VULNERABILITY, IMPACTS AND ADAPTATION ASSESSMENT IN THE EAST AFRICA REGION

CHAPTER 3:
WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE BASELINE FOR EAST AFRICA

OCTOBER 2017

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CONTENTS

ACRONYMS 4

PREFACE 5

EXECUTIVE SUMMARY 7

STATUS OF WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE IN EASE AFRICA 7
HISTORICAL SECTOR TRENDS 11
ASSESSING VULNERABILITY IN THE LAKE VICTORIA BASIN 12
SECTOR POLICY, LEGAL AND INSTITUTIONAL FRAMEWORK, AND PREPAREDNESS FOR CLIMATE CHANGE 12

1. STATUS OF WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE IN EAST AFRICA 14

1.1 WATER AVAILABILITY 14
1.1.1 Global 14
1.1.2 Africa 16
1.1.3 Africa Water Vision 20
1.2 FRESHWATER AVAILABILITY 21
1.2.1 Surface Water 21
1.2.2 Groundwater 22
1.3 ACCESS TO WATER RESOURCES 22
1.3.1 Global 22
1.3.2 East Africa 23
1.4 AQUATIC ECOSYSTEMS 24
1.4.1 Global 24
1.4.2 Africa 25
1.4.3 East Africa 25
1.5 LAKE VICTORIA BASIN 26
1.5.1 Extent and Hydrography 26
1.6 CLIMATE 27
1.6.1 Drainage System of LVB 28
1.6.2 Water Balance Model of Lake Victoria 30
1.6.3 Aquatic Ecosystems 31

2. SECTOR TRENDS FOR THE WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE SECTOR IN EAST AFRICA 32

2.1 TRENDS IN WATER AVAILABILITY, ACCESS, AND QUALITY 32
2.1.1 Availability 32
2.1.2 Access 33
2.2 WATER QUALITY 36
2.3 AQUATIC ECOSYSTEMS 38
2.3.1 Fisheries and Aquaculture 39

3. ASSESSING AND MAPPING CURRENT VULNERABILITY AND HOTSPOTS IN THE LVB FOR WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE SECTOR 43

3.1 MAPPING VULNERABILITY HOTSPOTS FOR THE WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE SECTOR 43
3.1.1 Identification and Selection of Indicators 44
3.1.2 Data Processing 45
3.1.3 Exposure 46
3.1.4 LVB Sensitivity Layers 48
3.1.5 LVB Adaptive Capacity Layers 49
3.1.6 Overall Vulnerability 50

4 SECTOR POLICY, LEGAL, AND INSTITUTIONAL PREPAREDNESS FOR CLIMATE CHANGE IN WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE **55**

4.1 POLICIES, INSTITUTIONS, AND PRINCIPLES GOVERNING WATER RESOURCES 55
4.1.1 EAC Overall Policy Framework 55
4.2 EAC POLICY PUSH FOR WATER RESOURCES MANAGEMENT 55
4.2.1 The East African Community: Extent and Strategic Visions 55
4.2.2 Harmonization of Water Policies by EAC Partner States 56
4.2.2 Policy and Institutional Framework at the National Level 57
4.3 LAKE VICTORIA BASIN POLICY AND INSTITUTIONAL FRAMEWORK 60
4.3.1 Lake Victoria Basin Commission 60
4.3.2 Lake Victoria Fisheries Organization 61
4.3.3 Key Principles of Shared Waters in Lake Victoria Basin 61
4.4 KEY WATER SECTOR STAKEHOLDERS, CAPACITIES, AND INITIATIVES 62
4.4.1 Water Sector Stakeholders 62

5. ONGOING PROGRAMS AND INITIATIVES **65**

5.1 GAPS IN INSTITUTIONAL CAPACITIES FOR ADAPTATION 65
5.2 EXAMPLES OF CURRENT EFFORTS TO SUPPORT ADAPTATION TO CLIMATE CHANGE 66

5. CONCLUSION **69**

REFERENCES **71**

ACRONYMS

AfDB	African Development Bank
AMCOW	African Ministers' Council on Water
CBD	Convention on Biological Diversity
CHG	Climate Hazards Group
COMESA	Common Market for Eastern and Southern Africa
EAC	East African Community
EACCCP	East African Community Climate Change Policy
EAGLON	East African Great Lakes Observatory Network
EWS	Early warning system
FAO	Food and Agriculture Organization
GDP	Gross domestic product
ICPAC	IGAD Climate Prediction and Applications Centre
IGAD	Intergovernmental Authority on Development
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
LVB	Lake Victoria Basin
LVBC	Lake Victoria Basin Commission
LVEMP	Lake Victoria Environmental Management Project
LVFO	Lake Victoria Fisheries Organization
MDG	Millennium Development Goals
MWEM	Ministry of Water, Energy and Mines
NAPA	National Adaptation Programs of Action
NBI	National Business Initiative
NDP	National Development Plan
NGO	Nongovernmental organization
NEPAD	New Partnership for Africa's Development
PREPARED	Planning for Resilience in East Africa through Policy, Adaptation, Research, and Economic Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
VIA	Vulnerability, Impacts and Adaptation Assessment

PREFACE

Background

Planning for Resilience in East Africa through Policy, Adaptation, Research, and Economic Development (PREPARED) is a medium-term (five-year), multi-organization, comprehensive program aimed at mainstreaming integrated, multisectoral, evidence-based, climate-resilient development planning and program implementation into the development agendas of the East African Community (EAC) and its Partner States.

The PREPARED Project is part of the program and is also a five-year initiative of USAID/East Africa. The project has five components: climate change adaptation; biodiversity conservation; water supply, sanitation, and hygiene; and two components pertaining to program coordination of cross-cutting elements and project management.

As part of the climate change adaptation component, PREPARED aims to assist EAC member states to undertake a Vulnerability, Impacts and Adaptation Assessment (VIA). The VIA aims to identify key climate change risks and vulnerabilities within the Lake Victoria Basin (LVB) and facilitate the development of a LVB Commission Climate Change Adaptation Strategy and Action Plan.

Following Intergovernmental Panel on Climate Change (IPCC) guidelines and protocols, five key thematic sectors that are crucial to EAC's sustainable development, were identified for analysis in the VIA. These were considered and confirmed with the Climate Change Technical Working Group. The five thematic sectors are as follows:

1. Agriculture and food security
2. Water, aquatic ecosystems, and water supply infrastructure
3. Health, sanitation, and human settlements
4. Terrestrial ecosystems, including forestry, wildlife, and tourism
5. Energy and transport infrastructure.

This report covers the water, aquatic ecosystems, and water supply infrastructure component of the VIA.

