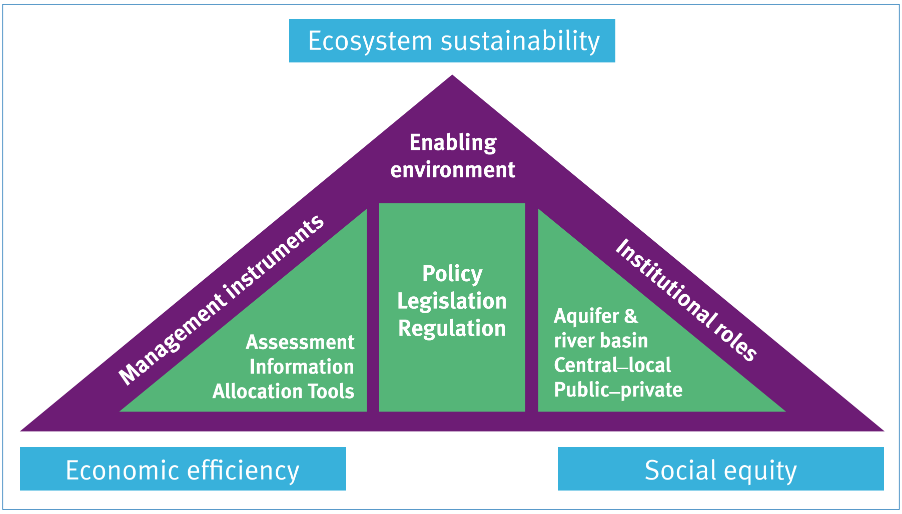
The boundaries and names shown and the designations used on the maps in this publication do not imply official endorsement or acceptance by UNESCO.

Table 29: Legislations in the Eastern Africa region on integrated water resource management

Country	Legislation
Ethiopia	In 2000 passed its Water Resources Management Policy based on IWRM principles that emphasized an integrated framework for water resources development as "a rural centered, decentralised management underpinned by a participatory approach" that shall ensure "social equity, economic efficiency, system reliability, and sustainability norms
Kenya	In 2002, Kenya passed a Water Act emphasising IWRM principles as the basis of water governance and established the Water Resources Management Authority (WRMA) with the mandate to manage, regulate and conserve all water resources, to ensure stakeholder participation, to enhance equitable allocation of water and to guarantee environmental sustainability. In 2010, the new constitution was passed, and the Water Act is now being revised to facilitate devolving functions to newly established county governments, especially for water supply and sanitation.
Uganda	In 1997 passed a Water Act to provide for the use, protection and management of water resources and supply; to provide for the constitution of water and sewerage authorities; and to facilitate the devolution of water supply and sewerage undertakings. In 1999 the National Water Policy was passed which promotes a new integrated approach to manage the water resources in ways that are sustainable and most beneficial to the people of Uganda. However, the guidelines on catchment-based water resources management only came into force in 2014
Rwanda	In 2004, Rwanda formulated its Water and Sanitation Policy in an effort to put a robust framework for the conservation, protection and management of the country's water resources into place. In 2008, Water Law No. 62 was passed and in 2011 the National Policy for Water Resources Management replaced the 2004 policy. The Water Law outlines an institutional framework for coordinating water resources management; devolves water resources management functions to districts and user organisations; and provides for charges to be levied for the use of water
Burundi	In 2012, Burundi established new water legislations based on IWRM principles. However, it did not introduce a catchment-based planning approach to water resources management. As a small country, Burundi opted for a centralized approach.
South Sudan	In 2012, South Sudan, as an emerging nation, initiated a draft of new water regulations through the Ministry of Water Resources and Irrigation. The focus is on regulation and water services provision as well as water resources management. The Kenyan Water Act was used as a guideline.
Somalia	In 2004, Somalia, mainly Somaliland (northern Somalia), initiated a National Water Policy and new water regulations. In 2012 it passed a Water Act as part of the state building process. The National Water Policy sets out the objectives, general principles, and guidelines for developing the water sector. The National Water Strategy (approved in 2004) outlines the priorities and detailed measures to permit the policy to be implemented. The Water Act sets the legal framework to support the strategy; defines organisations, mandates, and responsibilities; and procedures, obligations, and interdictions.
Eritrea	In 2008, Eritrea set out an Action Plan for IWRM based on the water resources policy drafted in 2004 and revised in 2007. The policy recognises the drainage basin as the basic unit of planning for development of water resources and calls for appropriate measures to optimize utilisation of this resource for the benefit of the people living in the basin.
Djibouti	In 2000, Djibouti introduced new water legislation, with the National Water Master Plan, which was revised in 2006. The first priority of the government is to enhance the water supply and sanitation sector. In 2004, the National Water Resources Plan was developed, which emphasizes an integrated approach to water resources management and stakeholder participation; however, it does not include the basin approach because of size of the country.

Source: GWP 2015

Figure 20: Framework for integrated water resource management (GWP 2015)



through coagulation and column filtration. The water is then disinfected using oxidants such as ozone and hydroxyl radicals produced from electrochemical. Low voltage is applied between two electrodes splitting water molecules into reactive radicals, known for the quick and efficient decomposition of organic pollutants. The treatment system is self-sufficient, operates through photovoltaic modules, and can produce up to 10,000 L of water per day. The technology is easy to install and operate and has been successfully applied in South Africa and Mozambique (EU, 2020).

Figure 21: Safewater Africa technology for water treatment for domestic use

Source: EU 2020

4.8 Water Access

Effective planning and policy developments can be informed by concrete data on water access by community members particularly in rural areas where complex water access patterns are still not understood. The use of innovative technologies such as remote data meters can help determine the impacts of water points on access, water volumes accessed by users, time of the day when users access water and the various uses of the water. Smart meters have been shown to benefit management, users and contribute to water sustainability.

Table 30 shows some of the major findings of smart meters application in a rural community in Tanzania (Ingram & Memon, 2020).

4.9. Hydropower Operation

Advanced technologies can allow for the digitalisation of hydropower and transform the design, development, operation and maintenance of projects. Rehabilitating and upgrading existing hydropower plants in Eastern Africa would provide the opportunity for digitalising equipment operation, which would prolong the lifetime of turbines, address cyber-security issues and increase efficiency. From current estimations, digitalisation could increase the world's installed capacity of 1225 GW by 42 TWh and reduce greenhouse gas emissions significantly. It will also drastically reduce the response time and allow for the assessment of the economic impact of offering reserve flexibility (Kougias et al., 2019). Additionally, digitalisation offers safety and reliability.

Table 30: Major findings of smart meters application in a rural community in Tanzania

Demand from Managerial Stakeholders	
Impacts on management of rural water supply	• Smart meters are overall more financially effective for operation and maintenance, with enhanced revenue collection from pre-payment, greater water use, less inefficiency because of automated operations, less non-revenue water, detection of leakages, and accurate revenue tracking. • Monitoring of breakdowns is quicker through smartphone apps.
User Experience and Demand	
Impacts on water collection, behaviours, and lives.	• Average time taken for collection is significantly reduced, more time is made available for farming and other economic activities leading to more income and schooling. • Fast monitoring increases speed of operation and maintenance because technicians can be mobilised early and therefore improves service levels for users. • Health of the community has benefitted from smart meters. Enhanced access to water means users can choose uncontaminated water from over the surface water sources, and benefit from shorter collection times and more income. Users can access greater quantities.
Accessibility	
Equity of use across community	• Women and children do most of the water collection and therefore are impacted the most by the innovation. • The reduced collection time incentivises users further away to choose distribution points collection over competing unimproved sources.

Source: Ingram & Memon, 2020

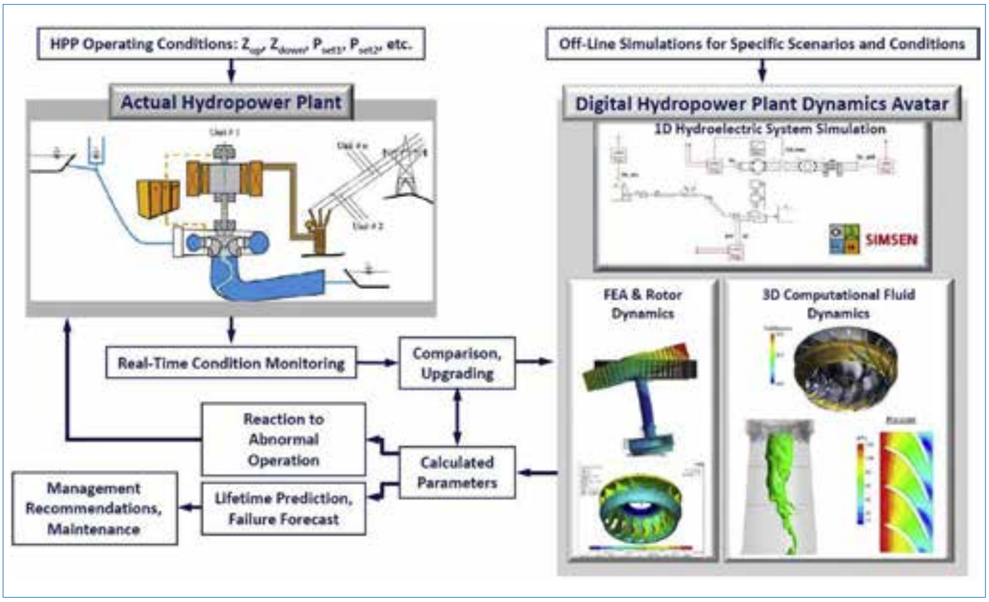
A multidisciplinary approach that covers hydraulic machinery and the associated components is needed for digitalising (Digital Avatar) the dynamics of a hydropower plant.

4.10. Water Quality

Data on water quality include biological, physical, and chemical parameters normally determined through conventional field sampling and laboratory analyses. Common parameters used for determining water quality include electrical conductivity, pH, dissolved oxygen, turbidity, temperature, organic content, suspended solids and nutrient concentrations (phosphorus and nitrogen). The conventional method of water quality analysis is labour intensive, time consuming, and costly thus hindering a synoptic view of the water sources. Data collected on a weekly, monthly, or sometimes seasonal basis prevents accurate decision-making informed by data for effective management of water resources or rapid response to operational accidents such as toxic pollutions. STI through advanced data collection systems can significantly improve the real-time monitoring and management of water resources, flood assessments and pollution control. Automated sampling can be used for pollutant load estimation in selected water streams (J. Park, Kim, & Lee, 2020).

Advanced water quality monitoring can be achieved through techniques such as in situ sensing and ICT-based systems. Real-time smart water quality monitoring systems can be applied for the management of potable water (drinking-water) supply to maintain the required quality standard. Smart monitoring can also prevent several unexpected accidents such as water treatment system malfunction and raw water contamination. Water in natural systems such as rivers, lakes, and seas can be managed effectively

Figure 22: Information flow for hydropower plant dynamics



Source: Kougias et al., 2019

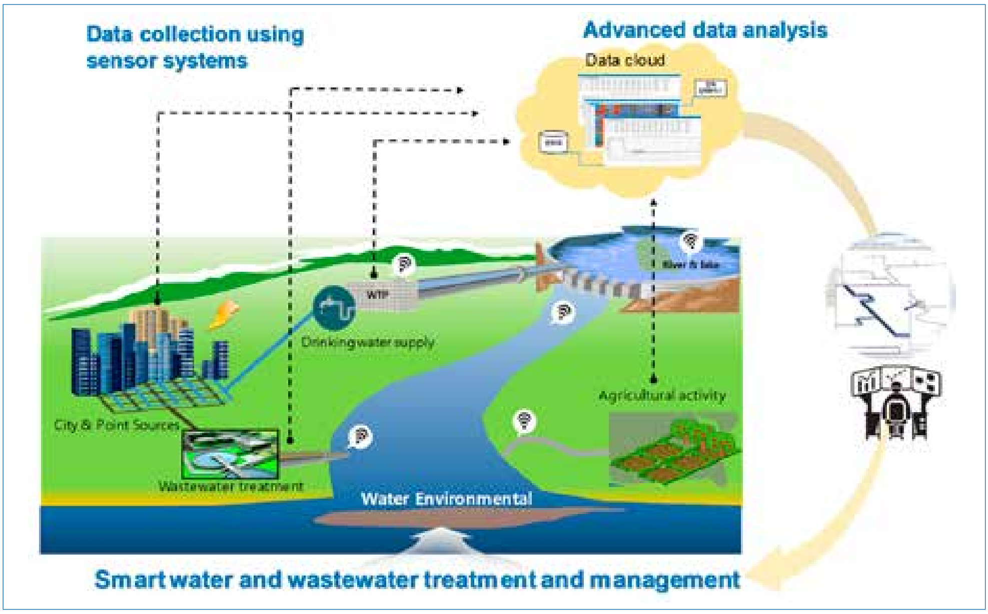
by systems based on in situ real-time monitoring whereby multi-spectral sensors are applied for data collection from a wide range. Recent advances in sensing technologies and ICT have enabled low-cost reliable measurements, transmission, and management of massive data on the environment (Figure 23). Several types of sensors exist including physical, chemical, biological and optical monitoring sensors. Table 31 gives the sensor types for the various water quality parameters.

The expansion of mobile network connectivity in the developing world in rural and urban areas has created platforms for the emergence of innovative digital solutions that have reduced the costs associated with the provision and accessibility of basic services including water, energy, sanitation, transport, and waste management.

4.11. Water-related Products and Services

Manufacturing plants and industries can manage their water usage more efficiently by employing ICT. Water is used in almost every manufacturing industry during operations for several purposes such as cooling and cleaning. Cooling systems in industries should be properly managed to reduce water and energy-related operational costs and minimize wastewater and chemical discharge. Process automation and the use of ICT in control systems can improve the performance of the plant and optimize water use. Other water-related products and services include water ATMs, prepaid smart water meters and self-billing platforms. Table 32 outlines some of the related water products and services in selected countries in the Eastern Africa region.

Figure 23: Real-time monitoring, transmission, and advanced data management system for smart water and wastewater treatment and management



Source: J. Park, Kim, & Lee, 2020

Table 31: Water quality parameters monitored by sensors

Content	Parameter	Sensor type
Basic monitoring	pH, dissolved oxygen, electrical conductivity, temperature, turbidity, and oxidation-reduction potential	In situ electrodes, colorimetry, conductivity cell, membrane electrode, optical sensor, potentiometric, thermistor, nephelometric
Organic compounds	Nitrate	Optical sensor for determining nitrate concentration from the relationship between UV light absorbance and nitrate concentration in a water sample
	Phosphate, Ammonium, Nitrate	Wet chemistry sensor where the nutrient concentration is measured based on a colorimetric reaction
Harmful algal blooms	Chl-a	In situ optical sensor with wireless data transport network
	Phycocyanin Cyanobacteria	In situ fluorometric sensor
Physical monitoring	Water level	In situ acoustic sensor where the distance from the surface of the water to the bottom is measured from the echoes of the acoustic waves
	Velocity	Velocity sensors

Table 32: Selected water-supported ICT projects in Eastern Africa

Country	Project/Technology	Description
Rwanda	Scaling mobile IT for safe water enterprises	Builds an open-source IT platform for safe water enterprises (SWEs) to be able to monitor who purchases water and where they live, how and how well it's delivered and produced (water quality, volumes, etc.)
	Pay your relatives' water bills	Offers an online platform on which Rwandan diaspora can pay various services to benefit their relatives back in Rwanda, making sure the money sent by Rwandan diaspora will definitely pay water only. The payment technology is integrated with the public water company and the water kiosks systems
	Storm forecasts for Musanze Ghana	Helps city residents and farmers get weather predictions with alerts on floods and lightning on their phones. The innovation works with innovative low-cost lightning data detectors to track lightning strikes in an area and produce alerts
Kenya	TAP21 purified water distribution in the twenty-first century	Introduces a franchise business model, whereby vendors dispense purified water via 24/7 prepaid water ATMs. Payments and performance are monitored online
	Maji Mkononi – helping communities in Kibera	Enables community members to use their mobile phone to acquire information about location and real-time availability of water at water points while providing water providers with essential information and water level data from their water points
	Reducing water loss by improved data systems	Seeks to minimise water losses by developing wireless sensors to collect data on water flow, pressure, levels – readings serve as early warning signals for burst and leakages or water theft. Sensors are used under the free radio frequency spectrum to transmit data into a consolidated dashboard (alongside SIM card-based data loggers) to decision-makers

Source: Mvulirwenande & Wehn, 2019.

4.12. Training and Research

Online platforms present an opportunity for offering training on water resources management. Though mainstream courses are rarely offered online, professional courses and certification training can be offered online thereby reaching a wide range of audiences. Participants might need to have access to an internet connection, computers, software, plug-ins, webcam, and speakers. In developing training programs for water practitioners, Isle (water technology provider) has developed e-classrooms and managed to reach participants based in the United Kingdom and South Africa.

The SDG framework seeks to integrate social, economic, and environmental concerns that highlight important synergies and trade-offs between the set priorities. Achieving the SDGs will require mobilization of policy developers to fully embrace and promote its implementation. The scientific community will play an important role in developing strategic environmental knowledge for promoting sustainability and resilience. Moreover, stakeholders, scientists and policymakers should promote the coordination for integrating science into the transitional processes in society (White et al., 2019).

Ensuring access to water and sanitation for all is well addressed by SDG6. Progress in attaining the targets set for SDG 6 will equally have positive effects on other SDGs including poverty eradication (SDG 1), ending hunger (SDG 2), ensuring good health and well-being (SDG 3) and enhancing economic growth (SDG 8). The targets for SDG 6 include water access, water affordability, water quality, improved sanitation and hygiene, efficiency of water processes, cooperation, integrated water resource management and participatory and inclusive decision making. Therefore, achieving SDG 6 is an important sustainable objective (White et al., 2019).

Attaining the SDGs requires collaborations and participation among decision makers, scientists, citizens, and stakeholders. Also, combining disciplines is important for informing sustainable development and avoid the degradation of environmental systems and human life that has resulted from climate change. Sustainable science and research call for diverse approaches and initiatives and have led to interdisciplinary, transdisciplinary, participatory, community-based and interactive collaborations. Interdisciplinary research needs the joint engagement of researchers to use their knowledge in developing solutions to the problems faced. Through the interdisciplinary interaction, researchers can use integrated and critical thinking to deepen the disciplinary knowledge while at the same time broadening its applicability and reach. Transdisciplinary research interconnects technical innovation, knowledge, and understanding in addressing and mitigating multiple requirements and risks, respectively. Transdisciplinary research focuses on the creation of transferable knowledge, mutual learning, societal problems, and collaboration among researchers coming from different academic disciplines and institutions of research.

Achieving SDG 6 and other related SDGs will require a multidisciplinary research approach for the targets or themes and create impacts under technological, policy, societal, environmental, and economic aspects.

A holistic, sustainable and integrated water resource management approach is needed for society to tackle the several challenges associated with water such as access, quality, supply, and pollution. The Water Joint Programming Initiative (JPI) by the European Union (EU) has identified strategic research areas under four themes that will directly address the targets of the UN SDG 6 (Water JPI, 2020). The themes include (i) Ecosystem, (ii) Health and wellbeing, (iii) Water value and usage, and (iv) Sustainable water management and apply to Africa and the Eastern Africa region. Table 33 gives the research themes and related research questions and the SDGs impacted.

Table 33: Research themes and questions on SDG 6 and related SDGs, 2020 - 2025

Theme	Research questions	SDGs impacted	Policy drivers
Ecosystems	• Developing tools for assessing and optimizing the function and structure of ecosystems • Developing and applying an approach to ecological engineering • Managing and adapting ecosystems to the effects of hydro-climatic extreme events.	2, 3, 6, 11, 12, 13, 14, 15	UN Framework Convention on Climate Change Paris Agreement Africa water vision 2030 Africa Union Agenda 2063
Health and wellbeing	• Monitoring and assessing effects of emerging contaminants and their remediation • Water dimension of antimicrobial resistance • Minimising risks resulting from water infrastructure and climate change • Promoting coordinated water resource management between people, nature, agriculture, and industry	2, 3, 5, 6, 8, 9, 10, 11, 12, 13, 15	
Water value and usage	• Smart technologies, systems, and infrastructure for climate change resilience • Water-smart societies and circular economy • Empowering water users, the public, and stakeholders in valuing water	2, 6, 7, 9, 10, 11, 13, 14, 15	
Sustainable water management	• Optimizing water-food-energy-climate change nexus approach • Adapting management of water resources to increased uncertainty • Enabling sustainable water resource management	2, 6, 7, 9, 10, 11, 13	

Source: Adapted from Water JPI, 2020

In 2019, the University of Leeds through its interdisciplinary water research group identified priority research areas in the Eastern Africa. The research audience consisted of students, water practitioners, water policymakers and non-water experts. Table 34 gives the most important research questions in the region based on broader themes including water quality, water security, water governance and sustainable management of water resources. Some sub-themes emerged from the broader sets. For instance, most of the questions bring into focus the important competing aspects of water use and how regional and transboundary conflicts emanating from the competitions can be addressed. Also, there are emerging sub-themes on water-food-energy-climate change nexus and the knowledge of emerging pollutants and water contaminants. Underlying all the proposed research questions are issues and concerns on power and politics and how the power play influence water use, conflicts, sharing of water and policy interventions. The University of Leeds in partnership with GWP launched a Water Knowledge Exchange Hub (KEH) in Tanzania to use evidence-based research and support informed decision making and water and sanitation investments in Eastern Africa (Ofori, Mdee, & Kongo, 2020).

Table 34: Most important water research questions for Eastern Africa, 2020

Themes	Research questions
Water Security and governance	• Can maximized water security minimize transboundary water conflicts? • How can groundwater resources in East African countries be best developed, utilized, and sustainably managed? • How does ecosystem degradation affect water security at scale? • How can the water governance efficiency of the river basins be measured in the context of bringing sustainable development of the resources? • What are the impacts of increasing competing demands of water-on-water resources sustainability?
Water quality	• What can be done to improve water quality monitoring, control, implementation, and enforcement? • In the advent of change of livelihoods and urbanization, are the pollutants of water continuously changing from organic to inorganic (emerging pollutants)? • What is the future of water quality and is the current science and infrastructure able to handle the emerging pollutants?
Sustainable water management	• Is it possible to establish the economic value of available data so that policymakers can get to know the economic implication of making decisions without sound analytics? • Is there a way of putting all the data concerning water and sanitation on a single database so that they can be accessible by everyone? • What mitigation measures have been put in place to protect and sustain various water projects that are being abandoned after the end of a project cycle?

Source: Ofori, Mede, & Kongo, 2020.

4.13. Water-related Marketing

Water supply, just like power and other utilities, follows peak demand patterns with consumption occurring mostly in the morning and evening hours. Differing demands can cause erratic water supply in some selected areas and since the required water pressure must be achieved even during peak hours for adequate and constant water supply. IoT through smart metering can allow efficient and effective monitoring of peaks and related issues. Measures such as on-site water storage tanks or peak tariffs can be put in place to control the demand profile (GSMA, 2017). Smart metering allows mechanisms for new pricing that can be arrived at by tying water consumption to cost. Thus, in areas facing water scarcity or where consumption by users is not excessive, a framework for price control can be effectively used to manage the consumption, while in areas with excessive consumption penalties can be applied by altering the framework. Through smart metering, the mechanism for price control can be made flexible and easily adapted to the customer's needs instead of the blanket application of the same model to all consumers (GSMA, 2017).

Water regulators are increasingly looking for ways to introduce competition to water service providers to ensure there is value for money for the users. New water service providers can enter the market and provide new water-related services through innovative technologies. Regulators can enable the existing service providers to improve or offer new water-related services to users or allow new service providers to enter the market and compete for customers. Smart metering is important for the realisation of new water service provision models and enabling users to make informed decisions by giving them access to data. Accurate and detailed water consumption data can allow for the design of new models to support new initiatives for the water market. Table 35 shows the smart water value chain including the stakeholders such as consumers (users), utility (service provider), regulation, and external forces.

4.14. Selected Case Studies of STI Systems and Practices in the Water Sector

a) *Jisomee Mita* in Kenya

Jisomee Mita is an infrastructure development project designed to improve access to the piped water system in Kayole Soweto. Kayole Soweto is an informal settlement (slum) in the outskirts of Nairobi, Kenya, inhabited by about 89,000 residents. Like several other slums in Nairobi, Kayole Soweto has sparse piped water connections (WSP, 2015). Water is only accessed from about 35 stand posts owned by private

Table 35: Value chain for smart water

Consumer	Utility	Regulation	External factors
Consumption	Distribution	Legal parameters	Climate change
Billing	Quality management	Technology drivers	Technology
Installation	Customer management	Price control	Water sources
Communications			

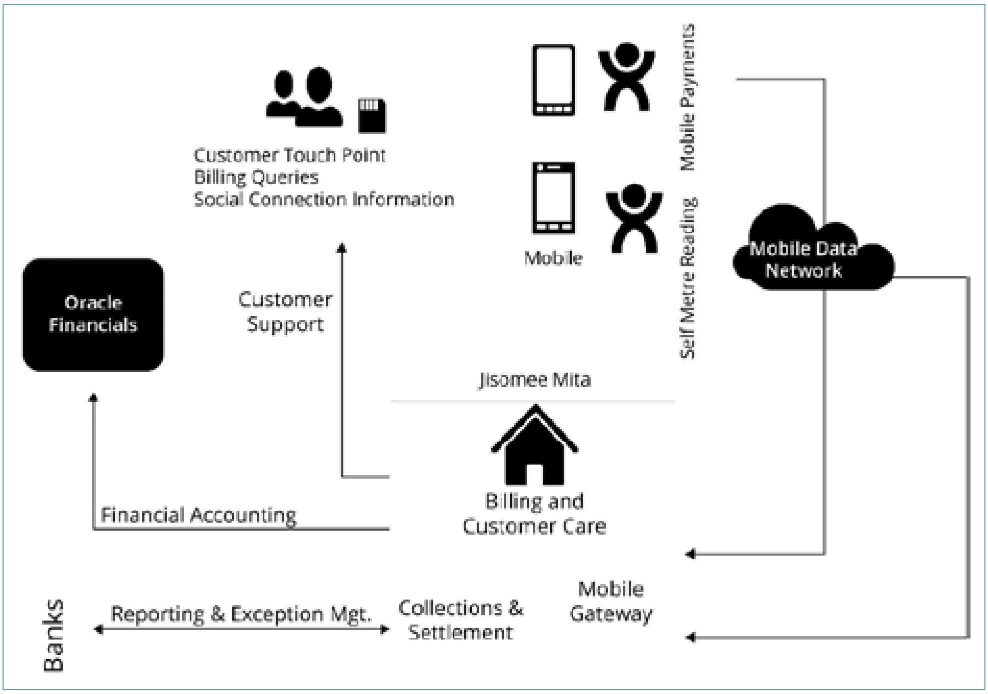
vendors selling water at 2/3 Kenya shillings (2/3 US Cents) for a 20-litre container, with the price rising during scarcity. The Nairobi City Water and Sewerage Company (NCWSC), the utility provider has pursued several innovations aimed at providing affordable water and sanitation services to the slum dwellers. Through the Social Connections Policy (SCP), NCWSC has piloted an innovative approach for affordable clean water provision in Kayole Soweto under the *Jisomee Mita* project. The SCP as adopted by the NCWSC promotes the right of non-discriminative access to affordable water and sanitation services, particularly for marginalised and disadvantaged groups.

The SCP subsidizes new connections in the slum areas thus addressing barriers such as non-existent primary infrastructure networks and high costs for materials and connections. The SCP was premised on the understanding that the best way of improving water supply and access in the slums is through a piped network. Increasing water access by increasing connection affordability and the customer and revenue base is key to the approach. Additional benefits to the utilities and users include weakened water cartels, use of high-quality materials including pipes, improved water quality, improved pricing, increased affordability of new connections, reduced water related diseases and improved sanitation and hygiene. Kenya's vision 2030 aims to ensure access to water and sanitation by all by the year 2030 in line with the UN's SDG6 targets 6.1, 6.2, and 6.3.

The objective of *Jisomee Mita* (self-meter reading) is to empower and facilitate the low-income dwellers of Kayole to read their water meters and make water bill payments through mobile money platforms. The project employs a hybrid technological constellation that links ICT with water network expansion. The technology enables the users to interact with the service provider linearly in facilitating self-meter reading and send the readings through a short message service (SMS) for billing (World Bank Group, 2015). Other technology firms dealing with mobile money payments then provide the platform for users to make payments to the utility provider. *Jisomee Mita* thus provides users with a mobile-based model for communication and financial transactions. The system allows for self-meter reading, invoice acquisition, related inquiries, billing, and making payments (Guma, Monstadt, & Schramm, 2019). Figure 24 shows the architecture of the *Jisomee Mita* system.

Before *Jisomee Mita* was introduced in Kayole Soweto, the few residents who had piped water connections relied on water utility provider (NCWSC) employees to read their water meters and send bills thereafter. The residents after receiving the bills had to walk several kilometers to NCWSC bill payment offices and wait in long queues to make payments on their water bills. With *Jisomee Mita*, Kayole Soweto residents receive the water bills and make payments on their phones, while NCWSC no longer prints paper bills thus making the whole process less costly and convenient (World Bank Group, 2015). The mobile payment platforms provide the users, mainly working in the informal sector with an advantageous flexible payment arrangement given their irregular incomes. Since the launch of *Jisomee Mita* in 2014, more than 2221 customers have been migrated from the old to the new metering system with about 1300 regularly sending their meter readings and making payments, resulting

Figure 24: Architecture of the Jisomee Mita system



Source: Guma et al., 2019

in an increased revenue collection by more than 50%.

The roll-out of *Jisomee Mita* had some challenges such as the need for community sensitization and outreach. Community development assistants (CDAs) were recruited from Kayole Soweto's youth to provide t residents with mobile phone use support by going door-to-door distributing flyers and training residents.

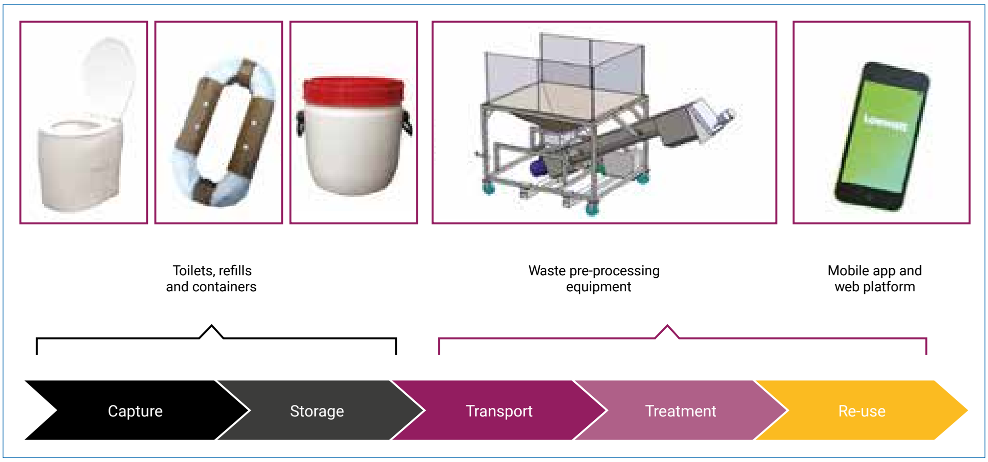
b) Loowatt (Antananarivo, Madagascar)

Loowatt provides off-grid households in Antananarivo, Madagascar with a sustainable sanitation solution through a waterless flush toilet system. In Antananarivo and other countries in the region, the sanitation choices available to most people include open defecation (ODF), and public/domestic pit latrines/toilets which sometimes empty into freshwater sources such as rivers or lakes. The pit latrines being open public spaces are difficult and sometimes dangerous for people to use, especially children and women. Also, emptying the pit latrines when full involves dangerous procedures such as emptying by hand with an individual going into the pit and digging out the faecal sludge before disposing of into open spaces. To overcome the sanitation challenges, the LooWatt system is a sustainable option for off-grid toilets/pit latrines and uses waste sustainably to create power and contribute to the circular economy. The LooWatt system aims to eliminate waste and environmental pollution and restore the natural systems. The system also plays an important role in promoting SDG 6 (target 6.2) by promoting access to adequate and equitable sanitation and hygiene for all and ending ODF, while paying special attention to the needs of girls and women.

The LooWatt system is a basic structure that consists of a toilet seat connected to an odorless cartridge. The cartridge has a biodegradable lining that is collected safely and hygienically for transportation and treatment in a centralized anaerobic digester. The lining is a polymer film and contains human waste and odors. The anaerobic digester installed and operated by Loowatt converts the collected waste into biogas and fertiliser. Loowatt designs and operates the toilet systems through its logistics team. The waste is regularly collected, and the used film liners are replaced with new liners (refills) purchased by the customers. Apart from saving water, the closed-loop treatment system transforms the waste into biogas, electricity, and fertiliser that are important for energy and agricultural applications. Through Loowatt's mobile app and web-based platform, the operational team is provided a tool for waste services management allowing for effective communication with customers, monitoring and scheduling of waste collection/toilet servicing, and tracking mobile money payments made for refill liners.

Over 100,000 customers have used the LooWatt toilet system leading to the safe management of more than 200 tonnes of faecal sludge transported and anaerobically treated in the closed-loop system. Up to 70% of Loowatt's customers in Antananarivo are female. By using smart mobile solutions such as mobile app and mobile money for logistical operations and collection of payments, Loowatt has reduced operational costs by up to 25% and serviced over 100 toilets in Antananarivo (GSMA, 2020). Loowatt has partnered with Airtel Madagascar for the provision of the mobile technology that is used to support the servicing and maintenance of waterless toilets. Customers can use Airtels's mobile money and SMS platforms to make payments for waste collection and schedule for the

Figure 25: Loowatt's sanitation value chain processes



Source: GSMA 2020

collections and toilet maintenance. Also, the Loowatt employees can use the web platform and mobile application to track waste collection and transportation to the central treatment facility and manage operations.

Despite the successful implementation of the LooWatt systems, some challenges were faced. The customers relying on mobile money faced several challenges including:

i) Difficulties in opening, validating and resetting an account.

ii) Several steps involved in the mobile money transactions led to sessions often timing out particularly with inexperienced customers taking too long navigating the alphanumeric strings.

iii) Distrust and fear made some customers wary of making payments to the wrong accounts and perhaps having their LooWatt toilets systems taken away as a result.

iv) Lack of perceived value by customers who did not understand the need for mobile money payment, yet they could instead make cash payments in person.

To overcome the mobile money challenges and increase its adoption, the Loowatt Customer Service Management supported the customers with the use of mobile money, reduced the number of keystrokes during mobile payments, minimized the likelihood of a timeout, and printed out easier instruction manuals (GSMA, 2020).

c) Using GIS technology to optimise pit emptying in Kampala

Kampala, the capital of Uganda has a population of about 1.3 million people. The lack of an appropriate urban development policy framework has led to a steadily increasing unplanned urbanization coupled with low industrialization and poor job creation. Kampala's wider metropolitan area thus has about 3.5 million residents mainly living in informal settlements with poor infrastructure and insecure land tenure. The setting has made the urban poor vulnerable and isolated them from basic services such as proper access to water and sanitation services. Sanitation is the most affected in Kampala, with about 94% of the city's population using non- sewered systems including decentralised systems (septic tanks and pit latrines). Lack of formal sewer collection and management services has given room for independent service providers who empty the tanks and pit latrines haphazardly and sometimes illegally dump the waste into water bodies thus risking the spread of water-borne diseases.

In response to the sanitation problem, the Kampala Capital City Authority (KCCA) launched a mobile app based on GIS. The app links customers with registered pit emptiers. Through its call center, KCCA receives jobs from customers requiring pit emptying services. KCCA then connects the customers with the available pit emptiers. The pit emptier after successfully carrying out the job, submit the related critical data to KCCA via the app. Submitted data include the customer's details, the amount paid for emptying, the volume of faecal matter emptied, and the location and type of the sanitation facility used by the customer. The app catalyzes the connection between customers and sanitation service providers and helps in ensuring safe and environmentally friendly disposal of sludge for a cleaner city. Through the platform, KCCA maps sanitation activities all over Kampala, thus allowing for monitoring and regulation of service delivery and identification of necessary interventions.

Also, KCCA has collaborated with MTN Uganda (mobile service provider) to promote mobile money for payments to pit emptiers. By January 2020, the KCCA initiative had facilitated more than 5,000 emptying jobs (pit latrines and septic tanks) and mapped more than 171,000 sanitation facilities. The imitative has improved the overall sanitation in Kampala and promoted capacity building for the pit-emptying providers. According to a survey, app users reported a 63% increase in revenue with 71% finding the app to be user friendly. Overall, up to 85% of service providers have reported regular use of the app, while according to the users, illicit disposal of faecal matter has reduced by about 87%. The employed GIS technology allows for the optimization of faecal sludge management by making planning and decision-making more sustainable, increasing the residents' access to sanitation service provision, and reducing transport costs and times.

Going forward, KCCA has received funding from USAID to develop the existing GIS platform, map informal settlements (slums) and provide subsidies for emptying pits in the slums. KCCA will develop an app that is customer-based to enable direct requests for services by the customers on the app. Also, KCCA is planning to scale the service and improve sanitation services in other municipalities in Uganda including Mbarara, Mityana, Wakiso, and Mukono (Schoebitz et al., 2017; GSMA, 2020).

d) Water ATMs in Kenya

In the arid and semi-arid parts of Northern, Kenya, residents - mostly women - must regularly leave their homes and walk for up to 20 km looking for water for domestic and livestock use. The shallow wells from where the water is drawn are sometimes dirty and contaminated thus posing the risk of contracting waterborne diseases. In some cases, children are forced to help with the collection of water causing them to miss school. About 40% of Kenya's population rely on rivers, ponds, and shallow wells as the primary sources of water. Also, less than 10% of the public water utilities offer a reliable supply of water. In the dry seasons with sparse rains, Kenyans are forced to use manmade water sources such as boreholes and wells.

Food for the Hungry (FH) through a partnership with the Millennium Water Alliance (MWA) is working to provide water, hygiene and sanitation services and educate people living in developing countries about healthy life practices. This is achieved through the provision of clean water and training on proper water handling and use. To address the issues of access to clean water and sustainability of the water supply systems, FH in collaboration with the Coca-Cola Foundation and IBM Africa has implemented innovative WASH projects in remote villages of Northern Kenya. FH has worked to construct water kiosks (water ATMs) that are run by community members. Residents are assigned days for filling their jerrycans and must load their prepaid cards with funds. At the kiosks, the community members must scan their cards to initiate the automatic dispensing of water. The water kiosks have software for water management for sending real-time data and information on water usage to the water utility provider including alerts for system maintenance.

The program initially designed to increase water coverage in five counties to 50% from 37% has had significant success including:

- Up to 184,172 people having access to improved safe drinking water;
- Improved basic sanitation services for more than 22,512 people;
- Up to 314,510 livestock having improved access to water through developed troughs.

e) The Tanzania pilot case study of integrated water resource management

The GWP in collaboration with its partners strives to address global water resource management challenges through several projects and activities across the globe. The projects are aimed at improving water security in relation to the UN SDGs with a major focus on SDG 6 and the related targets and other SDGs dealing with issues linked to water such as health, climate change, energy, and hunger. Technological advancements and innovations present great opportunities for improved design and planning of effective and sustainable projects for monitoring water. GWP leverages pervasive technologies to enhance sustainable water resource management. For instance, water data can be collected through smartphones and local citizens empowered to play significant roles in monitoring water resources at the local level. With a click, the smartphone app can allow users to take measurements of water levels, control water discharge into receiving streams or systems, and make information more reliable and accessible for other users in different parts of the world. By developing the existing water collection, access, and storage mechanisms, the data collected can add value by allowing the integration of non-traditional data sources.

A consortium of Swiss, GWP, and international partners, has developed innovative Monitoring and Modelling (iMoMo) systems to promote and develop new data sources. The new data sources complement the already existing sources used for observing water resource networks operated and maintained by national/regional hydrometeorological services. Through the approach, the longstanding gaps in data sourcing and management are filled with innovative solutions. Where it is possible, the new data sources are co-designed by relevant experts working in conjunction with the users in the communities.

The Themi river catchment in north-eastern Tanzania had increased water demand for irrigation, drinking and livestock thus putting pressure on the catchment. The pressure led to water shortages thus affecting dependant ecosystems, electricity (hydropower) generation, and the local community. The iMoMo initiative in collaboration with relevant local stakeholders enabled smart water usage through transparency on water allocation and availability. The project through software and hardware components integration and improved analytical decision-support has benefited the stakeholders and local communities. Some of the outcomes include (WMO, 2017):

- The iMoMo Service Centre supporting institution strengthening and building, outreach and project advocacy.