Introduction to the report

Water security is a priority for the livelihoods and economic development of rural and urban communities in EAC Partner States. Water demand for domestic and commercial or industrial uses or for energy already far outstrips available supply, so the impacts of climate change will further complicate the challenge of balancing demand and supply. Regarding aquatic ecosystems, biodiversity loss and habitat loss due to climate change will lead to species loss, range shifts, and constrained migration.

The main aim of this study is to:

1. Improve understanding of the impacts of climate change on the availability, accessibility, and quality of water resources and their effects on local communities in selected hotspots in the LVB to support evidence-based adaptation policy and planning.
2. Enhance understanding of the impacts of climate change and variability on selected aquatic ecosystems in the LVB region and hotspots to inform evidence-based policy and adaptation planning.

Specific objectives include:

1. To compile baseline information and data on the current situation regarding water, aquatic ecosystems, and water supply infrastructure.
2. To review historical trends and define indicators and thresholds, assess current vulnerability, and map hotspots in the LVB.
3. To collect and compile baseline information that addresses the impacts of climate change on the subsectors.
4. To examine and assess the impacts of extreme events on the subsectors.
5. To review the relevant regional and national institutional frameworks, policies, strategies, and plans.
6. To review regional and national capacity—including organizations, legislation, policies, and regulations—and assess the institutional capacities for dealing with climate change adaptation.

The report explains the status of water, aquatic ecosystems, and water supply infrastructure in the EAC Partner States; sector trends with some selected case studies; potential impacts of climate variability and climate change on the sector; assessment of sector vulnerability, mapping of hotspots, and sector policy, legislative, and institutional preparedness for climate change. While the baseline report focuses on the five East African states, the vulnerability assessments and hotspot mapping focuses on the LVB.

Chapter one of the report provides a detailed analysis of the sector; chapter two focuses on historical trends in the sector. Chapter 3 is on the assessment and mapping of sector vulnerability to climate change while chapter 4 outlines the sector policy, legal, and institutional preparedness for climate change. Chapter 5 presents the conclusions for the baseline report and offers recommendations.

EXECUTIVE SUMMARY

STATUS OF WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE IN EASE AFRICA

Water is an essential resource for sustaining life and economic development. Renewable fresh water is needed for drinking, crop production, livestock, and commerce, as well as for industry, hydropower generation, tourism, transportation, recreation, and waste disposal. These activities are central to human livelihoods and well-being as they provide employment and contribute significantly to national economies. Water is not only an economic good but also a social good. Safe water supply and appropriate sanitation are the most essential components for a healthy and prosperous life.

In many regions of the world, the amount and quality of water available to meet human needs are already limited. Available global water resources are under pressure due to demographic, land use and climatic changes, and increasing demands from economic sectors, all helping to drive more regions into water stress and insecurity. Only 3 percent of global water is freshwater; of the available freshwater, 87 percent is not accessible as it is locked in ice caps. Of the 13 percent of accessible freshwater, only 0.4 percent is surface flows in rivers and lakes, the rest is groundwater.

Groundwater is a significant source of water for human consumption, supplying nearly half of all drinking water in the world and around 43 percent of all water consumed in irrigation. Global groundwater abstraction has grown from about 100 cubic kilometers per year in 1950 to over 1,000 cubic kilometers per year, largely for use in agriculture.

Depending on recharge, groundwater is both a renewable and non-renewable resource. Many aquifers, in semi-arid and arid regions, are overexploited because abstractions exceed recharge rates, causing environmental problems, increasing pumping costs, and the loss of the resource for future generations. Non-renewable resources are locked in deep aquifers with insignificantly small, if any, current recharge, and are being mined when abstracted, raising concerns for future sustainability.

The resilience of groundwater resources to long-term shifts in climate is governed by the available groundwater storage and aquifer permeability. Larger groundwater bodies will respond very slowly to long-term changes in recharge. Smaller groundwater bodies with little storage are not resilient to long-term changes in climate, but they recover quickly from drought when recharged. Thus, groundwater could help to adapt to climate change and population growth in Africa. However, groundwater quality needs to be managed to ensure water security; groundwater faces both anthropogenic and geogenic contamination threats. For example, most wastewater (domestic and industrial) is not treated, so that pathogens, nutrients, heavy metals, and organic micro-pollutants enter the water cycle. In some coastal areas, over-pumping has led to saltwater intrusion. In other areas, the rocks are rich in inorganic elements that can be harmful to health, including fluoride in the East African Rift Valley, and arsenic, iron, and manganese in various other parts of Africa.

Water Availability

East Africa is endowed with freshwater resources, including several major towers such as Mounts Kenya, Kilimanjaro, and Elgon, as well as the Ruwenzori range. Surface water resources include rivers and lakes, one of which is Lake Victoria, the largest shared water resource in the region. On average, the region has a total renewable volume of 187 cubic kilometers per year with Uganda holding the largest share, 39 cubic kilometers per year. Other water resources include groundwater, riverine flows, and lacustrine swamps. These resources support most of the productive sectors in the EAC, including agriculture (both irrigated and rain-fed), livestock, wildlife, fisheries, and rich biodiversity.

East Africa is experiencing increased pressure on available water resources. Due to a rapidly growing population, the available water resources will reduce as demand steadily increases resulting in declining per capita water availability. It is obvious from the statistics that Kenya is in a precarious situation, having about 681 cubic meters of water per capita per year, which compares poorly with the globally recommended 1,000 cubic meters per capita per year. Moreover, due to increasing population, the per capita water availability is projected to decline to 235 cubic meters by 2025, meaning the country will be severely water stressed in a decade's time. Rwanda and Burundi face similarly severe water scarcity now and in the future.

Groundwater is an important source of water, particularly in arid and semi-arid area areas of East Africa. Its occurrence depends on geology, geomorphology, and effective rainfall (both current and historic). Thus, groundwater storage is highly variable in East Africa. Estimates show that Burundi and Rwanda have the lowest groundwater storage estimated at 47 and 49 cubic kilometers respectively, while Uganda has 339 cubic kilometers, Tanzania has 5,250 cubic kilometers, and Kenya has 55.973 cubic kilometers. However, these groundwater resources are poorly developed and their full potential remains unmapped and unknown.

Evaporation is also a key element of the water balance of Lake Victoria and changes in the rate of evaporation are critical for performance of the water sector. Changes in temperature affect evaporation and evapotranspiration rates and affect water availability. Yin and Nicholson (1998) developed a simple water balance for Lake Victoria expressing the balance between its inputs and outputs. This model is:

$$\boldsymbol{\Delta H = P_w + \text{Inflow} - (E_w + \text{Outflow}),}$$

where, ΔH is a change in lake level, while the inputs to the lake are the lake rainfall (P_w) and inflow from the 17 tributaries, and the outputs are the lake evaporation (E_w) and outflow via the White Nile at Jinja. The results from the water balance assessments indicate that Lake Victoria has a net water storage averaging at 33 m^3/s.