- Site instrumentation by equipping the catchment with river gauges enabling local communities to monitor daily irrigation measurements using smartphone applications.

- Tailored information delivered through SMS for end-users such as weather forecast updates and market prices.

- Data collection to inform the administration, management, and planning for water resources.

- Successful out scaling to other areas such as the Rufiji Basin also in Tanzania for compliance monitoring of water abstractions for irrigation by farmers.

Several lessons were learned from the iMoMo project including:

i. The importance of a usable technology since a successful technology uptake is dependent on the local context and needs. The local context requirements should be defined upfront and incorporated when designing the technology.

ii. Community involvement is important from the onset and communicating the benefits of timely and precise information on water resource use and availability. Community involvement over time creates a sense of responsibility and ownership thus promoting the sustainable use of the water resource.

iii. Valorization of efforts is important in ensuring the sustained engagement of community members, providing incentives and acknowledgment.

iv. Strongly vs weakly structured hydrometeorological monitoring cultures i.e., non-traditional monitoring technologies would benefit a community with little or no tradition of hydrometeorological monitoring. Communities with an existing strong hydrometeorological culture would benefit from the modernization of the existing systems.

Additional selected smart water management in Eastern Africa is given in Appendix B.

f) Promising technologies applicable in Africa

Smart water supply in Korea - Despite having high quality drinking water, the rate of direct drinking of tap water in Korea is about 5% and is lower than other advanced countries such as Japan (52%) and the United States (56%). Most Koreans do not trust the quality of tap water due to concerns with taste, smell, and aging pipes. Korea water introduced a Smart Water City (SWC) approach to provide healthy water services and increase the direct drinking of tap water. SWC integrates ICT through the supply process enabling people to check directly for themselves the real-time status of tap water including supply and quality. Implementation of ICT and real-time sensors has increased by up to 35% the rate of direct drinking of tap water in Paju Smart City in Korea. Also, the community's trust in water quality and safety has increased. Smart water supply can thus increase the community's awareness on water quality thereby improving decision making and increasing access to low-cost drinking water (Korea Water, 2018).

CityTaps which is a social enterprise solution has been developed to bridge the gap between the urban poor and water utilities in France. The tool has a prepayment service that employs smart, prepaid water meters connected to an ICT platform and billing software and allows users to prepay any water amount. The data from the smart meters are transmitted to keep track of usage in real-time providing information on leakages and thefts (GSMA, 2020).

4.15. Links to SDG 6 Targets

In line with the UN aim of sustainable development on water (SDG 6), it is necessary to assess how the STI interventions in the water sector in Eastern Africa can promote the realisation of the SDG 6 targets. Table 36 gives the SDG 6 targets that the reported case studies contribute to.

4.16. Country by Country Analysis of the Ongoing and Potential STI in the Water Sector

4.16.1. Kenya

Innovative technologies and systems aimed at improving access to water supply and sanitation services particularly by residents living in the low-income areas (urban, peri-urban, slums) have been under consideration since 2007. The innovations are widespread across the country and are majorly founded on the social connections approach. The targeted utilities have institutionalized the approach thus forming the starting point for all the proactive interventions for supporting the low-income areas with the improved provision of water and sanitation services. Other key aspects of the innovative approaches include consumer/utility microfinance,

Table 36: Links of STI interventions in Eastern Africa to SDG6 targets

SDG	Targets
6 CLEAN WATER AND SANITATION	**Target 6.1** – Achieving universal and equitable access to safe and affordable drinking water for all through increasing awareness and receptivity to drinking tap water through knowledge-sharing using real-time. **Target 6.2** – Achieving access to adequate and equitable sanitation and hygiene for all through ensuring efficient treatment of sanitation using real-time monitoring. **Target 6.3** – Improving water quality by reducing pollution through monitoring and filtering contaminants using real-time sensors. **Target 6.4** – Substantially increasing water-use efficiency through improved irrigation efficiency **Target 6.5** – Implement integrated water resources management at all levels through integrated river basin management. **Target 6.6** – Protect and restore water-related ecosystems through reduced pollutant loads in wastewater through smart monitoring and treatment. **Target 6A** – Expand international cooperation and capacity building to support developing countries through supporting transboundary basin agencies with flood and drought planning and management using satellite data. **Target 6B** – Strengthening the participation of local communities in improving water and sanitation management through involving local stakeholders from the beginning of the project.

advanced metering systems, self-meter reading, automated water systems, and electronic billing systems (mobile phone-based). Meeting the water and sanitation services provision by the unserved/ underserved millions of Kenyans requires a combination of increased investments, political commitment, stakeholders (local, national, and international) engagement, and innovative business models and solutions (World Bank Group, 2015).

4.16.2. Ethiopia

Despite making remarkable efforts leading to record growth in the recent past, the agricultural system in Ethiopia has not benefited significantly from the innovative technologies for water management and irrigation. The technologies are necessary for improving agricultural productivity and reducing the threats posed to the agricultural system due to climatic variability. Despite the existing potential for the deployment of innovative technologies in water resource management, several constraints which are related to technology, policy, strategy, institutions, capacity, market, and infrastructure exist. To achieve sustainable water resource management in Ethiopia, the constraints should be addressed (Awulachew, 2011).

4.16.3. Uganda

The water sub-sector prioritizes the sustainability investments made and a cost-effective technology implementation by developing equitable, sustainable, effective, and efficient water and sanitation services. This is achieved by rehabilitating, expanding, and constructing different innovative technologies which include borehole drilling, piped water schemes, gravity flow schemes, springs, shallow wells, rainwater harvesting, bulk water supply, dams, valley tanks, and sewer systems in urban areas. Despite the investments made so far, key issues remain including: the exhaustion of low-cost conventional technologies, little uptake of innovative technologies partly due to lack of knowledge, and inadequate funding given the rising costs of technology implementation. To enhance the implementation of STI-based technologies, the water sector should encourage the participation of the private sector to assist in developing, operating, and maintaining innovative water and sanitation facilities (Republic of Uganda, 2016).

4.16.4. Rwanda

The approaches to the management of water resources in Rwanda are characterized by several problems that need solving. Despite the availability of innovative technologies and practices, the implementation resulting in real-world applications is low. Rural communities in remote areas that are vulnerable would benefit from the implementation of innovative technologies. There are many existing development opportunities at the national and regional levels, however, more important is the innovation at the policy and administration level (Twahirwa, 2017).

4.16.5. Burundi

Burundi is endowed with water resources; however, the water supply infrastructure is in poor condition and inadequate. Municipalities and other water and sanitation service providers need support in deciding on investments in water supply infrastructure and developments.

4.16.6. Mauritius

Several innovative technologies have been considered in Mauritius for improved water resource management. The major technologies currently in use include rainwater harvesting (RWH), desalination technology, and hydrological models. For a successful uptake of the RWH, appropriate legislation, financial incentives and institutional support are needed to protect consumers against poor quality products and monitor the problems and benefits associated with RWH at the residential level. Major barriers to the desalination technology include high initial and operation costs, lack of skilled personnel, possible environmental effects of brine disposal, lack of proper legislation, inadequate institutional development for skilled personnel training and low financial assistance. To promote the uptake of hydrological models, there is a need to establish unit/offices focusing on modelling, provide training and develop appropriate legislation for digital data security (UNEP, 2013).

4.16.7. Seychelles

Water is one of the greatest concerns for Seychelles. The water challenges are exacerbated by the fact that Seychelles has no efficient systems for storing adequate water to last the dry season because of limited storage infrastructure (AfDB, 2019).

4.16.8. Sudan

There is a need for assessing accurately Sudan's conventional water resources to enable effective planning for sustainable development. Innovative techniques such as rainwater harvesting can be implemented in the rainfed agricultural sector to improve crop productivity. The groundwater resources in Sudan should be monitored, protected against pollution and developed through artificial recharge.

4.16.9. South Sudan

The larger international effort aimed at strengthening and building post-independence South Sudan has resulted in spending on projects including security, food and water. Some of the water related projects have focused on developing and implementing IWRM approaches inclusive of safe water supply for rural and urban areas, ecosystem and biodiversity conservation, water for agricultural activities (crop and livestock production) and improved management of water resources. The approaches have been achieved through implementation of innovative and traditional technologies such as abstracting, capturing and storing water in areas such as Kenneti Watershed and Greater Kapoeta. Some of the IWRM pilot projects are nationwide and should be scaled in other parts of the country taking into account lessons learned and best practices (NIRAS, 2021).

4.16.10. Tanzania

The existing conventional water services in Tanzania are generally perceived by the population as being poor, while innovative technologies such as mobile billing/payment and solar innovations offer desired benefits such as convenience, transparency and accountability. However, users of innovative technologies still encounter technical difficulties and disenfranchisement of vulnerable groups. It is thus important for the government to incorporate feasibility, user acceptability and scalability of the innovative technologies before large-scale uptake.

4.16.11. Madagascar

Significant change leading to the uptake of innovative technologies for water resource management can occur in Madagascar through strong government support by ensuring effective sector planning, co-ordination, regulation and resource allocation.

4.16.12. Djibouti

The water conditions in Djibouti are improving albeit slowly largely due to efforts made by international partners and the Ministry of Agriculture. Since 2007 more than 25,000 of the population in low income rural areas have gained access to clean water. However, to improve water quality and implement innovative technologies a lot still must be done.

4.16.13. Comoros

Better management of water quantity and quality will prevent the squandering of Comoros' very low water per capita. Revisiting/re-designing old systems and implementing new innovative water extraction technologies and service delivery policies such as promoting rainwater harvesting and water conservation, reducing water pollution and ensuring efficient urban usage will be important for achieving sustainable water use.

4.16.14. Eritrea

Over the past years, there has been considerable progress in improving access to water services in Eritrea. The government has committed to ensuring that all of Eritrea's population have access to adequate good quality water; it has also given water top priority in all development initiatives. Between 2010 and 2018, the government launched ambitious water supply initiatives with investments in large-scale systems mainly on rainwater. Despite the progress, several challenges such as inadequate innovative technologies for water resource management and limited information on the potential use, monitoring and management of existing water resources still exist (IAH, 2020).

5 Review and Analysis of the STI Infrastructure for Ground and Surface Water Development, Utilization and Management

In the USA after 9/11, water security was a rising area of concern therefore there was a need to have real-time monitoring and contamination detection systems in place. Consequently, several systems were developed where most of them were focused on contamination event detection. One of the first such systems, Canary, was built by Sandia National laboratories and was funded by the Environmental Protection Agency (EPA) and National Homeland Security Research Center. Deployed at Greater Cincinnati Water Works (GCWW), it provides several open-source components, most of them being online water quality monitoring and contamination event detection. It employs multiple direct and surrogate sensors to transmit continuous data to SCADA. It has an API, which allows the user to update its default algorithms. It is also Rest service friendly, allowing for XML input and output. It supersedes other systems in certain major aspects including algorithms' transparency, the capability to directly integrate operational data into its event detection component, and to have centralized processing on a single computing system as well as supports multiple sensors. Another such system is OptiEDS by Elad Salomons, which helps to detect anomalous water quality conditions in real-time.

Bluebox is another system that can identify the behavior of water quality parameters that cause abnormal behavior. It produces a reliable output even if some of the parameters are missing. It initially performs normalization, calculates the points' distance amongst the parameters in each data point, and plots the frequency curves of the distances to visualize. However, it is quite expensive, costing up to $92,500, and cannot directly integrate operational data into event detection. Another system, Event monitor was created by the Hach Company, which had the heuristic ability to learn events, automatically tune itself and define what constitutes an abnormality in the system. However, it is also quite expensive. Ana::tool is another EDS system, which falls under the umbrella of a vast system monitoring tool introduced by scan in 2010 which also includes a user interface reflecting a dashboard to reflect real-time water quality parameters (Canary 2010; EPA 2013).

The IoT domain proposes smart and low-cost solutions to the problem of water contaminant detection and water quality analysis. Geetha & Gouthami (2017) have proposed a generic IoT system for real-time water quality monitoring. It comprises sensors that read parameter readings, then those parameter readings are transmitted to a controller through wireless communication devices attached with sensors. Later the controllers, through some wireless communication technology, store those sensor readings to a data storage which are reflected in some customized applications. This is followed by the implementation of an instance of the generalized IoT system. They used four-parameter sensors for it namely conductivity, turbidity, water level, and pH. For connectivity, they used TI CC3200 which is a single-chip microcontroller with a built-in Wi-Fi module and ARM Cortex M4 core, which can be connected to the nearest Wi-Fi hotspot for Internet connectivity and in turn move the data to cloud or storage, and then some application could use that data storage to reflect the readings. If sensors were not connected directly to the controller, they could be connected using LoRa sensors.

Raju & Varma (2017) have proposed a real-time monitoring system for aqua farmers which allows them to be apprised of the anomalous events if the water body is contaminated. They have used Raspberry Pi 3 with a built-in Wi-Fi module, a solar panel, and a sensor node comprising of various sensors including those of Dissolved Oxygen, Ammonia, pH, Temperature, Salt, Nitrate, and Carbonates. The system continuously monitors and stores the sensor data and generates an alert for the farmer if any of the data deviates from the allowed range. There is a mobile application through which the farmers can monitor sensor data in real-time and access historical data.

Water is one of the most essential resources for survival and its quality is determined by the WQI, which is measured through various water quality parameters depending upon the type of standard used. Conventionally, to measure water quality parameters, expensive and time-consuming lab analyses are performed which makes timely contaminant recognition and its ramifications difficult. Alternatively, an IoT-based system can be employed to monitor the water quality in real-time, which is an efficient and low-cost solution to the problem. Several such systems such as CANARY are deployed at various places using IoT and they prove to be an effective alternative to expensive manual lab analysis. While IoT systems are employed for real-time water quality monitoring, machine learning techniques such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), regression, correlation analysis, hierarchical clustering, etc. aid in learning the trends of the water quality parameters, to predict WQI, and detect anomalous events like intentional contamination to enable real-time detection of contaminants and action. The proposed system makes use of IoT for real-time monitoring and uses machine learning algorithms to learn various trends of the data to incorporate its learning in the system and aid in decision making. Additionally, the review found a gap in the machine learning methodologies to estimate water quality with a lesser number of parameters which can be easily employed in a low cost IoT system using the minimal number of parameter sensors.

5.1. Groundwater Challenges

Groundwater science has grown tremendously over recent decades through the development of novel monitoring technologies and improved computational technologies that enable sophisticated modelling. Groundwater data from sources ranging from new satellites to low-cost good monitoring have begun to produce new insights; however, communicating how groundwater works to the wider public and decision makers remains difficult. The second challenge is the significant spatial and temporal lags between the occurrence of groundwater harms and detection of those harms. Each aquifer's geologic and groundwater characteristics influence the impacts of depletion and contamination, and we do not fully understand the long-term impacts of contemporary groundwater practices or events. The impacts of groundwater pumping, for instance, can take more than a decade to the surface and a longer time to remedy. Managing a resource today for impacts that become visible decades later presents significant challenges in terms of education, funding, and management practices. Groundwater is out of sight, and unless it is monitored (which often is not), the slowly spreading impacts from depletion and contamination may not be immediately noticed. As visibility (and litigation) of groundwater impacts has increased, states have had to create new regulatory structures, creating a third challenge to the multiple governance structures to which large aquifers may be subject.

5.2. STI Infrastructure in Groundwater

Water quantity and quality form the base of every water-related problem. Technology can contribute to addressing water quality problems and open new sources of brackish or saline water that were previously too cost prohibitive to treat. However, technology cannot manufacture additional water to solve the quantity problem. Currently, the only way to estimate groundwater quantity is through models that require understanding geology, porosity, boundaries, streamflow depletion, recharge, stream capture, etc. Collecting the baseline data requires funding, which has replaced science and technology as the limiting factor to understanding groundwater quantity. While data are not the solution, it plays a key role in modeling and decision-making, as well as in education, messaging, and markets.

In the United States, the USGS monitors and disseminates surface water and groundwater data through the National Water Information System (NWIS). The USGS has 877,845 wells with at least one water depth observation, and 300,000 wells with at least one water quality observation. There are 16,410 active groundwater wells measured at least once in the past 13 months, of which 1,133 wells are measured daily and 1,643 wells are measured in real-time. The USGS has also contributed to the development and implementation of the national groundwater monitoring network (NGWMN) to help address the major data gaps for managing groundwater resources. NGWMN pulls data from federal, state, and local groundwater monitoring networks into a single portal. The NGWMN has 6,743 active wells (5,724 water level and 1,315 water quality) between 19 contributing agencies and 52 states as of March 10, 2017. Participation in the groundwater portal is voluntary and allows data producers to maintain control over the data. The data are pulled into the portal in a standardized format to facilitate data sharing in real-time based on user queries. Funding for this program took 10 years to obtain and is part of the federal budget.

In addition to well-based approaches, satellite and remote sensing are increasingly used to understand how groundwater volume is changing over large areas. NASA's Gravity Recovery and Climate Experiment (GRACE) launched in 2002 is the only satellite that explicitly measures changes in the water column by measuring changes in mass each month. GRACE does not distinguish between snow, surface water, soil moisture, or groundwater; relying on the use of other data to determine which fraction relates to changes in groundwater. GRACE has enabled a large scale understanding of changing water budgets.

Remote sensing data provides another avenue to assessing groundwater changes at 30 to 120 m spatial resolutions every 16 days since 1982. The values of these data are in the composite image: vegetation index, land surface temperature, and a normalized difference water index. The Climate Engine Application (http://climateengine.org/) provides on-demand cloud computing and visualization on this remotely sensed data. The Climate Engine comes from a partnership between the University of Idaho, the Desert Research Institute, and Google. The application has been used to assess the impacts of groundwater pumping on vegetation.

5.3. STI Infrastructure in Surface Water

Surface water bodies are dynamic as they shrink, expand, or change their appearance or course of flow with time, owing to different natural and human-induced factors (Karpatne et al., 2016). Variations in water bodies impact other natural resources and human assets and further influence the environment. Change in surface water volume usually causes serious consequences. In extreme cases, a rapid increase in surface water can result in flooding. Therefore, it is crucial to efficiently detect the existence of surface water, extract its extent, quantify its volume, and monitor its dynamics. Remote sensing technology offers effective ways to observe surface water dynamics. Compared to traditional in situ measurements, remote sensing is much more efficient, because of its ability to continuously monitor Earth's surface at multiple scales. Remote sensing datasets provide spatially explicit and temporally frequent observational data of a number of physical attributes about the Earth's surface that can be appropriately leveraged to map the extent of water bodies at a regional or even global scale and to monitor their dynamics at regular and frequent time intervals.

Since the first Earth Resources Technology Satellite (ERTS-1, later renamed as Landsat-1) was launched in 1972, satellite-based optical sensors have demonstrated their potential to monitor large-scale land cover change on the Earth's surface (Deutsch & Ruggles, 1974). As a significant land cover change phenomenon, surface water dynamics have always been an important topic of Earth observation (Sakamoto et al., 2007; Schaffer-Smith et al., 2017). Spatial resolution refers to the area of ground observed within a pixel and determines the level of details captured by the sensors. As it is one of the most direct factors that control the usage of different sensors in the applications of detecting surface water, we have used the spatial resolution to categorize optical sensors into three groups—coarse (>200 m), medium (5–200 m), and high (<5 m).

The Visible Infrared Imaging Radiometer Suite onboard Suomi National Polar-orbiting Partnership (Suomi NPP-VIIRS) launched in 2011 is the upgrade and replacement of AVHRR and MODIS as a wide-swath multispectral sensor (Yu et al., 2005). It provides a series of multispectral bands with spatial resolutions ranging from 375 to 1,000 m. Its capability in detecting surface water has been tested (Huang et al.,2015). It has also been used for flood detection (Plumb, 2015) and has shown its potential for near-real-time flood monitoring due to its high temporal resolution (Li et al., 2018).

Spatio-temporal monitoring of water body dynamics is thus essential for understanding global or regional water availability, providing descriptive insights about the natural processes that shape the storage of water resources. Spatio-temporal monitoring of surface water dynamics is usually achieved by using multitemporal remote sensing images (Heimhuber et al., 2016; Mueller et al., 2016; Schaffer-Smith et al., 2017; Thito et al., 2016; Tulbure & Broich, 2013). One typical application is to monitor the dynamics of lake water bodies. Feng et al. (2012) used a time series of MODIS data to assess the surface water area of Poyang Lake from 2000 to 2010 and found that the lake area had been extremely variable over this period.

5.4. Water Management

Wireless Sensor Networks (WSNs) have turned into significant parts of acknowledging IoT. They have the detecting ability to gather data about the physical condition, and remote correspondence that empowers impromptu systems administration with no preset physical framework. WSNs are particularly instrumental in acquainting insight with IoT due to their capacity to participate and team up in completing data collection undertakings. The fundamental empowering factor for this promising worldview of IoT is the interoperability of a few innovations, consistent information sharing, and simplicity of correspondence. The influence of IoT on water licensing and monitoring of water permits is not yet fully recognised and exploited by the water utilities in the region and globally. The permit/license system is part of the whole groundwater sustainability system (Koning et al., 2000). Groundwater restrictions and rights enable effective groundwater management. Permits are granted and aimed at guarding the quality of groundwater resources and monitoring the duration of groundwater abstractions (Pandey VP et al., 2011). Permits also ensure distribution rates, sizes/ magnitude, work within limits that are politically acceptable, socially, and environmentally viable, and technically feasible (O'Connor et al., 1992). The basic importance of permits regarding groundwater sustainability is economic instruments, demarcating groundwater rights, and groundwater licensing. IoT can support the monitoring of groundwater abstraction.

Economic instruments are important as they conserve groundwater and control groundwater abstraction. Various methods have been used to lessen abstraction. These include enabling water rights trading, subsidy, and taxation. Compulsory licensing is a means by which all water users in a catchment area are given water based on their requirements and assessed needs. Compulsory licensing was introduced for several reasons as such IoT could lead to; fairness in water allocations, preservation of water quality in the public interest, guidance against over-abstraction, and promoting efficient water resources.

5.5. Country by Country Analysis of the STI Infrastructure for Surface and Groundwater Development

5.5.1. Kenya

Kenya has recorded significant innovations in water resource management. Several innovative technologies for surface water management have been implemented across the country for improved water supply, access and quality. However, lack of adequate knowledge of aquifers and their relationship with other social-ecological systems is a hindrance to the development of an effective and holistic system of management for sustainable use of groundwater. Utilization of groundwater should be considered within the context of future risks, disparities in water access, different uses of water and complex hydrogeology. In Kenya, key aquifers should be characterized urgently to ensure groundwater development is carried out with sufficient aquifer knowledge. Participation by private and public sectors in managing groundwater resources should be promoted through the implementation of decentralized management. The innovative technologies for water infrastructure should be effective in application and scale (Olago, 2019).

5.5.2. Ethiopia

The agricultural sector is the largest consumer of water using up to 93% of this vital resource. The Government seeks to increase access to water and sanitation services and promote more investments in water related innovative infrastructural developments.

5.5.3. Uganda

Uganda has several wetlands and lakes (surface water) which are entirely transboundary given the country's location. Groundwater in Uganda is substantial but spatially variable. The quality of groundwater and surface water is generally good in their natural state. However, in the recent past, domestic and industrial activities have increasingly led to the pollution of water resources (The World Bank, 2011).

5.5.4. Rwanda

The innovation techniques and technologies for improving water supply particularly in the rural areas are well known but with low uptake. Part of the problem is the shortage of technical and vocational skills needed to build and maintain water distribution networks. Technical capacity and engineering skills are needed to successfully explore and drill underground water.

5.5.5. Burundi

Groundwater is a new concept in Burundi, and since it is less polluted, it is considered safe, reliable and affordable. There are currently no reliable statistics on water resource coverage and existing infrastructures in Burundi. Innovative technologies and techniques that could be considered for groundwater development include technical exploration, remote sensing, hydrogeological and geophysical studies and capacity development. Some challenges faced in groundwater development include lack of technical expertise, inadequate financing and lack of community engagement leading to low uptake/acceptance of the innovative technologies (Baranyikwa, 2019).

5.5.6. Mauritius

The quality of existing water resources, infrastructure and qualified staff to manage the same are the key strengths of the water sector in Mauritius. The availability of funding from donors, interest by private partners to be involved in water sector management are some of the opportunities that could allow for the implementation of innovative technologies (Government of Mauritius, 2014).

5.5.7. Seychelles

The country's main island (Mahe) is entirely dependent on rainwater for water supply. To overcome the shortages occasioned by long droughts, the government has been investing in innovative desalination plants. Also, to mitigate water losses through leaks, the government is undertaking an ambitious programme of pipe replacement. The monitoring capacity for water resources is limited with outdated data management equipment. There is a need for significant improvements in the management of water information including human resource development, data management procedures, technical infrastructure for data management and the data application for decision-making. Implementation of innovative technologies could significantly improve the water information management system.

5.5.8. Sudan

About 40% of the urban population in Sudan relies on advanced/innovative water technologies and techniques for their water supply. In the rural areas, up to 70% of the population relies on boreholes and shallow wells. For both the rural and urban areas, around 25% of the population relies on surface water sources (World Bank, 2010). In the recent past, the government has promoted the use of smart ICT by integrating GIS, remote sensing, flood forecasting, and communication platform for flood management (Amarnath et al., 2018).

5.5.9. South Sudan

Based on the 2013 Infrastructure Action Plan for South Sudan, the government should undertake investment in innovative technologies and systems for surface storage and transportation of water to meet the demand currently and in the future. Also, there is a need to build institutional capacities that will ensure the full recovery of water supply costs for household, industrial, and agricultural use (African Development Bank, 2013).

5.5.10. Tanzania

Access to innovative technologies and systems for improved water service provision are important issues in Tanzania. The use of innovative technologies such as solar power and advanced metering is still low in Tanzania. For increased uptake of innovative technologies, it is essential to clearly understand the perceptions to facilitate technology deployment.

5.5.11. Madagascar

The main types of water supply infrastructures in Madagascar are mostly the conventional type: gravity water supply, shallow wells, boreholes, surface catchments (dykes, dams, and rafts), pipelines, and telescopic casing. Investment in innovative technologies for water resource management is required (GWP, 2009).

5.5.12. Djibouti

Djibouti is characterized by low rainfall and high temperatures leading to long-term droughts. The droughts have caused the overexploitation of groundwater to meet the demands of the population. Also, high saltwater intrusion poses a serious threat to groundwater and could lead to its contamination. Innovative technologies are therefore needed to sustainably manage the water resources (Arcanjo, 2020).

5.5.13. Comoros

The government is implementing projects to strengthen the management of water resources, monitor the environment, enhance groundwater management, expand the infrastructure for monitoring the hydrological and meteorological systems, protect ecosystems and promote local community involvement.

5.5.14. Eritrea

The Eritrean government has been developing the water infrastructure by investing in small to big structures for water storage. Extensive research is needed on water quality, water availability, hydro-informatics, hydro-geology, water efficiency and productivity, water resource management, and national and global concerns including climate change and associated impacts (Alemngus, Amlesom, & Bovas, 2017).

5.5.15. Somalia

Somalia relies on the Juba and Shabelle rivers for agricultural activities by providing fertile grounds and irrigation water for crop production. However, the poor condition of the existing irrigation infrastructure significantly impacts crop production. Also, the lack of reliable data has prevented the identification of potential gaps and required interventions (Arcanjo, 2020).

5.6. Way Forward for Groundwater in Eastern Africa

Groundwater can significantly contribute to the provision of safe and sustainable water supply in rural and urban areas and meet the irrigation demand in Eastern Africa. To ensure the sustainable development of groundwater for all, major risks would require further consideration, quantification, and understanding. Some of the risks include:

i. Unequal access i.e., disproportionate access to groundwater resources;

ii. Inadequate local-scale data and information to fully comprehend the availability of groundwater and minimize over-abstraction that could lead to depletion of resources;

iii. Groundwater pollution in the coastal areas due to seawater intrusion and poor waste management in populated urban and peri-urban areas.

In mitigating against the risks, technical/innovative- and governance-based solutions and political commitment are required. Financial and human resources, capacity, networks and data are needed for addressing the existing knowledge gaps. Some of the mitigation measures include:

- Characterization of aquifers and understanding the availability of groundwater at the aquifer scale;

- The impacts (local scale) of land use activities and climate change on groundwater availability;
- Data on groundwater and the economic benefits for investing in groundwater monitoring and management;
- Innovative groundwater-based technological solutions to promote climate-resilient water service provision for the poor populations;
- The political, economic and social factors with impacts on groundwater access.
- Sustainable approaches for ground and surface water allocation in strategic areas including urban or industrial centres.

6. The Current Infrastructural Challenges that May Be Militating Against Adoption of STI in Water Management Especially in Rural Communities

6.1. General Barriers and Risks

Several smart technologies have been adopted for the management of water resources including water quality, supply and treatment, water resource management, wastewater treatment and reuse, and water harvesting and storage. Despite the progress made, there are existing infrastructural and related challenges in adoption and scaling up.

Funding

Finding funding sources for smart innovative technologies is a major challenge particularly for the sectors that need technology solutions such as water management and agricultural sectors. These sectors are also the most challenged in terms of capital in remote parts of developing countries.

Adoption of smart technologies

Generally, water and wastewater treatment utility providers are slow to adopt smart and innovative technologies for several reasons including risks (perceived and real), zero incentives, lack of skilled personnel and isolated ownership. Since water utilities majorly focus on the safe delivery of high-quality drinking water, they tend to favour proven rather than emerging technologies. The need for training of the existing workforce is another major challenge to the adoption of innovative technologies. Since most of the existing water-utility personnel, particularly in rural areas, are not technologically savvy, workforce transformation through training - which may be costly - is necessary for the adoption and scaling of innovative technological solutions (World Economic Forum, 2018).

Cyber-security

Connecting the water infrastructure through ICT and the IoT has numerous benefits, but at the same time increases exposure to threats related to cyber-security that require proper management through improved and effective measures for data-security (World Economic Forum, 2018).

6.2. Barriers to Smart Water Metering

High costs of installing, updating and maintaining smart meters hinder their uptake by small water utilities, particularly in rural areas. Water service providers including retailers must secure the meters, pay for the installation and other related project costs. In rural areas, lack of skilled dedicated and experienced personnel brings about high cost and prolonged duration of meter installations. The complexity of some smart water meters and the related challenges of adopting new technologies hinder their uptake in rural areas since many of the users may find it difficult to access and understand how to use them. Transmission issues including the reliability of the network, electricity and power supply, damage by users and cross-connections can also hinder uptake of smart meters. Network and power outages are more acute in rural areas of less developed countries. Several water utilities have identified the lack of a clear, user-friendly integrated smart technology solution as a major deficiency in smart water metering. The lack of internationally recognised standard water meters pose additional challenges since systems are not compatible. (Sensus, 2012) (Cheong, Choi, & Lee, 2016).

6.3. Challenges to Integrated Water Resource Management

According to a 2018 status report on the implementation of Integrated Water Resources Management (IWRM) in Africa, several countries face obstacles leading to low levels of IWRM implementation. Some of the constraints include: (i) lack of effective water management plans, laws and policies, (ii) poor institutional establishment for stakeholders engagement, (iii) low application of instruments of management for implementation of IWRM, and (iv) poor water resource management financing (AMCOW, 2018). Infrastructural related challenges include:

- Lack of inclusive public participation in the management of water processes - key stakeholders like users need to be supported in accessing information and capacity development; there is also an unwillingness by the government to engage non-state actors;
- Low engagement of the private sector in water resource management processes due to lack of incentives;
- Lack of water management instruments, particularly for ground- and surface water monitoring and disaster mitigation. Also, where the instruments exist, they are sometimes broken, non-functional or aging.
- Mobilizing funding for the implementation of water resource instruments is more challenging at the local/rural level compared to the national level.
- Over-reliance on external funding (technical and financial partners) for implementation of water resource management.

6.4. Infrastructural Challenges to Groundwater Development

Improving electrification in the rural areas of Eastern Africa would allow for higher usage of groundwater and adoption of smart technologies for water resource management. Presently, most rural areas have scarce electrical connections while the prohibitive high energy costs are hindering groundwater development (World Bank, 2018).

6.5. Inadequate Information Systems

The lack of reliable information on the status of water resource and service providers across the region is a major hindrance to the adoption of STI in water resource management, particularly in rural areas. For instance, in Tanzania, data on water resource management and coverage published by the relevant ministry is unreliable since they are not based on an extensive review (Jiménez & Pérez-Foguet, 2010).

7. The Enabling Political, Institutional, and Financial Environment for Promoting and Scaling up Best Bet STI in the Water Sector

Ethiopia, Kenya, Rwanda, Tanzania and Uganda have aligned their national development agenda to Agenda 2063, from which STISA-2024 was generated. Under STISA-2024, initiatives spanning across the whole continent have been undertaken. Through STISA, financial resources have been accessible to the region since 2014 through 2019 by the initiatives under the African Development Bank and World Bank.

STI activities rely on short-term project funding and often linked to workshops and consultancies; therefore most initiatives are not sustainable. Important aspects of STI policy development such as monitoring and evaluation are not budgeted and, therefore, not resourced in most AU member states. These shortcomings account for the gaps in reaching the targeted 1% of the GDP of the AU member states allocated to R&D.

Most of the entities in charge of STI policy-making operate in isolation and continue to have weak links with academic institutions and the private sector. They are also not adequately linked to international and think tanks in policy research in Africa. In these circumstances, these entities are not able to easily access empirical material and emerging knowledge in STI policymaking.

Bilateral and multilateral partnerships have shaped STI development in Africa; these include the European Union–Africa Joint Strategy, the India–Africa science and technology initiatives and the China–Africa Science and Technology Partnership. However, most of these interventions and cooperation mechanisms are not adequately evaluated to promote ownership, accountability and sustainability.

STISA 2024 had set the minimum financing of the STI activities at 1% of the national GDP (AU, 2014). However, none of the fifteen countries are yet to meet this threshold. Even in countries like Kenya, where a higher threshold of 2% of GDP has been stipulated in the STI Act of 2013, financing is still below 1 % (GOK, 2014). Whereas there are no recent cumulative statistics for comparison of the performance of financing of STI sector among the fifteen countries in recent years, sectoral financing of STI activities in the agriculture sector documented by IFPRI can be used. It is also noteworthy that the agriculture sector is the single most sector with the highest proportion of GERD on STI activities among all sectors. The performance metrics of expenditure on agricultural R&D as a proportion of GDP is as follows: Tanzania (0.17%), Ethiopia (0.29 %); Rwanda (0.44 %); Kenya (0.48 %). Uganda at 0.62% leads among the fifteen countries (IFPRI, 2020). Additionally, as revealed by the Agricultural Science and Technology Indicators (ASTI) metrics, the R&D expenditure is majorly comprised of non-R&D activities whereby recurrent expenditure is more than half. In Rwanda, Kenya and Tanzania, the proportion of ASTI expenditure on non-R&D activities has been on the increase in recent years (IFPRI, 2020). This trend, which is also replicated in the private sector, brings to the fore the need for further mobilization of these key stakeholders across the fifteen countries (Hanlin, R. & Khaemba, 2017).

Countries that form EAC have enjoyed relative peace over the last two decades with only slight intervals of unrest. This period of stability has culminated in the establishment of democratic institutions and sustained economic growth. It has also enabled the partner states to articulate national policies to facilitate development of STI approaches within their countries. Kenya, Uganda and Rwanda for example have laid out their national aspirations about STI in their constitutions, which followed a period of conflict in those countries. Most of the countries in the region have also articulated the role of STI in socio-economic transformation in their national visions and development priorities.

It is important to note that significant portions of finances in STI activities in these countries are from donors. In Tanzania, it was found that donor priorities keep changing and the level of financing has been on the decline posing a serious challenge for continuity of STI initiatives. Moreover, government funding of R&D has also been shifted to focus on Higher Education institutions; providing them with more funds than the technical and vocational public institutions. In Rwanda, limited financing levels has been occasioned by the formation of NCST to mobilize funding for the STI sector (Tigabu, A. 2017).

Coordination among players in the innovation system has been a challenge in most African countries. To cure this challenge, the national STI policy of Rwanda recommended establishment of the National Council of Science and Technology (Tigabu, A. 2017). Similar initiatives were undertaken in Kenya where three agencies NACOSTI, KENIA and NRF were established with the principal purpose of coordinating various activities in the STI sector (GOK, 2014). However, poor coordination in the activities has been the key focus of capacity-building initiatives. Involvement of private sector players in STI activities in the five countries is also considered to be low and patchy (Chataway, J. et al., 2017). In this respect, Kenya was highlighted as a case study where private sector engagement with the Science Granting Council (SGC) seems to be visibly present; however, this was also noted to be restricted just to the presence of these stakeholders in the funding panels. In Rwanda, a gap in regulation of research activities in the country was realized (Tigabu, A. 2017); but going forward with the continued work of NCST, this is expected to be closed.

National Science Granting Councils and STI agencies have been granted the mandate and independence to manage the STI sector. However, with limited financing, the capacity of SGCs to effectively execute their mandate is questionable. (Hanlin, R. & Khaemba, 2017). In a study conducted among stakeholders in the system in Tanzania, there was consensus that COSTECH needed more autonomy in its management of the STI activities in the region (Hanlin, R. & Khaemba, 2017). Kenya on the other hand, has devolved units and there is a need for the STI agencies to be strengthened to enhance coordination of STI activities within these devolved units (Hanlin, R. & Khaemba, 2017); Kenyan stakeholders are yet to fully explore the opportunities created in the STI sector by devolution.

Imbalance in sectoral focus has also been blamed for slow progress in the STI sector. For instance, in Rwanda, it was found that with massive investment in agriculture, there is less capacity in the manufacturing sector which needs to be strengthened (UNCTAD, 2018). It was also noted in Ethiopia that overreliance on technology transfer (acquisition of technology from abroad) rather than innovation has crippled technological learning and local innovation.

According to the water services regulator, WASREB, sanitation coverage stood at 73% in Kenya's urban areas in 2013; this accounts for access to domestic sanitation facilities but not safe transport and disposal of human waste. Water sector reforms, which started with the enactment of the Water Act 2002, has transformed the water sector. Separation of policy-making from regulation, water services provision from water resources management and decentralization of key functions from the national level to the county level have been the main features of these reforms. Water services in urban areas are provided by Water Service Boards (WSBs) at the regional level. The WSBs oversee infrastructure construction and report to the national regulator: the Water Services Regulatory Board (WASREB). According to the 2002 reforms, Water Services Providers (WSPs) are tasked with provision of water services at the local level through an assets lease arrangement with the Water Services Boards. Devolution of water services to the newly created counties brought about by the 2010 Constitution, will enhance the decentralization which begun under the 2002 water sector reforms.

7.1. Challenges of ICT Focused Water Innovation Partnerships

A study by Mvulirwenande and Wehn (2019), analysing about 24 ICT-focused water innovation partnerships (ICT-WIPs) that have been implemented in Africa, found that despite having in place relevant governance and structural mechanisms, some ICT-WIPs experienced significant challenges:

- ***Low levels of commitment by partners:*** this results in poor delivery of inputs from stakeholders and can lead to early termination of the partnership.
- ***Difficult transfer of tacit knowledge:*** translating expert's knowledge into a digital manual/handbook that can be easily used by the operators and other users with zero experience and low educational background has been challenging. This is not surprising since most of the knowledge held by water experts is tacit, making it difficult to communicate and formalise.
- ***Asymmetries in resource exchange:*** challenges in data acquisition and sharing between the collaborating partners leading to delays in technology implementations. This challenge could be due to confidentiality concerns or management style.
- ***An ambiguity of partnership objectives:*** inadequate consultation among partnering organisations can lead to the implementation of technologies that do not apply to the local conditions.

7.2. Strategies in Scaling Up STI in the Water Sector

Institutional and organisational challenges prevent widespread use and uptake of promising and innovative technologies. A departure from the traditional approaches is needed by engaging all the stakeholders involved in the technology development and use. A coordinated approach among the Eastern Africa countries could be important in the following ways:

a) Promoting knowledge sharing on new innovative technologies through innovation platforms;

b) Promoting the development of methodologies for scaling up and sharing among member states;

c) Ensuring a coordinated approach for sharing new technologies and innovative processes across the borders;

d) Promoting networking amongst water and sanitation service providers across member states and in the sub-regions;

e) Creating a conducive policy environment to promote scaling in all countries;

f) Strengthening individual and institutional capacities required for scaling;

g) Mobilizing and allocating adequate resources for scaling innovative technologies.