Water availability, quantity, and quality in the LVB faces challenges associated with increasing population and intensified socioeconomic activities. These include over-abstraction of water for irrigation and urban uses, as well as human encroachment on the catchment areas through settlement, cultivation, over-grazing, and bush fires.

Water Access

Access to water influences economic development and social welfare of communities. Although access to safe drinking water has markedly improved in East Africa in recent years, a considerable proportion of the population still lacks such access. Though the level of access varies among the five Partner States, none has achieved the drinking water target of 100 percent access. Basic access to drinking water is currently 20 liters per capita per day for rural areas and 50 liters per capita per day for people living in urban areas with flushing toilets. Clean water availability is not keeping pace with population growth, thus hampering progress toward the achievement of the 2015 Millennium Development Goals (MDGs), and the post-2015 Sustainable Development Goals. Further, in all the Partner States, less than 75 percent of the population in rural areas has access to safe drinking water.

Each EAC Partner State faces an enormous water supply and infrastructure challenge. Most of the urban poor and the rural population rely on springs and boreholes, which are not fully developed, are easily contaminated, and in some cases over-abstracted. Water distribution is also not equal as some places have high volumes of water while others face drought and low levels of water. Supply and access to safe water is poor in most EAC countries. Uganda, due to recent reforms, has almost met its 2015 MDG targets, though there are discrepancies in access between rural and urban areas. The rapidly growing populations in the EAC Partner States and migrations to urban areas have resulted in the need to establish centralized water systems to supply potable water to residents. Further, climate change, affluence, and population growth have resulted in increasing demand of water for domestic, industrial, and agricultural use.

Water Quality

Sediment yield from degraded catchments within the basins have affected water quality in terms of suspended solids, turbidity, and nutrient concentrations. High nutrient loads have been attributed to agricultural runoff, which accounts for as much as 75 percent of the nitrogen flow into Lake Victoria. About 6,511,950 tons of total suspended solids per year are entering the lake from the catchment drainage. Sediment loading from degraded catchments is an important source of nutrient and sediment loads, which are transported by rivers and streams into gulfs, bays, and some near-shore areas within the LVB. High concentrations are recorded in the north and southern sections of the lake.

Considerable changes in the physical, chemical, and biological properties of water sources within the LVB have been observed over 50 years. The changes are particularly due to increasing and considerable pressure from a variety of interlinked human activities in the catchment. These include industrial and municipal activities within urban centers, wetlands degradation, and deforestation. The major urban centers of Kampala, Entebbe, Masaka, and Jinja in Uganda; Mwanza and Musoma in Tanzania; Kisumu in Kenya; and Kigali in Rwanda are hotspots for point and nonpoint sources of pollution within the LVB. Pollutants from the urban centers originate from manufacturing industries, inefficient wastewater treatment facilities, and dumping of solid wastes.

Among the most significant impacts from pollution is the increase in nutrient input in the form of nitrogen and phosphorus, which causes widespread eutrophication and proliferation of algal blooms. Compared to historical data, phosphorus concentrations in Lake Victoria have increased 4–8 times; from a range of 0.02–0.047 milligrams per liter to 0.078–0.140 milligrams per liter. In some sections of the lake, such as inner Murchison Bay, the concentrations are 4 milligrams per liter. Relatively high levels of total phosphorus of greater than 1 milligram per liter were also observed within the Mara River Basin. Similarly, nitrogen concentrations show an increasing trend with levels greater than 1 milligram per liter in open waters within the Mara River Basin and inner Murchison Bay. Algal blooms affect the dissolved oxygen content of the water leading to anoxic conditions with reported declining levels of oxygen spreading across large parts of Lake Victoria. Within inner Murchison Bay, dissolved oxygen levels of 0–2 milligrams per liter have been reported for a larger portion of the year. In recent years many of the bays around the shore have been invaded by water hyacinth (*Eichhornia crassipes*); the influence of this plant on the lake water balance will depend on its extent.

Aquatic Ecosystems

East African aquatic ecosystems are internationally recognized for their high levels of species richness and endemism. The region's freshwater fisheries include numerous endemic cichlid species resulting from adaptive radiation, many of which have not been described. This rich biodiversity supports a large commercial and artisanal fisheries sector that provides income and food security to a large portion of the poorer communities. Additionally, freshwater ecosystems provide immense benefits to local, national, and regional economies and provide the basis for indigenous medical practices, food, energy, shelter, crafts, and various raw materials.

Wetlands provide water and primary productivity upon which countless species of plants and animals depend for their survival. These areas support high concentration of birds, mammals, reptiles, amphibians, fish, and invertebrates. People depend on wetlands mainly for grazing their animals, food, water, medicine, and papyrus for roofing and making mats. Lake Victoria, for instance, provides proteins for approximately 8 million people, and supports over 100,000 fishermen. It also supports commercial freshwater fishing with estimated annual fish yields of about 500,000 tons, which contributes significantly to both local consumption and export earnings in the region. All five East African countries in the LVB have significant areas under wetlands. In Kenya, key wetlands include the Yala Swamp (17,500 hectares), which includes Lake Kanyaboli (1,050 hectares), Lake Sare (500 hectares), Lake Namboyo (1 hectares), the Nyando Swamp (15 by 6 kilometers); the Sondu-Miriu wetland (10,000 hectares); the Saiwa Swamp (20 kilometers long); and the Kimandi River wetland (4,800 hectares). Burundi, Rwanda, Tanzania, and Uganda have an extensive wetlands network.

The aquatic ecosystems of the LVB are fragile. A wide range of socioeconomic activities constrain the management and development of these ecosystems. Increasing stresses have raised conservation concerns, among them increased pressure on resources, losses of habitats and biodiversity, increased water pollution, and degradation of the environment. Competing land use and land and ecosystem degradation has been identified as an important factor in the persistence of biodiversity, ecosystems, and ecosystem services. The aquatic ecosystems in Burundi and Rwanda are mainly threatened by degradation of the riverbanks while those in Kenya, Tanzania, and Uganda face additional threats from pollution, sedimentation, habitat loss, eutrophication, and water hyacinth growth. These challenges have had serious effects in all five countries, leading to loss of critical habitats and to negative impacts on biodiversity.