7.3. Options for Scaling Up STI in the Water Sector

Systemized and sporadic pathways could be followed when scaling up technologies. The "Sporadic pathway" involves scaling up with little or no intervention whereby the technology is generated and few dissemination activities carried out. Technologies that follow the sporadic pathway are usually novel, lead to an invention and are usually accepted by key stakeholders. The systemized pathway on the other hand, requires stepwise interventions for a conducive environment to enable technology pass through the different stages of its generation.Technologies that follow a systemized pathway usually address a problem limiting productivity, which has not attained a threshold. Most technologies that lead to improved performance fall into the systemized pathway category. Table 37 shows some of the recommended pathways.

Table 37: Scaling up strategy mediators

Sporadic scaling	Systemised scaling
Technologies with superior performance over the current practice	Technologies developed with benefit pathway in view
Technologies that generate products that align with mega trends in social awareness and societal changes	Technologies that address improvement over the current practice Cost-effective socially acceptable
	Reduction in drudgery (time; rigour; complication); and timeliness, among others
Technologies with invention characteristics that provide a solution to a problem that has attained a threshold	Technologies that foster the development of a new product (require market stimulation)
Technologies with respond to market pull for specific output	Technologies that target commodity competitiveness (price/quality)

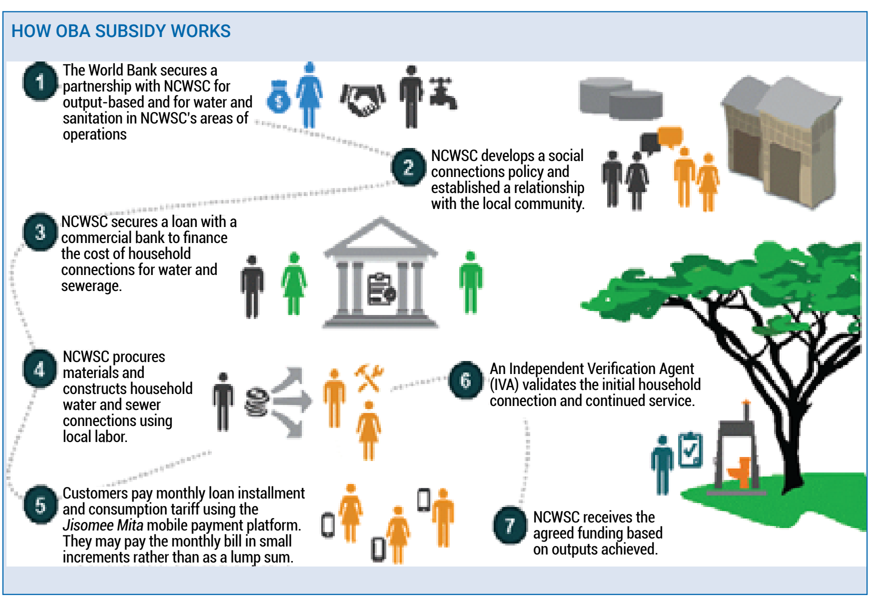
Social Connection Policy Implementation and the Resource Implications

The Case of Adoption of the social connection policy in Nairobi began with the development of the Athi Water Services Board (AWSB) Pro-Poor Policy in 2007. In 2008, NCWSC and the asset-holding entity - Athi Water Services Board (AWSB) - developed and adopted the Strategic Guidelines for Improving Water and Sanitation Services in Nairobi's Informal Settlements. The guidelines steered the AWSB, NCWSC and other stakeholders towards planning and carrying out a more systematic approach to improve water and sanitation services in informal settlements. Among the key approaches proposed within the guidelines were the technical capacity building of utility staff working in the informal areas and development and implementation of social connection programs. Subsequently, in 2008 NCWSC established an informal settlements department with the responsibility of implementing projects in informal settlements; the department had staff representation at the headquarters of the regional offices.

The Innovative Financing and Microcredit Scheme in Nairobi

The objective of the innovative financing and micro-credit scheme was to increase access to and efficiency of WSS in Kenyan informal settlements as well as to provide NCWSC with innovative access to finance. Small water infrastructure projects were financed through micro-finance and community equity that were subsidized through an Output-Based Aid (OBA) conditional on putting in place metered water connections and yard taps. OBA is a results-based financing mechanism that provides monetary incentives to expand basic services. In this case, the purpose was to incentivise NCWSC to connect 2,200 households to their water network. The OBA subsidy was transferred to NCWSC once the agreed result had been achieved. NCWSC in turn transferred the subsidy to the connected customers. Figure 26 illustrates the

Figure 26: Innovative Financing & Microcredit Scheme in Nairobi



Source: WASREB

financial performance of the project over 18 months. As of March 2015, 306 households had paid off their loan component.

7.4. Country by Country Analysis of Enabling Political, Institutional, and Financial Environment for Promoting and Scaling Up Best STI in the Water Sector

7.4.1. Kenya

At the national policy level, there is a conviction for the need to systematically position entrepreneurship and innovation as the drivers of economic development. This conviction is reflected in Kenya's development strategies including Vision 2030.

7.4.2. Ethiopia

Ethiopia has several policies, road maps, background studies and regulations needed to promote innovations and technological developments. However, a serious implementation gap exists across the various public bodies because of capacity constraints, resources and efforts misallocation. Advances on policy coordination and coherence should be put in place to promote the uptake of best STI practices in the water sector (UNCTAD, 2020a).

7.4.3. Uganda

Uganda's 2009 National STI policy is linked to key development goals such as improved water access and poverty eradication. However, lack of resources - finance, capital, human, institutional capacity and Intellectual Property (IP) are incompatible with the country's STI development plans. Engaging the private sector as the primary investor will be crucial in promoting application of STI particularly in the water sector (UNCTAD, 2020b).

7.4.4. Rwanda

Rwanda's water and sanitation sector is progressing sustainably given the sound principles enhanced by strategies and national policies aimed at achieving universal services as outlined in the UN SDG6. However, despite the progress and continued implementation of new and innovative infrastructure, the water sector still needs significant investment to attain the SDG6 targets. Institutional frameworks have been modified to address the modern challenges facing the water sector and promote the adoption of STI strategies (Water for People, 2019).

7.4.5. Burundi

The water sector is experiencing a new momentum after being integrated in Burundi's 10-year development plan, which will form the basis for economic growth allowing Burundi to attain "emerging country" status by 2027. Through political will, the water sector has been recognized as an important pillar for economic growth and the necessary funding will be raised. Just like other priority sectors, the water sector will be evaluated regularly by an established national committee, to monitor and ensure the funding and implementation of planned activities including those related to STI.

7.4.6. Mauritius

Mauritius has a National Water Policy (NWP) for water and sanitation sectors and is based on principles of integrated water resources management (IWRM). Of core importance, as outlined by the NWP, is a holistic approach for making water related decisions. The approach should take into consideration inter-sectoral and extensive decision-making process related to water. The NWP will promote sustainable development of the water sector and translate all strategies for water and sanitation into action plans (Government of Mauritius, 2014).

7.4.7. Seychelles

Seychelles has received major support for institutional, economic and financial reforms and infrastructure investments over the past years from international partners. The financing of the water sector is still dependent on external funds.

7.4.8. Sudan

In Sudan, a policy framework is needed to provide broad political directions for the implementation of innovative technologies for the management of the water sector. Also, needed for the water sector management is a strategic action plan that considers the priorities reflecting a good understanding of the social and economics of inefficient water sector systems (Omer, 2010).

7.4.9. South Sudan

Some of the key issues and priorities in South Sudan's water resources management policy include the promotion of water related scientific research and technical development to identify affordable and innovative technologies for the water sector and ensuring adequate financing for the management of water resources through private sector investment, fees and levies.

7.4.10. Tanzania

Tanzania has several policies for the water sector such as the National Development Vision 2025, which is supported by reforms in the Public Sector and Local Government. Operational goals are set and policy put in place in a functional framework as embodied in the National Water Sector Development Strategy (NWSDS).

7.4.11. Madagascar

Madagascar's Directorate of Water and Sanitation (DEA) in the Ministry of Energy and Mining (MEM) develops and promulgates water and sanitation policies. The National Government meets up to 40% of funding required by the National Program for Safe Water Supply and Sanitation (PNAEPA). The funding gap and the inability to secure adequate donor funding need to be addressed. Capacity building for financial management should be increased to attract and mobilize adequate funding (USAID, 2013).

7.4.12. Djibouti

The performance and institutional arrangements of the Djibouti National Water and Sanitation Office (ONEAD) should be strengthened and investment in the water sector increased. This could be achieved through improved monitoring and planning of activities, prudent procurement procedures improved ONEAD's technical and financial performance, and more resources for improved rural sanitation (UNDP, 2010).

7.4.13. Eritrea

The importance of water resources laws and policies is attracting more attention by planners and policymakers in Eritrea. However, despite the political commitment and progress made, Eritrea still has a draft water policy awaiting enactment and ratification of water regulations and laws. There are however strategies, action plans and policies relevant to the water sector which should be considered for effective and sustainable water resource management (MoLWE, 2019).

7.4.14. Somalia

Somalia's fragmented water sector requires coordination to establish a functioning and effective water governance system for the management of the sector. Thus, commitments from the government and all other affected stakeholders will be important to support the development of water resources in Somalia (Mourad, 2020).

8. The Strategies for Mainstreaming Best STI Interventions into National Water Sector Development Policies

Several smart water resource management projects and services are driven by regulatory requirements including water quality, efficiency targets and prevention of the depletion of groundwater resources. Whereas the regulations do not prescribe the real-time technologies needed to meet the set standards, their existence forces water service providers and users to come up with best practices and technologies for water management. It is thus important for policies and regulations to be introduced to enhance implementation of smart water management. Countries that have prioritised smart water management such as South Korea have put in place strong policy support mechanisms that have been pivotal for the success of smart technologies. Strong policies also act as drivers for relevant stakeholders - such as technology developers - to participate in the adoption of smart technologies. Localised plans and policies applicable to rural setting can be major drivers of implementing STI in rural areas. In contrast, the lack of adequate government support whether in terms of plans, policies or funding can significantly affect adoption of smart technologies (Korea Water 2018).

8.1. Starting Small

Water utilities should 'start small' while reducing some of the risks that may be difficult to reverse. The utilities can then build on the initial step as they make a series of changes to the project ensuring the realization of a full commercial service and citizen engagement. Some of the core steps to be followed and factors to consider for smart water metering are outlined in Table 38 and Table 39.

8.2. Policy, Planning, and Governance

The Korea Water Resources Corporation (K Water) in collaboration with the International Water Resources Association (IWRA) and over 40 contributing organisations spread across the world carried out a major study on Smart Water Management (SWM). The study which was based in developed and developing countries focused on exemplary SWM projects addressing the use of STI to tackle water challenges across several scales from household to transboundary. The study identified the factors outlined below as being key to the successful uptake of SWM (Korea Water, 2018):

- ***Long-term investment*** from the government and institutions will allow for continued research, testing, and development of new smart water technologies.

- ***Funders should value short-term benefits that are non-financial*** including governance, technical, environmental and social benefits of SWM. This should be done with the full knowledge that financial-benefits are only realisable in the medium- to long-term.

Table 38: Steps to be followed for smart water metering

STRATEGY & SCOPE	PILOT	ESTABLISH	SCALE	EVOLVE
Identify issue to be resolved	Refine processes	Incremental Go-live	Scale to multiple sites	Monitor performance
Define required outcomes	Test network performance	Live Data integration	Introduce new public services	Adjust service parameter if needed
Secure budget commitments	Understand installation needs	Apply lessons learnt and changes	Publish open data APIs	Undertake maintenance
Secure stakeholder commitments	Generate test data	Establish trusted foundation system	Integration with city dashboard	Sharing learnings with other cities

Source: GSMA, 2017.

Table 39: Factors to consider for smart water metering

SMART WATER				
Identify issues that need	Ensure data formats are open and accessible to stakeholders	Understand impact on wider systems	Ramp-up installation in wider areas	Monitor performance against baseline
Research regulatory requirements & price control issues	Test network performance	Undertake data integration with billing systems	Introduce new tariff and services	Use data to inform future regulatory decision making
Build requirements for data collection	Audit water meter locations	Undertake initial data analysis	Use data for regulatory reporting requirements	Gradually alter service parameters to change consumer behaviour
Understand how the wider city environment will be affected	Obtain feedback on service from users	Begin replacement installation process	Feedback performance to stakeholders	Demonstrate continued savings in other operational areas
Understand learnings from other water utilites				

- ***Internal and external engagements*** for the implementation of collaborative projects, data sharing, and improving outputs.

- ***Top-down*** support and multi-stakeholder engagement to enable the continued development and implementation of smart water projects.

- ***Promotion of the SWM potentials*** for reduced additional infrastructural needs.

- ***Engaging and collaborating with the stakeholders*** from the initial stages particularly local agencies to ensure a good understanding of project complexities and having all stakeholders on board with decision making and implementation.

- ***Policies and regulations, and government support*** to drive the Smart Water Management (SWM) projects.

- ***A clear understanding of the varying approaches for successful implementation of SWM technology*** dependent on the implementation tools (such as individuals, institutions, or mixed), and the required additional support such as governance, engagement, or business models.

- ***Building trust in the community*** through engagement with reliable real-time data increasing water conditions awareness, positive behavioural changes, and informed decision-making.

- ***Developing strong business models*** leading to the creation of new sustainable jobs and opportunities for the community and water users.

- ***A two-pronged approach*** by including governance networks, business models, and engagement tools for strengthening the potential for successfully implementing SWM technologies that are long-term.

- ***Training and capacity development*** for community members to ensure successful monitoring and management of installed technologies and systems.

- ***Achieving short-term results*** such as increased water quality, reduced consumption, efficient water management, and reduced water conflicts. The short-term results will promote enthusiasm for the continued implementation of SWM.

Smart metering (Jisomee Mita) in Kayole Soweto, Nairobi; successes and challenges

Jisomee Mita (a smart metering technology) rolled out in Kayole Soweto, Nairobi, Kenya, and employed community sensitization through provision of mobile phone use to members of the community. Residents including landlords were trained on the use of smart technology. Staff at the utility level were also trained on the functionalities of the new technology. At the beginning of the project, there was resistance to the unknown new technology and doubt on the ability of low-income earners to pay their bills. The establishment of a dedicated office for Kayole Soweto residents by the service provider was important for the successful project implementation. Under the social connection policy, the office handled water accounts and emerging complaints related to the new technology. The good relationship between the utility staff and the community members equally contributed to the technology acceptance by the users. Continuous outreach, training, and communication have been necessary for ensuring the customers are conversant with the new technology and can use it with ease. Moreover, the system undergoes constant technological improvements to match up with the changing trends (World Bank Group, 2015). Considering the factors outlined as being key to the successful uptake of SWM, gives strategies that would promote the successful implementation of smart water technologies.

Table 40: Policy recommendations for the adoption of smart water management technologies

Sector	Strategy
Society	SWM for an improved quality of life
Economy	Investment in SWM for improved resilience and sustainable development
Environment	SWM for protecting and conserving water resources and ecosystems
Technology	Support evolving SWM development and adoption
Governance	Building capacity and networks for increased resilience and collaboration

8.3. Action Areas for Integrated Water Resource Management

There is a need for a shift from policy, strategies and laws to practical implementations. For effective water resource management at the national, municipal and rural levels, integrated approaches are necessary. Recommended action areas include enabling environments for IWRM, financing IWRM, applying management tools, developing infrastructure, and establishing institutional and governance frameworks as shown in Table 41 (AMCOW, 2018).

The principles of IWRM are embedded in the national policies of the member countries in the region. Also, each country has put in place an enabling environment to promote the implementation of IWRM practices. This includes rules and regulations to determine intentions and actions necessary for the sustainable supply of sufficient water resources to promote economic growth and social development. The progress in the implementation of the different stages for the implementation policies and regulations for the IWRM concept in the Eastern Africa region are shown in Table 42 and management instruments in Table 43.

Several countries have put in place policies, institutional arrangements, and legislation that incorporate an integrated approach, though infrastructural development is still lagging. Countries such as Kenya, Djibouti, Tanzania,

Table 41: Action areas for integrated water resource management

Action area	Targets
Enabling environment for IWRM	• Target and provide priority support to countries that are falling behind with IWRM implementation, including by creating environments, especially in countries recovering from conflicts, political crises, and disasters. • Enhance political will for water reforms by conceiving and implementing specific programmes on information and awareness-raising and targeting advocacy towards policymakers.
Establishing governance and institutional frameworks	• Promote the establishment of effective governance and institutional frameworks at the transboundary, national, and local levels. • Enhance capacity-building at all levels to obtain the necessary human resources for IWRM implementation.
Applying management instruments	• Improve the monitoring of water quality, quantity, and use. • Develop appropriate water allocation models. • Promote forecasting and early warning systems through peer learning from existing good experiences.
Infrastructure development and financing	• Promote preparation of basin plans for IWRM, including comprehensive investments programmes. • Strengthen and sustain the African Water Facility
Financing IWRM	• Build the knowledge base on the best practices regarding the implementation of the user pays and polluter pays principle • Increase government financing of water resources management, to help increase national contributions for water resource development. • Support countries in creating an environment suitable for private sector financing.

Table 42: Status of IWRM planning and implementation in Eastern Africa Country

Status of IWRM planning and implementation in Eastern Africa

Country	Policy and legislation	Infrastructure platform	Sustainable financing	Institutional arrangements	Institutional capacity
Burundi	Some progress, but limited achievements	Little progress achieved	Little progress achieved	Some progress, but limited achievements	Some progress, but limited achievements
Djibouti	Substantial achievements or progress	Little progress achieved	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements
Eritrea	Some progress, but limited achievements	Some progress, but limited achievements	Little progress achieved	Some progress, but limited achievements	Some progress, but limited achievements
Ethiopia	Substantial achievements or progress	Some progress, but limited achievements	Some progress, but limited achievements	Substantial achievements or progress	Some progress, but limited achievements
Kenya	Substantial achievements or progress	Some progress, but limited achievements	Some progress, but limited achievements	Substantial achievements or progress	Substantial achievements or progress
Rwanda	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements
Somalia	Little progress achieved	Little progress achieved	Little progress achieved	Little progress achieved	Little progress achieved
Sudan	Some progress, but limited achievements	Substantial achievements or progress	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements
Tanzania	Substantial achievements or progress	Some progress, but limited achievements	Some progress, but limited achievements	Substantial achievements or progress	Some progress, but limited achievements
Uganda	Substantial achievements or progress	Some progress, but limited achievements	Some progress, but limited achievements	Substantial achievements or progress	Substantial achievements or progress

Little progress achieved | Some progress, but limited achievements | Substantial achievements or progress

Source: UN water, 2008; GWP EnA and GWP Southern Africa, 2009.

Table 43: Implementation of IWRM management instruments in Eastern Africa Country

Implementation of IWRM management instruments in Eastern Africa

Country	IWRM planning	Water use efficieny	Stakeholder engagement	Allocation mechanisms	Monitoring information	Environmental sustainability
Burundi	Some progress, but limited achievements	Little progress achieved	Some progress, but limited achievements	Little progress achieved	Some progress, but limited achievements	Little progress achieved
Djibouti	Some progress, but limited achievements	Little progress achieved	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements
Eritrea	Substantial achievements or progress	Some progress, but limited achievements	Substantial achievements or progress	Little progress achieved	Some progress, but limited achievements	Some progress, but limited achievements
Ethiopia	Substantial achievements or progress	Substantial achievements or progress	Substantial achievements or progress	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements
Kenya	Substantial achievements or progress	Substantial achievements or progress	Substantial achievements or progress	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements
Rwanda	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements	Substantial achievements or progress
Somalia	Little progress achieved	Little progress achieved	Little progress achieved	Some progress, but limited achievements	Little progress achieved	Some progress, but limited achievements
Sudan	Some progress, but limited achievements	Some progress, but limited achievements	Substantial achievements or progress	Some progress, but limited achievements	Some progress, but limited achievements	Some progress, but limited achievements
Tanzania	Substantial achievements or progress	Substantial achievements or progress	Substantial achievements or progress	Substantial achievements or progress	Some progress, but limited achievements	Some progress, but limited achievements
Uganda	Substantial achievements or progress	Substantial achievements or progress	Substantial achievements or progress	Some progress, but limited achievements	Substantial achievements or progress	Some progress, but limited achievements

Little progress achieved | Some progress, but limited achievements | Substantial achievements or progress

Source: UN water, 2008; GWP EnA and GWP Southern Africa, 2009.

Ethiopia, and Uganda have introduced policies and legislations for setting up the IWRM framework. There is limited progress in Burundi, Sudan, Rwanda, and Eritrea, while little progress has been made in Somalia (GWP 2015).

Whereas the institutional capacity development has progressed, much still needs to be done. Countries like Kenya, Ethiopia, Rwanda, Uganda and Sudan have put in place water use efficiency measures, IWRM strategic and management plans, stakeholder engagement forums, water allocation plans and approaches, progress monitoring, information monitoring and practical tools for adhering to sustainable environmental practices (GWP 2015). Table 44 gives an overview of IWRM instruments including policies in selected countries in the Eastern Africa region. Policies for all the countries in the Eastern Africa region are given in Appendix C.

Table 44: IWRM instruments in selected countries in the Eastern Africa region

Country	National WRM strategies	National WRM regulations	National WRM plans	Basin-specific management strategies
Ethiopia	National Water Sector Strategy, 2001	Water Resources Management Proclamation, 2000.	Water Sector Development Programme, 2002.	River Basins Integrated Master Plan Implementation Proclamation. Proclamation on Establishment of RBOs, 2007.
Kenya	NWRMS 2006, 2010 (every six years).	WRM Rules 2007 and amendment.	Annual WRM Plans (2005 onwards).	CMSs 2009 (revised every 5 years).
		Water Quality Regulations 2009.		Guidelines for Catchmentbased Water Resource Planning in Guidelines, 2013.
Rwanda	National Policy for WRM (2011).	Water Law (2008).	WRM Strategic Plan (2011–2015).	National Water Resources Master Plan (2014).
	National Water Supply and Sanitation Policy (2010).	Law on use, conservation, protection and management of water resources regulation (2008).	Green Growth and Climate Resilience Strategy (2011).	Rwanda Irrigation Master Plan (2010).
Uganda	National Water Policy 1999	Water Act Cap 152.	Water Action Plan in 1995.	Framework and Guidelines for Source Protection, 2013.
	Water Sector Reform Study 2005 and 2006.	National Water and Sewerage Act 1997.	National Development Plan (NDP).	Operationalisation of catchment-based water resource management
	Environment Health Policy 2005.	Water Act 1997. Public Health Act 2000.	Vision 2020 and 2040.	
	National Policy for WRM (2012).		Economic Development and Poverty Reduction Strategy (EDPRS II) (2013–2017).	
			Strategic Plan for the Transformation of Agriculture in Rwanda – Phase III (PSTA III 2013–2017).	

Source: GWP, 2015.

9. The Strategies for Promoting South-South Cooperation and Intercountry Learning on the Application of STI in the Water Sector

9.1. Guiding Principles for Effective SSC in the Water Sector

South-South Cooperation (SSC) goes beyond financial transfers. It can foster adaptation measures through the replicability of experiences and technologies that countries accumulate in their own development processes. SSC is based on the premise that developing countries are better positioned to mutually contribute to the solution of their development challenges because they often have similar challenges. Technologies and expertise in developing countries are therefore more likely to be attuned to similar geo-climatic conditions, scaled down to levels appropriate to the size of their markets and adaptable to the reality of low-income consumers. Also, as technological protectionism and intellectual property rights are strengthened, acquiring advanced technologies can become more difficult for some countries (UNIDO, 2006; Srinivas, 2009). An essential alternative for developing countries is thus to step up cooperation in more cost-effective technologies for adaptation amongst themselves.

According to the Framework of Operational Guidelines on the United Nations Support to South-South and Triangular Cooperation, SSC is a process whereby two or more developing countries pursue their individual and/or shared national capacity development objectives through exchanges of knowledge, skills, resources and technical know-how and through regional and interregional collective actions, including partnerships involving governments, regional organizations, civil society, academia and the private sector, for their individual and/or mutual benefit within and across regions. SSC contributes to increasing countries' adaptive capacity, by building capacities and enhancing abilities to respond successfully to climate change. Triangular Cooperation (TrC) is further defined as a typically Southern-driven initiative that might include an element of SSC supported by a developed country, multilateral organization or any other third party. In line with the principles of national sovereignty and ownership, developing countries themselves initiate, organize and manage SSC and TrC. Developed countries and international organizations play a facilitation role and do not take the lead in executing South-South operational activities, which remain solely the domain of developing countries themselves.

The potential for SSC in technologies for adaptation remains largely untapped. In addition to limited awareness of where this knowledge and technology are available, other challenges include lack of or inadequate access to financial resources; inadequate legal and regulatory frameworks; and insufficient organizational and technical capacity limiting the transfer of technologies for adaptation among developing countries. Global institutions like the Technology Executive Committee (TEC) and the Climate Technology Centre and Network (CTCN) have the potential to catalyze SSC for technologies for adaptation through the promotion of the use of local knowledge and technology, the promotion of capacity development, and the replication and up-scaling of successful initiatives. The TEC can further work with the Adaptation Committee in encouraging countries to commit to SSC initiatives for technologies for adaptation. Similarly, the operating entities of the UNFCCC's Financial Mechanism, the Global Environmental Facility (GEF), and the Green Climate Fund (GCF) may have the potential to play a larger role in financing SSC for technology. Other international organizations and financial institutions with a tradition in SSC and knowledge exchange, like the United Nations Office for South-South Cooperation (UNOSSC), the World Bank15, the New Development Bank, and other global, regional, and emerging organizations and financial institutions can further support this process.

The relatively few SSC initiatives in technologies for adaptation in the agriculture and water sectors tend to concentrate in a small number of countries. Two main factors seem to contribute to this phenomenon. First, the lack of a universally accepted definition of SSC poses questions on whether SSC encompasses people-to-people in addition to government-to-government cooperation. The Framework of operational guidelines on the United Nations' support to South-South and Triangular Cooperation places partnerships involving governments, regional organizations, civil society, academia, and the private sector at the heart of SSC and TrC. This understanding seems to be in line with the shift from more traditional aid models – in which States play a central role in project design and implementation – to partnership arrangements in which all development actors share responsibilities and results of their engagements. This also implies structured approaches, beyond traditional project-type interventions. These include the exchange of both tacit and normative knowledge through different means, including informal exchanges to online platforms and networks.

Second, and possibly influenced by the lack of a universal definition of SSC, is the still relatively low visibility of SSC. Cooperation among developing countries, whether through governments or non-state actors is not a new phenomenon. Yet, much attention has been placed on SSC in recent years largely driven by the financial crisis that has affected Northern countries and its impact on traditional aid, combined with the emergence of BRICS countries in global economics and particularly in development financing. This seems to have contributed to narrowing the scope of SSC as an instrument of foreign policy by 'emerging powers' when in fact it includes a much wider array of countries, actors, and modalities. As such, many SSC initiatives fall off the radar: SSC partners do not classify their engagements as SSC, and opportunities for SSC are missed. For example, when projects have a SSC component, these are not explicitly defined in project documents and reports. There are also few case studies recounting initiatives led by governments, private sector, and non-state actors, as well as few databases on demand and supply of knowledge and technologies, SSC experiences, and flows SSC initiatives in technologies for adaptation in the agriculture and water sectors can be divided into three main types of engagement. First, bilateral and global initiatives where Middle-Income Countries (MICS) act as providers. Second, regional initiatives where Least Developed Countries (LDCs), Low-Income Countries (LICs), and Small Island Developing States (SIDS) are both providers and recipients. These two types of engagement can be facilitated by an international organization either through funding, support to project implementation, or knowledge sharing through trilateral arrangements. The third type of engagement happens when SSC is a component of a traditional cooperation project or a stand-alone initiative that promotes South-South engagements promoted by an international organization.

The role of international organizations in SSC in technologies for adaptation in water and agriculture cannot be underplayed. Climate change adaptation requires collective solutions through cooperation with other developing countries, and therefore international organizations have a key role to play in convening partners, brokering demand and supply of technologies for adaptation by mapping existing technologies in the South, matching knowledge and technology needs with countries' demand, piloting new initiatives and rolling out bilateral experiences or SSC components in larger projects to other countries. Increased visibility of existing technologies and networks from the SSC goes beyond financial transfers. It can foster adaptation measures through the exchange of technologies that countries accumulate in their development processes and their adaptation to other similar environments. Yet, evidence shows that many SSC initiatives, particularly in technologies for adaptation, remain unaccounted for. This is mainly due to the lack of a universally accepted definition for SSC, the overall fragmentation, and low visibility of SSC initiatives in organizations' portfolios.

Action may include indicators for identifying SSC projects and activities, and the development of an SSC 'marker' to identify whether a project is designed to effectively promote the exchange of technologies for adaptation among developing countries or when technology from another developing country has been used.

9.2. Strategies for Effective SSC in the Water Sector

a) ***Create a policy space and network to promote SSC in technologies for adaptation.*** The world needs a better understanding of what SSC is and is ready to fully gain strength from the diversity it brings. There is still some blurry understanding of the concept. Besides, SSC frequently happens under different modalities, which are normally not assessed; there is currently no systematic and widely available information on the trends and patterns of SSC, and there is a lack of monitoring and evaluation frameworks that can assess its strengths and weaknesses in which developing countries can use. There also needs to be an enabling environment and space in which institutions and experts from the South can share information and knowledge to which they can easily and freely access.

b) ***Develop an online knowledge repository and exchange platform to identify and match the demand with the supply of SSC in technologies for adaptation.*** The creation of a SSC marker to identify SSC projects and activities in technologies for adaptation or when technology from another developing country has been used. It may also facilitate a global initiative to map technologies and systematize exchanges among developing countries, in partnership with research institutions, governments, and academia worldwide. Developing a registry with all relevant information on SSC in technologies for adaptation (e.g. existing technologies, demand for technologies for adaptation, funding mechanisms, how to access these funds, etc.) and information on Parties' technologies for adaptation in water and agriculture that could be matched with countries' demands. The registry would serve as a "one stop shop" to be hosted on a website. It could also serve as a knowledge repository and include case studies of solutions exchanges and the lessons learned for future program design and implementation.

c) ***Facilitate the creation of partnerships at the local, national, and regional levels.*** Countries and organizations should be encouraged to share information on SSC on technologies for adaptation. Exploration of the potential for Arab States, Eastern Europe, and other regions as providers of sharing technologies for adaptation with other developing countries by identifying centers of excellence in these regions and engaging them in its network.

d) ***Assist Parties access and make better use of funding mechanisms.*** A review of the operational procedures of the Green Climate Fund (GCF) and the Global Environment Facility (GEF) to ensure these mechanisms can best support SSC in technologies for adaptation. An example could be China's USD 3.1 billion commitment to mainstream investments in line with the 2 degrees goal as well as an additional USD 60 billion in climate finance for development projects in Africa.

e) ***Recommend actions to enhance country-level support, mainly in the least developed and most vulnerable countries.*** Joint research work could be explored at the National Designed Entities in liaising with national stakeholders, developing projects that are contextually relevant and in line with national development priorities, mobilizing new resources, following up on commitments, and monitoring project implementation. While exchanges still take place on a more informal and ad-hoc basis, support to SSC begins to prioritize capacity-building initiatives for more sustainable transfers and uptake of technologies for adaptation. Delivery modalities and instruments that build relationships and capacity beyond the project lifespan are gaining traction and being combined depending on the context in more structuring interventions.

10. Best Practices/STI Opportunities Need Critical Consideration for Water Security in Eastern Africa

10.1. Introduction

Technological advancements and innovations present great opportunities for improved design and planning of effective and sustainable projects for improving water access and supply and managing water resources.

10.2. Advanced Water Metering

In the urban/municipal areas, the introduction of smart metering approaches to give accurate real-time data on water distribution thus reducing non-revenue water losses and achieving accurate billing is promising and should be considered. Smart metering is an integrated system of communication networks, post-paid and prepaid meters, and data management enabling two-way communication involving customers and water utilities. The communication will enable the smart meters to be controlled remotely and managed on a fixed network over a private network or through cloud computing. The smart meters would be placed strategically over the supply network and will provide a management and evaluation system which would ensure early detection of leakages. The prepaid meters will be placed in the households and business premises and will allow the consumers to have financial control and accurate billing. Pre-paid meters will also provide a pay-as-you-use format which will improve revenue collection. In other related projects that we have carried out, advanced, prepaid, and smart metering systems have been shown to significantly reduce the NRW, improve technical operation and maintenance, reduce maintenance costs by promoting lean and effective staff establishment, and improve revenue collection and customer service.

In rural areas, the water supply is majorly community-based. A committee is elected to manage the communal water points by overseeing fee collections, daily operations, and maintenance. Water distribution is often done through water kiosks under the management of the committee. This type of water management is prone to several challenges such as lack of transparency on the fee collection, favouritisms, and inadequate technical capacity thus making the management system unsustainable. We propose the introduction of pre-paid water ATMs at the kiosks in the rural areas. The community members will be assigned user cards which must be loaded with water credits purchased via mobile money. They can access the water by scanning the user card on the water ATM at the kiosks to initiate water dispensing. The ATM periodically transmits all data related to revenue collection and water collection to a central dashboard which can be accessed remotely. Availability of this information improves recordkeeping and accountability. Overall prepaid water metering in selected rural-based projects has been proven to be more financially effective for the community-based water service providers, with increased efficiency and water use, improved revenue collection, enhanced operation and maintenance, and accurate revenue tracking. Digital payments including mobile money which is widespread in Eastern Africa make the revenue tracking process more accurate.

10.3. Water Management Using ICT

ICTs are becoming more important in developing countries including Eastern Africa with positive signs already observed in several countries. In Ugandan villages, for instance, farmers can access information on the Internet regarding weather forecasts for water management and irrigation. Also, GIS technology is being used in new ways to support water management. ICTs have the potential to improve water management through the adoption of the smart systems concept. The smart systems for water management employ the use of ICT applications for efficient water resource management at all the different levels of the water cycle. In Kenya, water supply chain monitoring, quality management, customer management, and water supply station mapping using GIS are some of the important water management functions requiring ICT applications the most. Table 45 gives the key areas of ICT for water resource management applicable to Eastern Africa.

Table 45: ICT areas and tools for water resource management

Areas for ICTs in water management	Examples of ICT tools	Benefits for water management
1. Weather forecasting	Remote sensing satellite systems; in situ terrestrial sensing systems; wireless sensor networks; GIS	High-quality and standardised observations of the atmosphere and ocean surface; real-time exchange of meteorological data and information
2. Mapping of water resources	GIS; satellite mapping; water portal systems; supervisory control and data acquisition (SCADA)	Improved understanding of the water resource base; improved knowledge of current levels of water abstractions and use; improved prediction of water resources supply and demand
3. Asset management	GIS, buried asset identification and electronic tagging; smart pipes, hand pumps and meters; supervisory control and data acquisition (SCADA)	Improved management of distribution networks; reduced water losses; reduced network damage And deterioration; reduced risk of infection in the water system; shortened response time, reduced maintenance costs
4. Early warning systems	GIS; sensor networks; early warning websites; mobile phone applications; digital delta	Improved reservoir management; flood mapping; improved data management (quick acquisition, processing, analysis and dissemination to warn the public)
5. Water demand forecasting	GIS, ground penetrating radars; optical and pressure sensors; cloud computing; SCADA	Rain/storm water harvesting; managed aquifer recharge; improvements in water resource management
6. Service delivery	e-payment systems; GIS; call centres	Improved service delivery: timely access to water information, operational efficiency of water sector institutions – shortened response time, improved financial management, increased revenue collection
7. Governance and visualisation	Smart mobile phone applications; websites	Improved public participation, transparency and accountability; improved customer relations

Replication and scaling of STI in the water sector

Based on the reported case studies of STI-related technologies in selected countries in Eastern Africa, a series of applicable policy recommendations are given in Table 46. The recommendations are in line with technological, social, environmental, governance, and economic strategies for policymakers across the different levels of government.

Table 46: Policy recommendations for STI uptake for water resource management in Eastern Africa

Strategy	Policy Direction
STI for an improved quality of life.	Facilitate adoption of STI tools, especially in developing countries, to support access to basic services, and to support equality for poverty reduction, public health and quality of life. Include capacity development, technology sharing, collaborative business models and community governance and decision-making opportunities.
	Build trust and community engagement using STI tools in areas where the community feels unsafe using the local water sources
	Empower people in developing countries with smart tools to reduce the time spent on water management and increase farm income and time available for other activities (e.g., further schooling, and additional work opportunities)
Investment in STI for improved resilience and sustainable development.	Strengthen collaboration across and within sectors to provide opportunities for networks to share information and data to assist with effective and efficient water management
	Value non-financial benefits (e.g., environmental, social, governance and technical benefits) as equally important as financial benefits for STI implementation, as they contribute to building resilience to the effects of climate change and increasing populations
	Support long-term investments for STI implementation to enable adequate research, development and testing.
STI for protecting and conserving water resources and ecosystems.	Introduce policies, regulations, and incentives to drive environmental and ecosystem protection through use of STI.
	Encourage STI solutions to increase water quality, manage demand and use, water reuse, reducing groundwater depletion and increase energy efficiency, etc.
	Introduce STI solutions for climate adaptation plans for flood and drought planning and management and major storm events
Support evolving smart technology development and adoption.	Develop standards to ensure all STI technologies are compatible (can communicate) with each other to enable tools to be purchased across various suppliers to enable those implementing STI to create the right set of tools for each context.
	Support on-going research, testing and development of STI tools to advance them to a point where they are robust and require minimum maintenance and are ready to be commercialized (Government policies that support taking STI tools from R&D to market.
	Support technology to assist in regions without built infrastructure or the adequate resources (e.g., electricity), as currently STI infrastructure is (almost always) reliant on built infrastructure
Building capacity and networks for increased resilience and collaboration (Governance)	Empower people, especially those in developing countries, by providing them with STI tools, data and capacity development and education to enhance/support local decision-making.
	Strengthen the capacity to adapt to climate change by adopting STI planning and operational technology
	Plan for water disasters in advance by creating proactive policies instead of reactive policies

Conclusion

The Africa Water Vision 2025 and Africa's Agenda 2063 provide the route for achieving water security and sustainable water resource management. Science, Technology and Innovation (STI) is a key enabler for achieving sustainable development goals and targets related to water. In this regard, Eastern Africa and the larger Sub-Saharan Africa region faces several challenges including low access to improved water sources and sanitation, increased pollution of water resources and adverse effects of climate change. Also, improvements in service delivery and economic growth witnessed in the last decade do not match the high rate of population growth. Thus, in some countries in Eastern Africa, the percentage of the population with access to improved water and sanitation services has declined over the years. This exploratory study sought to advance the knowledge and define the entry points for developing and scaling up best STI interventions for water security in Eastern Africa.

On the status of water resources, it was found that compared to the western, central, and southern Africa, Eastern Africa has the least water resources, representing about 6.5% of the continent's internal resources. The western part of Eastern Africa has surplus rainfall, while the northern part have large water deficits. Kenya and South Sudan were found to be water-scarce based on the available renewable water sources. Tanzania and Uganda were found to be vulnerable while the remaining countries in Eastern Africa were mostly water-stressed. By 2025, most countries in Eastern Africa are projected to face water scarcity. Groundwater could be used as a major source of water to meet the demand; however, there are limited knowledge and development of groundwater sources in the region as this source of water is the least monitored and understood. Several threats to water resources and security exist. These include pollution from industrial emissions and effluents, agricultural activities, rapid urbanization, increased population growth and climate change. These threats are likely to negatively impact water quality and access if not mitigated. Moreover, climate change will continue to cause increased temperature and variability in precipitation and severe negative effects on water resources availability, food security, tourism, human health, biodiversity and coastal development.

The study found some potential and on-going STI interventions undertaken in the region particularly for enhancing water provision (supply, treatment, quality, and access), sanitation, and agricultural services. Some of the interventions which include real-time monitoring of water quality, quantity, and system performance and digitalization of water systems have been undertaken by private institutions, NGOs, government/public sectors and through public-private initiatives. The study showed that smart technologies such as prepaid water meters, advanced metering systems, water ATMs and mobile money payments widely adopted in Kenya, Rwanda, Uganda, and Tanzania have significantly reduced the non-revenue water, improved technical operation and maintenance, reduced maintenance costs by promoting lean and effective staff establishment, increased revenue collection, and improved water resource management. For most of the existing smart STI interventions, the adoption rate considering prevalence use is however still below 30%. The low adoption is caused by the existing infrastructural challenges including inadequate funding, lack of skilled personnel, inadequate institutional support and network and power problems.