Biodiversity in Lake Victoria faces major threats. Deforestation and discharge of agro-chemicals, waste, and refuse to water bodies pollutes the water and results in decrease in fish biodiversity and altered food webs. Water hyacinth is believed to be a major reason for the alteration of many communities of aquatic and terrestrial species associated with the lake. These changes are also strongly affecting the harvesting of aquatic resources. Coupled with inputs of nitrogen and phosphorus from atmospheric deposition and nutrient inputs from land, tributary watersheds give rise to excessive nutrients in the water, which is detrimental to aquatic life.

The LVB has over 500 endemic fish species. Three main species support the commercial fishery: Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*), and dagaa, also known as omena (*Rastineobola argentea*). Both Nile perch and Nile tilapia were introduced into the LVB in the late1950s to 1960s and have flourished, though with significant ecological effects and impacts on other species. Apart from diverse species of fish, LVB hosts various bird species, some of which are endemic to certain wetlands. The common species include a variety of gulls, terns, papyrus yellow warbler (*Chloropeta gracilirostris*), white-winged warbler (*Bradypterus carpalis*), and papyrus gonolek (*Laniarus mufumbiri*).

The Lake Victoria fishery is estimated to produce 1 million tons of fish per year. Of this, about 67 percent is from the Tanzanian part of lake, 19 percent from Uganda, and 15 percent from Kenya based on the three commercial species. This is a change from a diverse multispecies fishery of the 1980s. The fishery provides food security to a large segment of the population throughout the region but specifically supports over 3 million livelihoods. The fishery also contributes to national GDP: 2 percent for Kenya, and 3 percent for Tanzania and Uganda. The state of fisheries is of a major concern to the riparian states and there has been a general view that fish catches are declining and that the fishery may be in danger of collapse.

Historical Sector Trends

Historical climate variability has affected the hydrological cycle as well as the quality of water resources and water availability, but these changes are not uniform across the Partner States. A summary for each country is provided below.

- In **Burundi,** analyses of climatic data for 30 years (1974–2006) show inter-annual and inter-decadal variability in temporal and spatial rainfall distribution; irregularities in early and late rainy seasons; increased frequency of extreme climatic events; and more frequent dry episodes, particularly in the Bugesera region.

- In **Kenya**, climate data trend analyses have shown a temperature increase since 1960 and a decline in long rainy seasons and increase in short rainy seasons. Long rains in central Kenya have declined more than 100 millimeters since the mid-1970s. A warming of more than 1°C may exacerbate drying impacts, especially in lowland areas. The drying trends could particularly affect densely populated areas to the east, north, and northwest of Nairobi.

- In **Rwanda,** comparison of 1971–1990 and 1991–2009 periods indicates that the monthly average number of rain days decreased for most months, including April and November, which are normal have the highest rainfall in the year. The annual number of rainfall days decreased from 148 days in 1971 to 124 days in 2009. Annual average rainfall totals decreased from 1,020 millimeters to 920 millimeters. The trend analyses of the average annual temperatures from the Kigali Airport Station (1971–2007) and Kamembe station showed an increase of 1.2°C in 39 years.

- In **Tanzania**, minimum and maximum temperatures have increased over a period of 30 years especially for January, July, and December. Further, between 1922 and 2007, minimum and maximum temperatures in central Tanzania increased by 1.9°C and 0.2°C, respectively. A study of records of total annual rainfall for 21 meteorological stations in selected regions found a decreasing trend for over 62 percent while 33 percent of the stations recorded rainfall increases.

- In **Uganda**, analysis of data on temperature variability shows sustained warming, especially over the southern parts of the country. Mean daily temperatures are predicted to increase 3–5°C throughout the country. The regions warming the fastest are in the southwest of Uganda where the rate is of the order of 0.3°C per decade. The minimum temperature is rising faster than the maximum temperature. Records of regional dry and wet years between 1943 and 1999 confirm the increase in rainfall variability in most regions of Uganda.

Droughts are now receiving more attention due to the recent increase in their frequency and intensity. Since water is integral to the ability to produce goods and provide services, drought produces a complex web of impacts that spans many sectors of the economy. Recurrent incidences of drought have been experienced in East Africa. For instance, East Africa has undergone periods of both prolonged drought and of high rainfall changes and variations, resulting to prolonged floods. Over a 20-year period, the region experienced prolonged droughts in 1983/84, 1991/92, 1995/96, 2004/05 and the La Niña–related drought of 1999/2001 leading to famine and decrease in stream flow. A drought in 2011 had severely affected approximately 12.4 million people and resulted in degradation of aquatic ecosystems.

Extreme climatic events resulting in unusually heavy rainfalls are becoming common in East Africa. Unlike droughts, which have slow onsets and tend to persist, floods are normally short-lived but more disastrous. Flood-related hazards have been increasing in magnitude and frequency. Occurrences such as the El Niño–related floods of 1997/98 have been linked to climatic changes. The 1997/98 floods increased water levels in Lake Victoria by 1.7 meters.

ASSESSING VULNERABILITY IN THE LAKE VICTORIA BASIN

This study undertook analyses of temporal trends in rainfall and maximum and minimum temperatures in the LVB and in its sections in each of the five East African countries between 1900 and 2014. The analyses were based on blended satellite and station data. The trends in total monthly rainfall varied significantly. In the LVB, and in the Burundi, Kenya, Rwanda, Tanzania, and Uganda sections, the total monthly rainfall for October and November increased significantly between 1900 and 2014. The modelled trends suggest that this trend is likely to continue. Concurrent with this increase is a significant decrease in rainfall in April, particularly in the LVB overall, and in Burundi, Rwanda, and Tanzania, as well as marginally in Uganda, but not in Kenya. In aggregate, the temporal patterns in monthly rainfall suggest that the short rains are increasing while the long rains are decreasing over most of the past century. The total annual rainfall showed considerable inter-annual variation between 1900 and 2014 and increased from 1960–61 to a peak in 1968–69 before declining to the pre-1960 average. This trend was pervasive and consistent across the LVB and in each of the five country sections.

The spectral analysis of the annual rainfall series confirms a strong five-year cycle of rainfall. The spectral densities are largest when the estimated cycle period is five years, meaning that the oscillation with the five-year period is the most dominant of the cyclical oscillations in annual rainfall in the LVB. This result is consistent with wet phases of about five years, followed by dry phases of about five years.