For effective adoption and implementation of STI-related smart technologies, all stakeholders should be brought on board including the users and local communities. The approach should be to 'start small' (pilot) while reducing some of the risks that may be difficult to reverse. The technology providers/implementers should then build on the initial step while making a series of changes and ensuring the realization of sustainable service and citizen engagement. Success of the pilot project will then inform the subsequent projects and necessary technology adjustments during scale-up. Also, for enhanced adoption of STI strategies regulations should be put in place to promote best practices and technologies for water resource management. Strong policies are needed to support the implementation of smart technologies and ensure participation by all stakeholders. For the rural areas, localized plans, and policies applicable to the rural setting can be a major driver for the implementation of STI.

References

ACGE. (2018). *The South African Water Innovation Story* (Vol. 11). Retrieved from https://www.m-culture.go.th/mculture_th/download/king9/Glossary_about_HM_King_Bhumibol_Adulyadej's_Funeral.pdf

Adelana, S. M. A., & Macdonald, A. M. (2008). Groundwater research issues in Africa. *Applied Groundwater Studies in Africa,* (October 2014), 1–7. https://doi.org/10.1201/9780203889497.ch1

Adesina, M. A. (2019). The Health Status and Demographics of a Conflicting Country: The Sudan Experience. *European Journal of Environment and Public Health,* 4(1), 1–4. https://doi.org/10.29333/ejeph/5933

Adhikari, U., Nejadhashemi, A. P., & Herman, M. R. (2015). A review of climate change impacts on water resources in East Africa. *Transactions of the ASABE,* 58(6), 1493–1507. https://doi.org/10.13031/trans.58.10907

Adhikari, Umesh, Nejadhashemi, A. P., & Woznicki, S. A. (2015). Climate change and eastern Africa: A review of impact on major crops. *Food and Energy Security,* 4(2), 110–132. https://doi.org/10.1002/fes3.61

African Development Bank. (2012). Indian Ocean Commission Countries: A Flagship Study on Regional Integration. Summary Final Report, (December 2012).

African Development Bank. (2016). Federal Democratic Republic of Ethiopia Country Strategy Paper.

African Development Bank. (2019). African Economic Outlook 2018 - Seychelles, (December 2017).

African Development Bank. (2020). *African Economic Outlook 2020 Amid O VID-19 SUPPLEMENT.* Retrieved from https://www.afdb.org/sites/default/files/documents/publications/afdb20-04_aeo_supplement_full_report_for_web_0705.pdf#page=60

African Development Bank. (2013). South Sudan : An Infrastructure Action Plan South Sudan. A Program for Sustained Economic Growth, 1–321.

African Development Bank. (2009). An Infrastructure Action Plan for Burundi: Accelerating Regional Integration, (September).

African Development Bank. (2020). *African Economic Outlook African Economic Outlook.*

African Development Bank. (2019). East Africa Economic Outlook 2019.

African Union. (2020). Framework for Irrigation Development and Agricultural Water Management in Africa, 42.

African Union Commission. (2014). STISA-2024 Science, Technology and Innovation Strategy for Africa 2024, 52.

Afrik21. (2020). Eastern Africa Lake Victoria clean-up programme. Retrieved from https://www.afrik21.africa/en/eastern-africa-lake-victoria-clean-up-programme-underway/

Alemngus, A., Amlesom, S., & Bovas, J. J. L. (2017). An Overview of Eritrea's Water Resources. *International Journal of Engineering Research and Development,* 13(3), 74–84.

Amarnath, G., Simons, G. W. H., Alahacoon, N., Smakhtin, V., Sharma, B., Gismalla, Y., … Andriessen, M. C. M. (2018). Using smart ICT to provide weather and water information to smallholders in Africa: The case of the Gash River Basin, Sudan. *Climate Risk Management,* 22 (September), 52–66. https://doi.org/10.1016/j.crm.2018.10.001

AMCOW. (2018). *2018 Status Report on the Implementation of Integrated Water Resources Management in Africa: A regional report for SDG indicator 6.5.1 on IWRM implementation.*

AQUASTAT. (2020). AQUASTAT - FAO's Information System on Water and Agriculture. *Food and Agriculture Organization of the United Nations (FAO).*

Arcanjo, M. (2020). *Water Security in the Horn of Africa : Climate Change in Somalia, Ethiopia, Eritrea, and Djibouti.*

African Union. (2015). The African Union Commission Agenda 2063. The Africa We Want. *African Union,* (April), 201. Retrieved from https://au.int/sites/default/files/documents/36204-doc-agenda2063_popular_version_en.pdf%0Ahttp://www.un.org/en/africa/osaa/pdf/au/agenda2063.pdf

Awulachew, S. B. (2011). Water-centered growth challenges, innovations, and interventions in Ethiopia. *International Water Management Institute Conference Papers,* (h044260 PG-). Retrieved from NS -

Bertelsmann Stiftung's Transformation Index. (2020a). BTI 2020 Country Report — Burundi. *BTI,* 1–39. https://doi.org/10.4135/9781483375519.n485

Bertelsmann Stiftung's Transformation Index. (2020b). BTI 2020 Country Report — North Macedonia. *Bertelsmann Stiftung,* 1–39. https://doi.org/10.4135/9781483375519.n485

Cheong, S. M., Choi, G. W., & Lee, H. S. (2016). Barriers and Solutions to Smart Water Grid Development. Environmental Management, 57(3), 509–515. https://doi.org/10.1007/s00267-015-0637-3

Chong, W. C., Mohammad, A. W., Mahmoudi, E., Chung, Y. T., Kamarudin, K. F., & Takriff, M. S. (2019). Nanohybrid membrane in algal-membrane photoreactor: Microalgae cultivation and wastewater polishing. *Chinese Journal of Chemical Engineering,* 27(11), 2799–2806. https://doi.org/10.1016/j.cjche.2019.05.015

Darvas, P., Favara, M., Arnold, T., Darvas, P., Favara, M., & Arnold, T. (2017). Country Context; Rwanda. *Stepping Up Skills in Urban Ghana: Snapshot of the STEP Skills Measurement Survey,* (November 2002), 1–6. https://doi.org/10.1596/978-1-4648-1012-1_ch1

Deutsche Welle. (2018). Contaminated drinking water in South Sudan – no solution in sight Africa. *Dw.* Retrieved from https://www.dw.com/en/contaminated-drinking-water-in-south-sudan-no-solution-in-sight/a-46278678

East African Community. (2007). Treaty for the Establishment of the East African Community.

Edokpayi, J. N., Odiyo, J. O., & Durowoju, O. S. (2017). Impact of Wastewater on Surface Water Quality in Developing Countries: A Case Study of South Africa. *Water Quality.* https://doi.org/10.5772/66561

European Union. (2020). Self-Sustaining Cleaning Technology for Safe Water Supply and Management in Rural African Areas - SafeWaterAfrica. https://doi.org/10.14332/svc19.proc.0005

EuropeAid. (2015). *Rural Infrastructure Strategy in South Sudan.*

Food and Agriculture Organization. (2005). *Irrigation in Africa in figures. Irrigation in Africa in figures.*

Food and Agriculture Organization. (2018a). *Africa Regional Overview of Food Security. Meat Science* (Vol. 95). https://doi.org/10.1016/j.meatsci.2013.04.036

Food and Agriculture Organization. (2018b). *More people, more food, worse water?*

Fresh Water. (2004). Freshwater Country Profile Mauritius.

Government of Mauritius. (2014). Mauritius National Water Policy, 26(2), 177–180.

Global System for Mobile Communications. (2017). Smart Parking: A Guide to Ensuring a Successful Mobile IoT Deployment. Gsma, 17. Retrieved from www.gsma.com/smartcities

Global System for Mobile Communications. (2020). *Digital Solutions for the Urban Poor.* Retrieved from https://www.gsma.com/mobilefordevelopment/resources/digital-solutions-for-the-urban-poor/

Guma, P. K., Monstadt, J., & Schramm, S. (2019). Hybrid constellations of water access in the digital age: The case of Jisomee Mita in Soweto-Kayole, Nairobi. *Water Alternatives,* 12(2), 636–654.

Global Water Partnership. (2009). IWRM Survey and Status Report: Madagascar. *Global Water Partnership,* (March), 1–19. Retrieved from https://www.gwp.org/globalassets/global/gwp-saf-files/madagascar-iwrm-report.pdf

Global Water Partnership. (2015a). *Integrated Water Resource Management in Eastern Africa: Coping with "complex" hydrology Sub-Saharan Challenge Programme View project.* https://doi.org/10.13140/RG.2.1.5054.2164

Global Water Partnership. (2015b). *Integrated Water Resources Management in Eastern Africa.*

International Association of Hydrogeologists. (2020). National Conference on Climate Resilient Water Supply and Water Resources Management in Eritrea - IAH - The International Association of Hydrogeologists.

IFP-EW. (2011). *Water, Crisis and Climate Change in Uganda. A Policy Brief.*

Intergovernmental Authority on Development. (2014). *IGAD Policy Brief: Reviewing the Region's Progress in Reaching the Goals of the Second Decade of Education for Africa.*

Intergovernmental Authority on Development. (2016). *IGAD Regional Strategy: Volume 1: The Framework* (Vol. 1).

Ingram, W., & Memon, F. A. (2020). Rural water collection patterns: Combining smart meter data with user experiences in Tanzania. *Water (Switzerland),* 12(4). https://doi.org/10.3390/W12041164

INTELLIGENT CIO. (2019). How technology can conserve and improve access to water - Intelligent CIO Africa. Retrieved from https://www.intelligentcio.com/africa/2019/03/21/how-technology-can-conserve-and-improve-access-to-water/

International Peace Support Training Centre. (2010). Role of Sub-Regional Organizations in Preventing Water-Related Conflicts in the Eastern African Region (April).

International Space Station. (2010). Climate Change and Natural Resources Conflicts in Africa. *Access,* 170, 1–261.

International Water Association. (2008). Compendium of Sanitation Systems and Technologies. *Development,* 158. Retrieved from http://www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_sesp/downloads_sesp/compendium_high.pdf

Jiménez, A., & Pérez-Foguet, A. (2010). Challenges for water governance in rural water supply: Lessons learned from Tanzania. *International Journal of Water Resources Development,* 26(2), 235–248. https://doi.org/10.1080/07900621003775763

Jimoh, T. A., & Cowan, A. K. (2017). Extracellular polymeric substance production in high rate algal oxidation ponds. *Water Science and Technology,* 76(10), 2647–2654. https://doi.org/10.2166/wst.2017.438

Kougias, I., Aggidis, G., Avellan, F., Deniz, S., Lundin, U., Moro, A., … Theodossiou, N. (2019). Analysis of emerging technologies in the hydropower sector. *Renewable and Sustainable Energy Reviews,* 113(July), 109257. https://doi.org/10.1016/j.rser.2019.109257

Loha, K. M., Lamoree, M., Weiss, J. M., & de Boer, J. (2018). Import, disposal, and health impacts of pesticides in the East Africa Rift(EAR) zone: A review on management and policy analysis. *Crop Protection,* 112(June), 322–331. https://doi.org/10.1016/j.cropro.2018.06.014

MacDonald, A. M., Taylor, R. G., & Bonsor, H. C. (2013). Groundwater in Africa: is there sufficient water to support the intensification of agriculture from "land grabs"? *Handbook of Land and Water Grabs Foreign Direct Investment and Food and Water Security,* (May 2012), 1–9.

Mapani, B., Makurira, H., Magole, L., Meck, M., Mkandawire, T., Mul, M., & Ngongondo, C. (2019). Integrated Water Resources Development and Management: Innovative Technological Advances for water security in Eastern and Southern Africa. *Physics and Chemistry of the Earth,* 112(August), 1–2. https://doi.org/10.1016/j.pce.2019.08.004

Mauritius Trade. (2020). Economic Outline of Mauritius - Mauritius Trade Easy - Expanding markets and Facilitating compliance. Retrieved from http://www.mauritiustrade.mu/en/trading-with-mauritius/mauritius-economics-outline

Ministry of Foreign Affairs. (2018). Climate Change Profile South Sudan, (April), 1–21.

MoLWE. (2019). Impact of Mega-projects on the Human Rights to Water and Sanitation.

Mourad, K. A. (2020). A water compact for sustainable water management. *Sustainability (Switzerland),* 12(18), 1–18. https://doi.org/10.3390/SU12187339

Mvulirwenande, S., & Wehn, U. (2019). Promoting Smart Water Systems in Developing Countries Through Innovation Partnerships : Evidence from VIA Water-Supported Projects in Africa Promoting Smart Water Systems in Developing Countries Through Innovation Partnerships : Evidence from VIA Water-Su, (December). https://doi.org/10.1007/698

Mwendera, E. (2010). 2010 Situation Analysis for Water and Wetlands Sector in Eastern and Southern Africa Draft Report.

Nair, R., & Landani, N. (2020). *WIDER Working Paper 2020 / 38 Making agricultural value chains more inclusive through technology and innovation Reena das Nair and Namhla Landani *.*

Nanni, M. (2016). Water challenges in the IGAD region: towards new legal frameworks for cooperation. *Water International,* 41(4), 635–651. https://doi.org/10.1080/02508060.2016.1169620

Ngaira, J. K. W. (2009). Challenges of water resource management and food production in a changing climate in Kenya. *Journal of Geography and Regional Planning,* 2(4), 97–103. Retrieved from http://www.academicjournals.org/JGRP

NIRAS. (2021). Water resources management and food security in South Sudan.

ODI. (2013). Achieving water security: lessons from research in water supply, sanitation and hygiene in Ethiopia. *Achieving Water Security: Lessons from Research in Water Supply, Sanitation and Hygiene in Ethiopia.* Retrieved from http://www.odi.org.uk/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8606.pdf

Ofori, A., Mdee, A., & Kongo, V. (2020). What are the most important future water research questions in East Africa?

Oguttu, H. W., Bugenyi, F. W. B., Leuenberger, H., Wolf, M., & Bachofen, R. (2008). Pollution menacing Lake Victoria: Quantification of point sources around Jinja Town, Uganda. *Water SA,* 34(1), 89–98. https://doi.org/10.4314/wsa.v34i1.180865

Olago, D. O. (2019). Constraints and solutions for groundwater development, supply, and governance in urban areas in Kenya. *Hydrogeology Journal,* 27(3), 1031–1050. https://doi.org/10.1007/s10040-018-1895-y

Omer, A. M. (2010). Water resources management and sustainable development in Sudan. *International Journal of Water Resources and Environmental Engineering,* 2(2), 190–207.

Park, J., Kim, K. T., & Lee, W. H. (2020). Recent advances in information and communications technology (ICT) and sensor technology for monitoring water quality. *Water (Switzerland),* 12(2). https://doi.org/10.3390/w12020510

Park, K. Y., Kweon, J., Chantrasakdakul, P., Lee, K., & Cha, H. Y. (2013). Anaerobic digestion of microalgal biomass with ultrasonic disintegration. *International Biodeterioration and Biodegradation,* 85, 598–602. https://doi.org/10.1016/j.ibiod.2013.03.035

Patients, S. and P. C. in S. C., Hassan, B. A. R., Yusoff, Z. B. M., Othman, M. A. H. and S. Bin, Chapter, A. information is available at the end of the, & Http://dx.doi.org/10.5772/55358. (2012). Smart Rainwater Management: New Technologies and Innovation. *Intech,* 13. https://doi.org/10.1016/j.colsurfa.2011.12.014

Pragst, F., Stieglitz, K., Runge, H., Runow, K. D., Quig, D., Osborne, R., … Ariki, J. (2017). High concentrations of lead and barium in the hair of the rural population caused by water pollution in the Thar Jath oilfields in South Sudan. *Forensic Science International*, 274, 99–106. https://doi.org/10.1016/j.forsciint.2016.12.022

Qadir, M., Drechsel, P., Jiménez Cisneros, B., Kim, Y., Pramanik, A., Mehta, P., & Olaniyan, O. (2020). Global and regional potential of wastewater as a water, nutrient, and energy source. *Natural Resources Forum,* 44(1), 40–51. https://doi.org/10.1111/1477-8947.12187

REACH. (2015). REACH Country Diagnostic Report: Ethiopia, 24. Retrieved from https://reachwater.org.uk/wp-content/uploads/2015/12/CDR-Ethiopia-WEB.pdf

The Republic of Uganda. (2016). Appropriate Water and Sanitation Technologies : Challenges of meeting Uganda's demands BMAU Briefing Paper (4 / 16), (April), 1–4.

Schoebitz, L., Bischoff, F., Lohri, C. R., Niwagaba, C. B., Siber, R., & Strande, L. (2017). GIS analysis and optimization of faecal sludge logistics at City-Wide Scale in Kampala, Uganda. *Sustainability (Switzerland),* 9(2), 1–16. https://doi.org/10.3390/su9020194

Sensus. (2012). Water 20/20: *Bringing Smart Water Networks Into Focus.* Retrieved from http://www.ghbook.ir/index.php?name=مجموعه مقالات دومین هم اندیشی سراسری رسانه تلویزیون و سکولاریسم&option=com_dbook&task=readonline&book_id=13629&page=108&chkhashk=03C706812F &Itemid=218&lang=fa&tmpl=component

Singapore International Water Week . (2016). A Global Blueprint for Innovation.

Solé-Bundó, M., Garfí, M., & Ferrer, I. (2020). Pretreatment and co-digestion of microalgae, sludge, and fat oil and grease (FOG) from microalgae-based wastewater treatment plants. *Bioresource Technology,* 298(December 2019), 122563. https://doi.org/10.1016/j.biortech.2019.122563

Tanja Maidorn, H. S., & UN-Water. (2011). *Capacity Development for Drinking Water Loss Reduction: Challenges and Experiences.*

The World Bank. (2011). Uganda Water Assistance Strategy. *Uganda Water Assistance Strategy.* https://doi.org/10.1596/27437

TWAHIRWA, A. (2017). Innovation to sustainable water management in Rwanda. *XVI World Water Congress, International Water Resources Association (IWA),* 1–5.

United Nations. (2019). Population | United Nations. *Un.* Retrieved from https://www.un.org/en/sections/issues-depth/population/%0Ahttps://www.un.org/en/sections/issues-depth/population/%0Ahttps://www.un.org/en/sections/issues-depth/population/%0Ahttps://www.un.org/en/sections/issues-depth/population/index.html

UN Water. (2020). *World Water Development Report - Water and Climate Change. Houille Blanche* (Vol. 2020-June). https://doi.org/10.1051/lhb/2020024

United Nations Conference on Trade and Development. (2011). Water for Food-Innovative Water Management Technologies for Food Security and Poverty Alleviation. File:///C:/Users/Kmede/Desktop/Doutorado/Adebayo2014.Pdf File:///C:/Users/Kmede/Desktop/Doutorado/Dias2018.Pdf, 39.

United Nations Conference on Trade and Development. (2018). East African Community Regional Integration: Trade and Gender Implications, 1–81. Retrieved from http://unctad.org/en/PublicationsLibrary/ditc2017d2_en.pdf

United Nations Conference on Trade and Development. (2020a). *Ethiopia; Science Technology and Innovation Policy Review. Housing Studies* (Vol. 18). https://doi.org/10.1080/02673030304250

United Nations Conference on Trade and Development. (2020b). Uganda; Science, *Technology & Innovation Policy Review. European Environment* (Vol. 7). https://doi.org/10.1002/(sici)1099-0976(199705)7:3<97::aid-eet112>3.0.co;2-b

United Nations Development Programme. (2010). Country Sector Assessments: UNDP GoAL WaSH Programme Djibouti, 1, 32.

United Nations Development Programme. (2016). Africa Human Development Report - Accelerating Gender Equality and, 1–192. Retrieved from http://hdr.undp.org/sites/default/files/afhdr_2016_lowres_en.pdf

United Nations Development Programme. (2019). Human Development Report 2019: Inequalities in Human Development in the 21st Century Jordan, 1–10. Retrieved from http://hdr.undp.org/en/data

United Nations Economic Commission for Africa. (2018). *Country Profile; South Sudan. Africa Yearbook* (Vol. 9). https://doi.org/10.1007/978-3-319-01384-8_672

United Nations Environment Programme, D. (2013). *TNA REPORT III TECHNOLOGY ACTION PLAN ADAPTATION (WATER, AGRICULTURE AND COASTAL ZONE)* (Vol. 1). Retrieved from http://dx.doi.org/10.1016/j.cirp.2016.06.001%0Ahttp://dx.doi.org/10.1016/j.powtec.2016.12.055%0Ahttps://doi.org/10.1016/j.ijfatigue.2019.02.006%0Ahttps://doi.org/10.1016/j.matlet.2019.04.024%0Ahttps://doi.org/10.1016/j.matlet.2019.127252%0Ahttp://dx.doi.o

UNESCO International Centre for Water Security and Sustainable Management. (2019). *Water Security and the Sustainable Development Goals. Unesco.*

United Nations Children's Fund. (2020). *Water, sanitation and hygiene - Burundi.*

United Nations. (2015). *TECHNOLOGY AND INNOVATION REPORT; Harnessing Frontier Technologies for Sustainable Development. Advances in Computer Vision and Pattern Recognition* (Vol. 54). https://doi.org/10.1007/978-1-4471-6699-3_9

Urama, K. C., & Ozor, N. (2010). IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES IN AFRICA : the Role of Adaptation. Network, (December), 1–29.

United States Agency for International Development. (2013). Madagascar Water and Sanitation Profile. *Water.*

United States Agency for International Development. (2017a). Ethiopia Development Trends Assessment, (March), 1–178. https://doi.org/AID-663-C-16-000010 – ISSAfrica-001

United States Agency for International Development. (2017b). Vulnerability, Impact and Adaptation Assessment in the East Africa Region. Chapter 9: Water, Aqautic Ecosystems, and Water Supply Infrastructure - Future Impacts from Climate Chnage., (November).

Wang, H., Wang, T., Zhang, B., Li, F., Toure, B., Omosa, I. B., … Pradhan, M. (2014). Water and Wastewater Treatment in Africa - Current Practices and Challenges. *Clean - Soil, Air, Water,* 42(8), 1029–1035. https://doi.org/10.1002/clen.201300208

Water.org. (2020). Kenya's water and sanitation crisis. Retrieved from https://water.org/our-impact/where-we-work/ghana/

Water for People. (2019). Finance Assessment of the Wash Sector in Rwanda, (April).

Water JPI. (2020). Water jpi strategic research and innovation agenda 2025, (April).

Water, K. (2018). *Case Study Report SMART WATER SMART WATER.*

World Bank Group. (2012). Uganda ' s Infrastructure A Continental Perspective. *Policy Research Working Paper 5963,* 1(8), 1–60.

White, D. D., Lawless, K. L., Vivoni, E. R., Mascaro, G., Pahle, R., Kumar, I., … Asfora, M. (2019). Co-Producing Interdisciplinary Knowledge and Action for Sustainable Water Governance: Lessons from the Development of a Water Resources Decision Support System in Pernambuco, Brazil. *Global Challenges*, 3(4), 1800012. https://doi.org/10.1002/gch2.201800012

World Meteorological Organization. (2017). Innovative and Community-based Sustainable Water Management. *World Meteorological Organization (WMO)*. Retrieved from https://public.wmo.int/en/resources/bulletin/innovative-and-community-based-sustainable-water-management

World Bank. (2010). Sudan's Infrastructure: A Continental Perspective. *Development*, (March).

World Bank. (2018). Assessment of Groundwater Challenges and Opportunities in Support of Sustainable Development in Sub-Saharan Africa. *Assessment of Groundwater Challenges and Opportunities in Support of Sustainable Development in Sub-Saharan Africa*. https://doi.org/10.1596/30266

World Bank. (2020a). Burundi: Overview. *31 /10/2017*. Retrieved from http://www.worldbank.org/en/country/burundi/overview%0Ahttps://www.wfp.org/countries/burundi/overview

World Bank. (2020b). Mauritius Overview. Retrieved from http://www.worldbank.org/en/country/mauritius/overview#1

World Bank. (2020c). Rwanda Overview. *The World Bank*. https://doi.org/http://www.worldbank.org/en/country/rwanda/overview

World Bank Group. (2015). *Innovation in scaling up access to water and sanitation services in Kenya Briefing note to support innovation in scaling up access of water and sanitation services to urban low-income areas*.

World Economic Forum. (2018). *Harnessing the Fourth Industrial Revolution for Water*. Retrieved from https://www.weforum.org/reports/harnessing-the-fourth-industrial-revolution-for-water

Water and Sanitation Programme. (2015). Leveraging Water Global Practice knowledge and lending : Improving services for the Nairobi water and sewerage utility to reach the urban poor in Kenya, (February), 1–8.

World Wide Fund. (2006). Climate Change Impacts on East Africa. *Climate Change*. Retrieved from https://www.wwf.or.jp/activities/lib/pdf_climate/environment/east_africa_climate_change_impacts_final.pdf

Younes Hamed, A. G. S. (2014). Water Resources of African Circum-Sahara Sub Region (Renewable and Non-renewable Approach). *Journal of Geology & Geosciences*, 03(06). https://doi.org/10.4172/2329-6755.1000181

Appendices

Appendix A: Threats to Water Security in the Eastern Africa Region

Description of the threat	Likelihood	Impact
UGANDA		
Water pollution from sediments, nutrients, organic pollutants, and toxic compounds contained in urban and agricultural storm runoffs	Critical	Critical
Deforestation leading to excessive sediment loads ending up in dams, and lakes.	Critical	Critical
Crop production i.e., change from forest to cropland and inappropriate production practices are responsible for land degradation and water pollution in places like Murchison Bay.	Occasional	Marginal
Animal husbandry where livestock grazing in wetlands or direct watering from streams leading to pollution of water bodies.	Occasional	Negligible
Wetlands degradation for example brick making activities leading to increased suspended solids in water bodies	Occasional	Marginal
Increased industrialization and increase in population leading to increased disposal of wastes into water streams	Critical	Critical
TANZANIA		
Expanding coastal populations and emerging industrial activities are exerting ever-increasing pressures on coastal water systems through increased pollution thus negatively affecting water quality	Critical	Critical
Water pollution from land-based activities such as agriculture, industry, and mineral exploitation.	Critical	Critical
Pollution from industries and other users of chemicals particularly on the island of Zanzibar.	Critical	Critical
Discharge of raw sewage into the freshwater body in places such as Tanga	Critical	Critical
SOUTH SUDAN		
Increasing concentration of people in urban areas and the use of an increasing number of chemical and toxic products.	Critical	Marginal
Direct discharge of wastes from hospitals and electricity power plants into water bodies and the environment.	Critical	Marginal
Oil spills causing contamination at exploration facilities and around pipelines; disruptions to the local hydrology; contamination because of disposal and release of produced water; pollution from human waste, solid waste from oil camps, and/or fuel and lubricants associated with mechanized equipment	Critical	Marginal
Discharge of raw sewage directly into water streams such as River Nile.	Critical	Marginal
Industrial discharge	Critical	Marginal
Dumping and discharging of agricultural wastes	Critical	Marginal

Description of the threat	Likelihood	Impact
SUDAN		
Disposal of industrial wastewaters into rivers and other water bodies.	Critical	Critical
Agricultural run-offs and increasing use of fertilizers, herbicides, insecticides, and pesticides in places such as Gazira, Manage, Rahad, and other agricultural schemes.	Occasional	Marginal
Discharge of domestic sewage effluent containing high concentrations of organic matter leading to lower dissolved oxygen, undesirable taste, and objectionable odour in water bodies.	Critical	Critical
Stormwater and surface runoff from urban areas.	Occasional	Marginal
Oil exploration and development; Oil development carries potential risks for local inhabitants and may cause severe damage to water resources.	Occasional	Marginal
SOMALIA		
Human population growth and expansion, and the intensification of land use. Consequently, large quantities of plastic waste, human sewage, and industrial and domestic waste, including fertilizers and pesticides, are being dumped on the beaches or gradually make their way to the sea.	Critical	Critical
Industrial waste, toxic waste, biohazardous and domestic waste, speedboats, oil spills, and oil pollution, and destructive fishing methods such as trawling.	Critical	Critical
KENYA		
Agricultural activities that produce sediments and agrochemical residues.	Occasional	Marginal
Industrial processing of agricultural and forestry products.	Critical	Critical
Untreated or inadequately treated municipal sewerage is a major source of ground and surface water pollution		
Lack of proper sanitation and sewerage system	Critical	Critical
Pollution and degradation of catchment areas	Occasional	Marginal
MAURITIUS		
Wastewater from industries discharged to receiving streams.	Critical	Critical
Disposal of sewage to water bodies.	Critical	Critical
Pollution of water bodies by wastewater from sugar mills.	Critical	Critical
Agricultural runoffs.	Occasional	Marginal
Marine transportation and pollution.	Occasional	Marginal
MADAGASCAR		
Sewage discharge and the contamination of groundwater by non-hygienic latrines	Critical	Critical
Agricultural runoff i.e., chemicals and pesticides used by the farmers which defile the land and seep then.	Occasional	Marginal
Soil erosion	Occasional	Marginal
Floods	Occasional	Marginal
Climate change	Occasional	Marginal
Massive deforestation	Critical	Marginal

Description of the threat	Likelihood	Impact
RWANDA		
Climate variability together with lack of proper rainfall harvest leads to sediments transport and consequently pollutes water bodies.	Occasional	Marginal
Lack of proper waste management	Critical	Critical
Agrochemicals	Occasional	Marginal
The steepness of Rwandan soil and land mismanagement	Occasional	Marginal
Climate change and population growth	Occasional	Marginal
Industrial waste	Critical	Critical
ETHIOPIA		
Industrial wastes generation leading to the contamination of rivers in Addis Ababa with heavy metals.	Critical	Critical
Municipal wastes solid waste is often piled on available open grounds, stream banks, and near bridges, where it is washed off into rivers.	Occasional	Marginal
Pollution by medical waste i.e., the clinical waste finds its way into the nearby streams that are tributaries.	Critical	Marginal
COMOROS		
Saltwater intrusion into coastal aquifers	Critical	Critical
Sedimentation of river water (increasing with greater soil erosion following deforestation and by reduced river recharge rates).	Occasional	Marginal
Pollutants (there is no waste management regime in effect in Comoros).	Critical	Critical
Climate change	Critical	Critical
ERITREA		
Unsanity waste system; about 85% of the country's population uses unimproved sanitation facilities (ranging from improper toilets to defecating in the open) leading to the contamination of groundwater by faecal matter.	Critical	Critical
Flood influxes of rushing water causing damage to sewage and water treatment plants, spreading faeces and harmful E. coli bacteria.	Occasional	Marginal
Climate change	Occasional	Marginal
Hygiene & the Contamination of Public Water Sources: Lack of basic access to clean water has forced citizens to use public water sources like rivers and streams directly leading to the contamination of the water sources.	Critical	Critical
Agricultural activities involving extensive irrigation lead to rising of the water-table and salinization by the irrigation water. Also, irrigation tail-waters transport large concentrations of nutrients and pesticides to the receiving waters.	Occasional	Marginal
DJIBOUTI		
Disruption of the local hydro-geological system resulting from the sinking and operation of boreholes.	Occasional	Marginal
Inadequate water storage facilities causing water contamination	Critical	Critical
Degradation of hygienic conditions due to an increased amount of wastewater	Critical	Critical
Dwindling groundwater; the major source of water.	Critical	Critical

Description of the threat	Likelihood	Impact
BURUNDI		
Pollution of water bodies by raw industrial (agrochemicals) and municipal sewage.	Critical	Critical
Overfishing and use of destructive gears.	Critical	Marginal
Rapid population growth and poverty contribute to environmental damage and habitat destruction in the Lake basin.	Critical	Critical
Eutrophication caused by an excessive supply of nutrients in an aquatic environment leading to plants proliferation (Algae), oxygen depletion, and general degradation of water quality	Occasional	Marginal
SEYCHELLES		
Solid wastes	Critical	Critical
Oil spills	Critical	Marginal
Chemicals leading to contamination of wetlands and groundwater.	Occasional	Marginal
Microbiological	Occasional	Marginal

Appendix B: Smart Technologies for Water Resource Management in the Eastern Africa Region

Name of the Technology	Primary use of the technology 1- Domestic 2- Industrial	Country	Adoption rate of the technology	SDG Target Responding To							
			1: <30% 2: 30-60% 3: >60%	6.1	6.2	6.3	6.4	6.5	6.6	6.A	6.B
Pay your relatives' water bills	1 and 2	Rwanda	1	Y		Y					
CityTaps	1 and 2	Rwanda	1	Y		Y	Y				
FLOW	1 and 2	Rwanda	1	Y	Y	Y	Y			Y	
Storm forecasts for Musanze	1 and 2	Rwanda									Y
Smart water metering	1 and 2	Rwanda	2	Y		Y	Y				
Flood and Drought Monitoring Tools	2	Tanzania	2					Y	Y		
Maji Matone	1	Tanzania	1	Y		Y		Y		Y	
Wonderkid	1 and 2	Kenya	1	Y		Y					
Maji Voice	1	Kenya	1	Y		Y				Y	
Large-scale piloting of public prepaid meters	1 and 2	Kenya	2	Y	Y	Y	Y				
Smart tap	1	Kenya	1	Y	Y	Y	Y				
Prepaid meters	1 and 2	Kenya	2	Y	Y						
Jisomee Mita (Read your Meter)	1 and 2	Kenya	1	Y	Y						Y
Water ATM	1	Kenya	2	Y	Y	Y	Y				
HydroIQ	1 and 2	Kenya	1	Y	Y	Y	Y				
Climate Smart Water ATM	1	Ethiopia	1	Y	Y	Y	Y				
dSpirit	1 and 2	Ethiopia	1	Y	Y	Y	Y				
Loowat	1	Madagascar	1		Y				Y		
Setting up District Metered Areas	1 and 2	Madagascar	2	Y	Y	Y	Y				
KCCA: Using GIS technology to optimise pit emptying	2	Uganda	2		Y				Y		
Prepaid water ATMs	1	Uganda	1	Y		Y	Y				

Name of the Technology	Primary use of the technology 1- Domestic 2- Industrial	Country	Adoption rate of the technology	SDG Target Responding To							
			1: <30% 2: 30-60% 3: >60%	6.1	6.2	6.3	6.4	6.5	6.6	6.A	6.B
Integrating smart technology with traditional borehole handpumps	1	Uganda	1	Y		Y	Y				
E-Water Billing	1 and 2	Uganda	3	Y		Y	Y				
M4W (Mobile for Water)	1 and 2	Uganda	1					Y	Y		
Itron software for service analytics, meter data management software and water metering automation solutions.	1 and 2	Burundi	1	Y		Y	Y				
Water ATM	1 and 2	Somalia	1	Y		Y					
Real-time water related information by using smart Information and Communication a Technology (ICT)	1 and 2	Sudan	1				Y				Y
Nitrogen-15 isotopic technique and soil moisture neutron probe technique	1	Sudan	1				Y	Y			Y
Drip Irrigation	1 and 2	Seychelles	1				Y				
Drip Irrigation	1 and 2	Comoros	1				Y				

Appendix C: Policies for Water Resource Management in the Eastern Africa Region

Full name of the policy	Category A. Policy B. Program C. Strategic Plan D. Legislative instrument E. Development agenda/ plan F. Other	Year of issue	Thematic water areas A. supply B. quality C. access D. treatment E. Wastewater treatment F. irrigation G. Water resources management
BURUNDI			
PNA Implementation Action Plan	E	2018	A,B,C,D,E,F,G
The National Sanitation Policy	A	2013	A,B,C,D,E,F,G
The Water Code	A	1992	A,B,C,D,E,F,G
Water Sector Policy	A	2005	A,B,C,D,E,F,G
The Environment Code	A	2000	A,E,G
COMOROS			
Water Act	A	1994	A,B,C,D,E,F,G
National Environmental Policy	C	1993	A,B,C,D,E,F,G
National Poverty Reduction Strategy Paper	A	2011	A,B,C,D,E,F,G
The Organic Law	A	2005	A,B.G
DJIBOUTI			
The Environment Code	A	1996	B, G
Integrated Water Resources Management Policy	A	2009	A,B,C,G
The Water Code	A	1996	A,B,C,D,E,F,G
ERITREA			
Interim Poverty Reduction Strategy	C	2004	A,B,C,D,E,F,G
Eritrean Water Resources Policy	A	2007	A,B,C,G
Action Plan for Integrated Water Resource Management (IWRM)	E	2009	A.C.G
Water Policy	A	2010	A,B,C,D,E,F,G
ETHIOPIA			
Ethiopian Water Sector Strategy	C	2001	A,B,C,D,E,F,G
Ethiopian Water Resources Management Policy	A	2004	A,B,C,D,E,F,G
National Water Sector Strategy and Water Sector Development Program	B	2004	A,B,C,D,G
Water Resources Management Proclamation and Regulation	A	2000	A,B,C,D,G
Water Resource Management Policy	A	1999	A,B,C,D,G

Full name of the policy	Category A. Policy B. Program C. Strategic Plan D. Legislative instrument E. Development agenda/ plan F. Other	Year of issue	Thematic water areas A. supply B. quality C. access D. treatment E. Wastewater treatment F. irrigation G. Water resources management
KENYA			
The National Water Master Plan 2030	A	2014	A,B,C,D,E,F,G
Water Act 2016	A	2016	A,B,C,D,E,F,G
Water Act 2002	A	2002	A,B,C,D,E,F,G
National Water Services Strategy	A	2007	A,B,C,D,E,F,G
Water Rules	A	2012	A,B,C,D,E,F,G
MADAGASCAR			
Water Law	A	1995	A,B,C,D,E,F,G
The National Program for Safe Water Supply and Sanitation (PNAEPA)	B	2005	A,B,C,D,E,F,G
The National Sanitation Policy and Strategy	C	2017	A,B,C,D,E,F,G
MAURITIUS			
The Ground Water Act	A	1973	A,B,C,D,E,F,G
The Ground Water Act Regulations	A	2011	A,B,C,D,E,F,G
Central Water Authority (Amendment) Act of 2005	A	2005	A,B,C,D,E,F,G
Rivers and Canal Act	A	1863	A,B,C,D,E,F,G
Ground Water Act	A	1969	A,B,C,D,E,F,G
Central Water Authority Act	A	1971	A,B,C,D,E,F,G
RWANDA			
National Sanitation Policy Implementation Strategy	C	2016	A,B,C,D,E,F,G
National Sanitation Policy	A	2016	A,B,C,D,E,F,G
Rwanda National Water Resources Master Plan	E	2015	A,B,C,D,E,F,G
Rwanda National Water Resources Law	A	2008	A,B,C,D,E,F,G
National Policy for Water Resources management	A	2011	A,B,C,D,E,F,G
SEYCHELLES			
Public Utilities Corporation Act	A	2017	A,B,C,D,E,F,G
Water Regulations	A	2012	A,B,C,D,E,F,G
National Water Policy and National Integrated Water Resource Management (IWRM) Plan	E	1999	A,B,C,D,E,F,G

Full name of the policy	Category A. Policy B. Program C. Strategic Plan D. Legislative instrument E. Development agenda/ plan F. Other	Year of issue	Thematic water areas A. supply B. quality C. access D. treatment E. Wastewater treatment F. irrigation G. Water resources management
SOMALIA			
National Development Plan 2017-2019.	E	2017	A,B,C,D,E,F,G
Water, Sanitation and Hygiene Policy	A	2019	A,B,C,D,E,F,G
SOUTH SUDAN			
Southern Sudan Water Policy	A	2007	A,B,C,D,E,F,G
Water, Sanitation & Hygiene (WASH) Sector Strategic Framework	C	2011	A,B,C,D,E,F,G
South Sudan: An Infrastructure Action Plan	E	2012	A,B,C,D,E,F,G
Draft Water, Sanitation and Hygiene (WASH) Program 2013-2018	B	2013	A,B,C,D,E,F,G
SUDAN			
Sudan national water policy	A	2010	A,B,C,D,E,F,G
The Water Resources Act	A	1995	A,B,C,D,E,F,G
Water Policy Development	A	1999	A,B,C,D,E,F,G
TANZANIA			
National Water Policy	A	2000	A,B,C,D,E,F,G
National Water Sector Development Strategy	C	2006	A,B,C,D,E,F,G
The Water Supply and Sanitation Act, 2019	A	2019	A,B,C,D,E,F,G
The Water Resources Management Act	A	2009	A,B,C,D,E,F,G
UGANDA			
Final Communication Strategy	C	2019	A,B,C,D,E,F,G
The Uganda National Climate Change Communication Strategy	C	2017	A,B,C,D,E,F,G
The National Climate Change Policy	A	2016	A,B,C,D,E,F,G
Mwe Internal Control Framework	A	2007	A,B,C,D,E,F,G
Clients Charter 2018-2022	A	2018	A,B,C,D,E,F,G
Environment Impact Assessment Regulation	A	1998	A,B,C,D,E,F,G
National Environment Act	A	1995	A,B,C,D,E,F,G

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