Statistical analysis indicated that temperature increases recorded for most of the months were significant for the LVB and across all five country sections. The estimated magnitude of the temperature increase between 1920 and 2013 ranged between 0.1°C and 2.5°C for both the maximum and minimum components

The Cyohoha, Navugabo, and Mwanza gulfs were identified as potential hotspots, as was the southwest of Mau, where the headwaters of the Mara River are located and where the main perennial tributaries, the Amala and the Nyangores, drain from the western Mau Escarpment into the Mara River. The climate-related impacts projected in these hotspots include increase in water stress at the watershed level due to increased water withdrawals or decreasing availability of water, the fragile nature of the ecosystems, resource availability, socioeconomic factors, and climate variability.

SECTOR POLICY, LEGAL AND INSTITUTIONAL FRAMEWORK, AND PREPAREDNESS FOR CLIMATE CHANGE

The Partner States, after signing the EAC Treaty in 1999, declared the LVB an Economic Growth Zone and committed to develop it in a coordinated and sustainable manner. Under Article 94 (p), the signatories promise to jointly tackle inland water pollution through effective monitoring and control. In addition, the EAC's Vision and Strategy Framework for Management and Development of Lake Victoria Basin (2011), under the Sector Strategies for Water Resources Management, has a requirement to "Promote water quality and quantity monitoring." Thus, the EAC integration and cooperation is cognizant of a regional approach, while also being sensitive to country-specific concerns.

The governments of the five Partner States are making serious efforts to address water resources issues in their own countries, as well as to use transboundary water resources for the social and economic benefit of the region. These efforts have included developing and strengthening of national policies, institutional frameworks, and laws and regulations that are essential to meet the existing and emerging water resources challenges. They also have proposed to strengthen regional cooperation to address transboundary threats and challenges jointly and seek opportunities to enhance sustainable management of shared water resources.

Water is a factor in many national development plans and strategies. Some relevant national policy and legal instruments include National Water Acts in respective EAC countries. A wide range of national, regional, and international organizations have mandates for governance and management of water resources and aquatic ecosystems in the East African region, such as the EAC, Common Market for Eastern and Southern Africa (COMESA), Intergovernmental Authority on Development (IGAD), and African Ministers' Council on Water (AMCOW), a specialized technical committee of the African Union that promotes cooperation on water and sanitation, as well as the Lake Victoria Basin Commission (LVBC), which serves as an overall institution for the management of issues related to the LVB.

The gaps in institutional capacity and capability may compromise design, implementation, and monitoring of adaptation measures at local and national levels. Human technical capacity in water resources management is limited, which compromises effective design and implementation of adaptive measures and actions. This situation is compounded by lack of financial and technological resources at the national and local levels. Most of the projects in the region are implemented by international agencies with limited technology transfer. The institutional capacity and capability to assess and quantify the impact of climate change on different sectors and systems and socioeconomic consequences of the loss of ecosystems and of economic activities, as well as of certain choices in terms of mitigation and adaptation to climate change, is also limited.

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1. STATUS OF WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE IN EAST AFRICA

1.1 WATER AVAILABILITY

1.1.1 Global

Water is an essential resource for sustaining life and economic development. Renewable freshwater is needed for drinking, crop production, livestock, and commerce, as well as for industry, hydropower generation, tourism, transportation, recreation, and waste disposal. These activities are central to human livelihoods and well-being as they provide employment and contribute significantly to national economies. Water is not only an economic good but also a social good. Safe water supply and appropriate sanitation are the most essential components for a healthy and prosperous life.

The provision of safe drinking water and adequate sanitation facilities to the rural and rapidly expanding urban populations can reduce mortality rates related to water-borne and water-related diseases, such as cholera, diarrhea, and malaria. In many regions of the world, however, the amount and quality of water available to meet human needs are already limited or strained. This is because the available global water resources are under pressure due to demographic, land use, and climatic changes, as well as increasing demands from the various economic sectors, all contributing to driving more regions into water stress and insecurity (UN-Water 2014).

Water covers three-quarters of the Earth's surface, yet the proportion of freshwater available for human consumption and economic activities constitutes a very tiny fraction. This is because only 3 percent of the total global water is freshwater (97 percent being saline water in oceans and seas). Of the available freshwater, 87 percent is not accessible as it is locked in ice caps. Of the remaining accessible freshwater, only 0.4 percent is surface flows in rivers and lakes, the rest is groundwater (GWSP 2005). Water connects several interlinked, geophysical, socio-ecological and economic systems and, in this sense, constitutes a "global water system."

The distribution of global water movement through the hydrological cycle makes up the largest of these flows, delivering an estimated 113,000 cubic kilometers per year of water to the land as snow and rainfall (Figure 1).

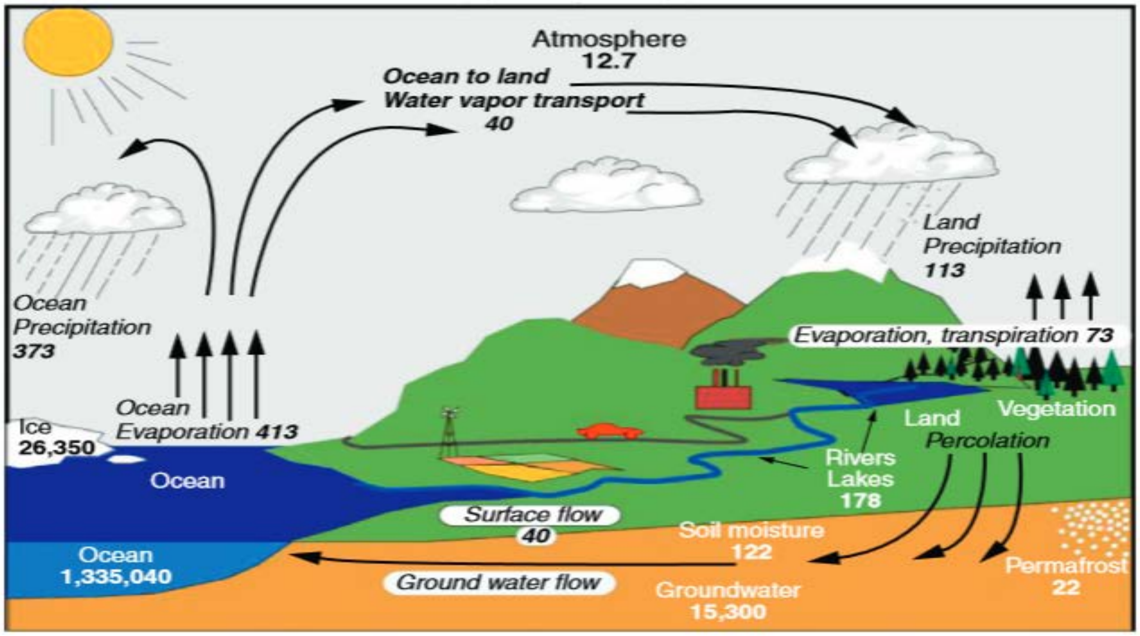


Figure 1: Global Water Circulation, *Note:* Units are thousands of cubic kilometers for storage, and thousands of cubic kilometers per year for exchange (source: Bogardi et al. 2012)

About two-thirds of the terrestrial component of the global water system, some 73,000 cubic kilometers per year is "green water" (water held in plant biomass and evaporated into the atmosphere), while the remaining amount, approximately 40,000 cubic kilometers per year, is "blue water," primarily making up the water resources for conventional uses and management (Bogardi et al. 2012).

Although the available volume of freshwater on land is small, the annual global freshwater budget is a balance between evaporation, atmospheric transport, precipitation, runoff, and storage. The distribution of freshwater over the Earth is highly uneven, varying with latitude due to general atmospheric circulation. There is also large variability due to landforms and the interaction of land with global weather systems. As the Earth's climate varies through natural and human-induced causes, there is a potential for redistribution of water, and acceleration of the global hydrological cycle.

Groundwater is a valuable natural resource and an essential part of the hydrological cycle. It sustains streams, lakes, wetlands, and ecosystems in many parts of the world. Its occurrence is an interaction between geology and prevailing climate conditions. Groundwater is now a significant source of water for human consumption, supplying nearly half of all drinking water in the world (WWAP 2009) and around 43 percent of all water effectively consumed in irrigation (Siebert et al. 2010). Global groundwater abstraction has grown from about 100 cubic kilometers per year in 1950 to over 1,000 cubic kilometers per year, largely for use in agriculture (approximately 90 percent), particularly in Asia (Shah et al. 2007).

Depending on recharge, groundwater is both a renewable and non-renewable resource. Many aquifers in semi-arid and arid regions are overexploited because abstractions exceed recharge rates, causing environmental problems, increasing pumping costs, and depleting the resource available for future generations. Non-renewable resources are locked in deep aquifers with insignificantly small, if any, current recharge, and are being mined when abstracted, raising concerns for future sustainability (Margat et al. 2006).

1.1.2 Africa

Surface Water

Africa is the second largest continent in the world with a land area of nearly 30 million square kilometers. It has a wealth of natural resources that few other parts of the globe can match, including minerals, forests, wildlife, and rich biological diversity. Africa also is endowed with immense renewable natural resources, including freshwater resources. The renewable freshwater resources in Africa average about 3,950 cubic kilometers per year (Table 1). This amounts to about 10 percent of the freshwater resources available globally (UN-Water Africa 2014). Africa has more than 50 internationally shared river and lake basins, the main ones being the Lake Chad, Lake Victoria, and Niger, Nile, Zambezi, and Orange River basins. Most of the surface water resources are concentrated in the Congo, Niger, Nile, Ogooue, and Zambezi basins (Figure 2). The continent's 160 lakes have over 27 square kilometers of surface area. Africa currently uses about 4 percent of its renewable freshwater resources, yet water is becoming one of the most critical natural resource issues.

Table 1: Renewable Water Resources in Africa

Sub-region	Population (million)	Area (1,000 km^2)	Average precipitation (mm/yr)	Internal water resources (km^3/yr)	Renewable water resources (km^3/yr)	Percentage
Northern Africa	174	8,259	195	1,611	79	>1
Western Africa	224	6,138	629	3,860	1,058	27
Central Africa	82	5,366	1,257	6,746	1,743	44
Eastern Africa	144	2,758	696	1,919	187	5
Southern Africa	150	6,930	778	5,395	537	14
Western Indian Ocean islands	19	594	1,518	2,821	345	9
Total	**793**	**30,045**	**744**	**22,352**	**3,949**	

Source: AQUASTAT 2003.

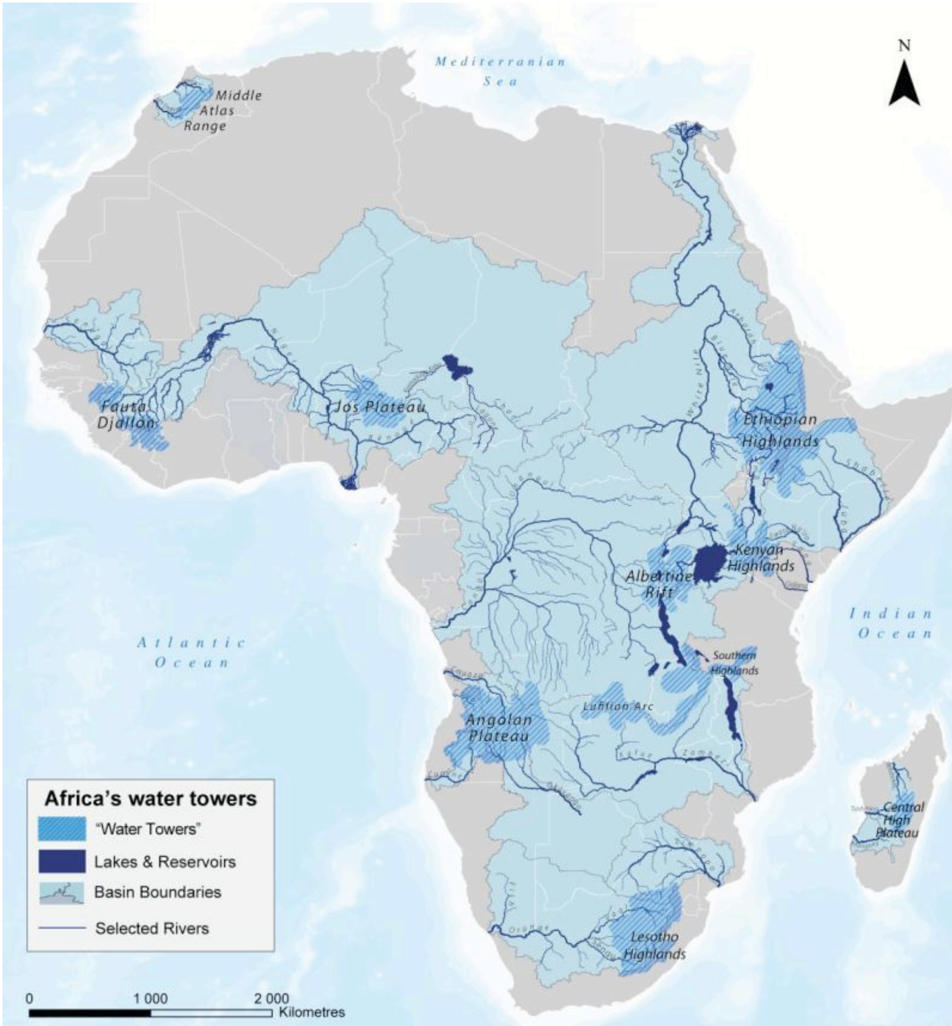
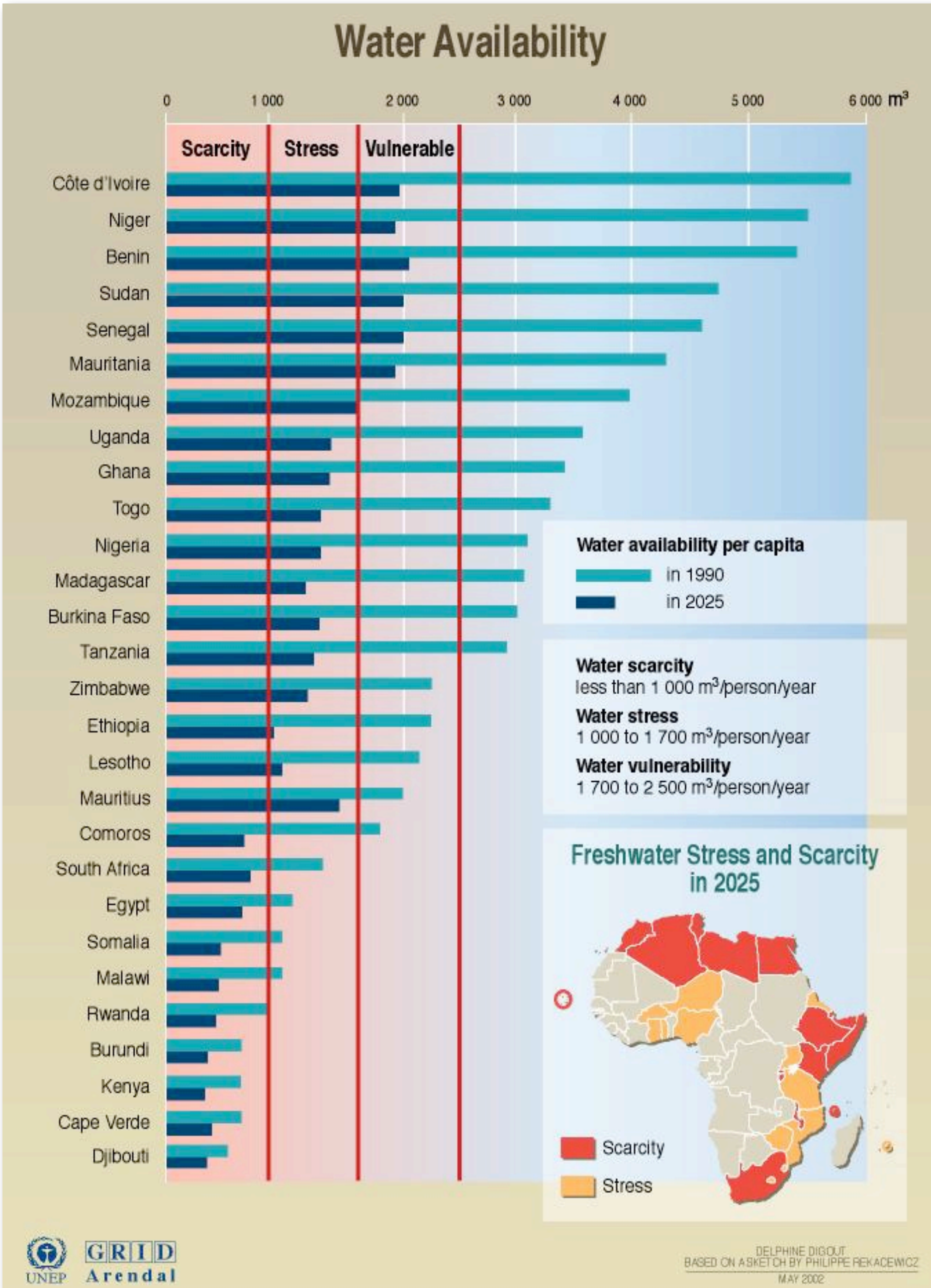


Figure 2: Major water towers and river basins in Africa (source: Diop 2012)

With these water resources, Africa also holds hydropower potential of about 1,750 terawatt hours (12 percent of the global capacity). But hydropower generation remains low, due limited investment and development. The information provided by, among others, Algeria, Congo, Democratic Republic of Congo, Ethiopia, Ghana, Mali, Mauritania, Senegal, Sierra Leone, and Sudan indicates that the installed hydropower capacity in Africa increased from 26,765 megawatts in 2000 to 45,936 megawatts in 2013 (African Union 2015). Although the mean annual rainfall in Africa is about 670 millimeters per year, it is highly variable, ranging from less than 100 millimeters in deserts to over 2,000 millimeters in rainforests and highlands. Thus, large areas of Africa are already facing water stress—1,700 cubic meters or less per person annually—or water scarcity conditions—1,000 cubic meters or less per person annually (Figure 3). The scarcity is propelled by rapid population growth in the continent and unplanned urban development.



Source: United Nations Economic Commission for Africa (UNECA), Addis Ababa ; Global Environment Outlook 2000 (GEO), UNEP, Earthscan, London, 1999.

Figure 3: Water availability per capita in African countries, showing water scarcity in Rwanda, Burundi, and Kenya and stress levels in Uganda and Tanzania

The continent also has some of the driest deserts, largest tropical rain forests, and highest equatorial mountains in the world. Key natural resources are unevenly distributed. For example, more than 20 percent of the remaining tropical forest is in the Democratic Republic of the Congo, while a major share of the continent's water resources is in a few large basins (such as the Congo, Niger, Nile, Zambezi, and Lake Victoria). The Congo watershed accounts for about 30 percent of the continent's annual runoff.

Groundwater

Groundwater potential in Africa is also highly variable (Figure 4). The hydrogeological environments in Africa can be divided into five main types (Macdonald et al. 2009). The consolidated sedimentary rocks occupy the largest surface area, about 37 percent; these are sandstones, mudstones, and limestone. These support high-yielding boreholes, especially in sandstones, and yields are 10–50 liters per second. Precambrian crystalline basement rocks occupy 34 percent of land surface area and consist of crystalline rocks with little primary permeability or porosity. Unconsolidated sediments form the most productive aquifers in Africa and cover about 25 percent of the land area; borehole yields in these sediments can be 5–50 liters per second. Volcanic rocks occupy about 4 percent of land area and are found in east and southern Africa, groundwater tends to be found in fractures, yields of 1–5 liters per second can be achieved through well-sited boreholes, but storage is highly variable (MacDonald et al. 2011).

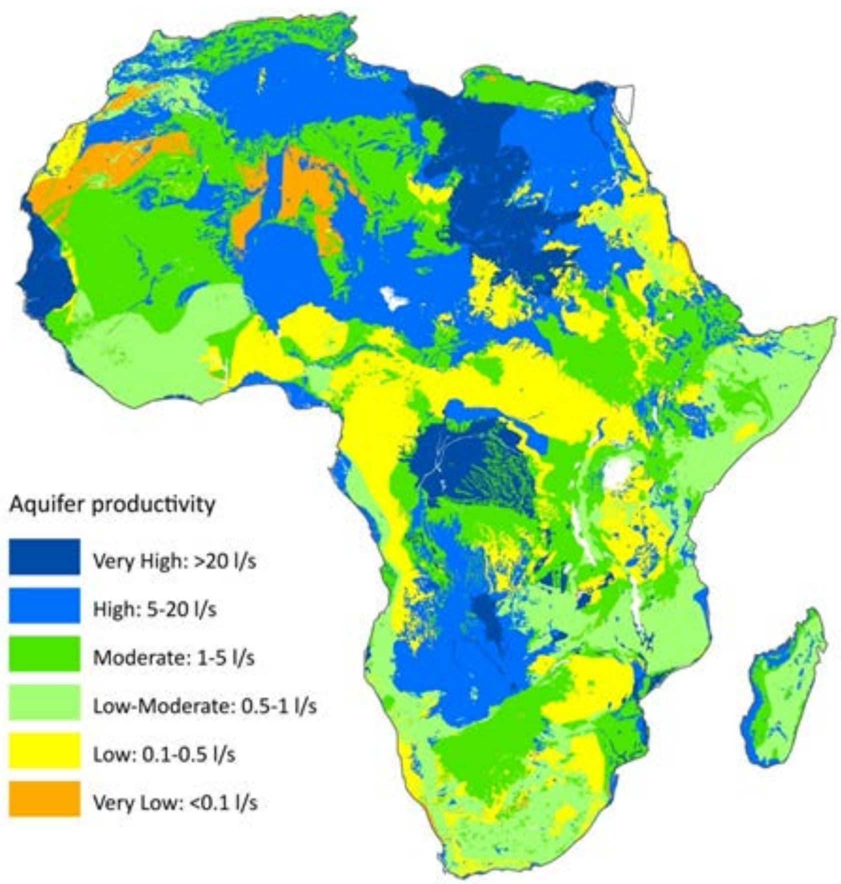


Figure 4: Groundwater potential in Africa (source: British Geological Survey [MacDonald et al 2011]

The resilience of groundwater resources to long-term shifts in climate is governed by the available groundwater storage and aquifer permeability. Larger groundwater bodies will respond very slowly to long-term changes in recharge. Smaller groundwater bodies with little storage are not resilient to long-term changes in climate, but they recover quickly from drought when recharged (MacDonald et al. 2009). The largest groundwater storage is in the large sedimentary basins of North Africa, which are not actively recharged at present. Much of the water in these aquifers is pale-waters recharged when the climate was much wetter more than 5,000 years ago. These are also the most resilient areas (Edmunds 2009, MacDonald et al. 2011). The aquifers with the least storage generally occur in thin weathered crystalline rocks. Many of the basement aquifers are in areas with high average annual recharge, which increases the resilience of groundwater-dependent supplies in these areas.

Thus, groundwater could help to adapt to climate change and population growth in Africa. However, to ensure water security groundwater quality needs to be managed and protected from anthropogenic and geogenic contamination threats. For example, most wastewater (domestic and industrial) is not treated, so pathogens, nutrients, heavy metals, and organic micro-pollutants enter to the water cycle. In some coastal areas, over-pumping has led to saltwater intrusion. In other areas, the rocks are rich in inorganic elements that can be harmful to health, including fluoride in the East African Rift Valley, and arsenic, iron, and manganese in various other parts of Africa.

1.1.3 Africa Water Vision

A shared Africa Water Vision and water supply and sanitation targets were defined at the World Water Forum in The Hague in 2000. The vision calls for a new way of thinking about water and a new form of regional cooperation. It aspires to "An Africa where there is an equitable and sustainable use and management of water resources for poverty alleviation, socioeconomic development, regional cooperation, and the environment." Specific targets (Box 1) have been set to achieve this (ECA et al. 2000). Achieving this vision requires new approaches to governance and institutions, including, among other things, the adoption of integrated and participatory approaches, management at the lowest possible level, and mainstreaming of gender issues. It is also important to develop plans and strategies related to climate change impacts on water resources.

Box 1: Africa Water Vision Targets

By 2015	By 2025
❖ Reduce by 75 percent the proportion of people without access to safe and adequate water supply.	❖ Reduce by 95 percent the proportion of people without access to safe and adequate water supply.
❖ Reduce by 70 percent the proportion of people without access to safe and adequate sanitation.	❖ Reduce by 95 percent the proportion of people without access to safe and adequate sanitation.
❖ Increase by 10 percent water productivity of rain-fed agriculture and irrigation.	❖ Increase by 60 percent water productivity of rain-fed agriculture and irrigation.
❖ Increase the area of irrigated land by 25 percent.	❖ Increase the area of irrigated land by 100 percent.
❖ Realize 10 percent of the development potential for agriculture, hydropower, industry, tourism, and transportation.	❖ Realize 25 percent of the development potential for agriculture, hydropower, industry, tourism, and transportation.
❖ Implement measures in all countries to ensure the allocation of sufficient water for environmental sustainability.	❖ Implement measures in all river basins to ensure the allocation of sufficient water for environmental sustainability.
❖ Implement measures in all countries to conserve and restore watershed ecosystems.	❖ Implement measures in all river basins to conserve and restore watershed ecosystems.

Source: EAC 2004.

1.2 FRESHWATER AVAILABILITY

1.2.1 Surface Water

The EAC region is endowed with freshwater resources and has several major towers such as Mounts Kenya, Kilimanjaro, and Elgon, as well as the Ruwenzori range and others (Figure 5). The surface water resources include rivers and lakes, among which is Lake Victoria, the largest shared water resource in the region. On average, the region has a total renewable volume of 187 cubic kilometers per year, with Uganda holding the largest share, 39 cubic kilometers per year (UNDP 2000). The region also has groundwater resources, rainwater, riverine flows, and lacustrine swamps. These resources support most of the productive sectors in the region, including irrigated and rain-fed agriculture, livestock, wildlife, and fisheries, as well as rich biodiversity.

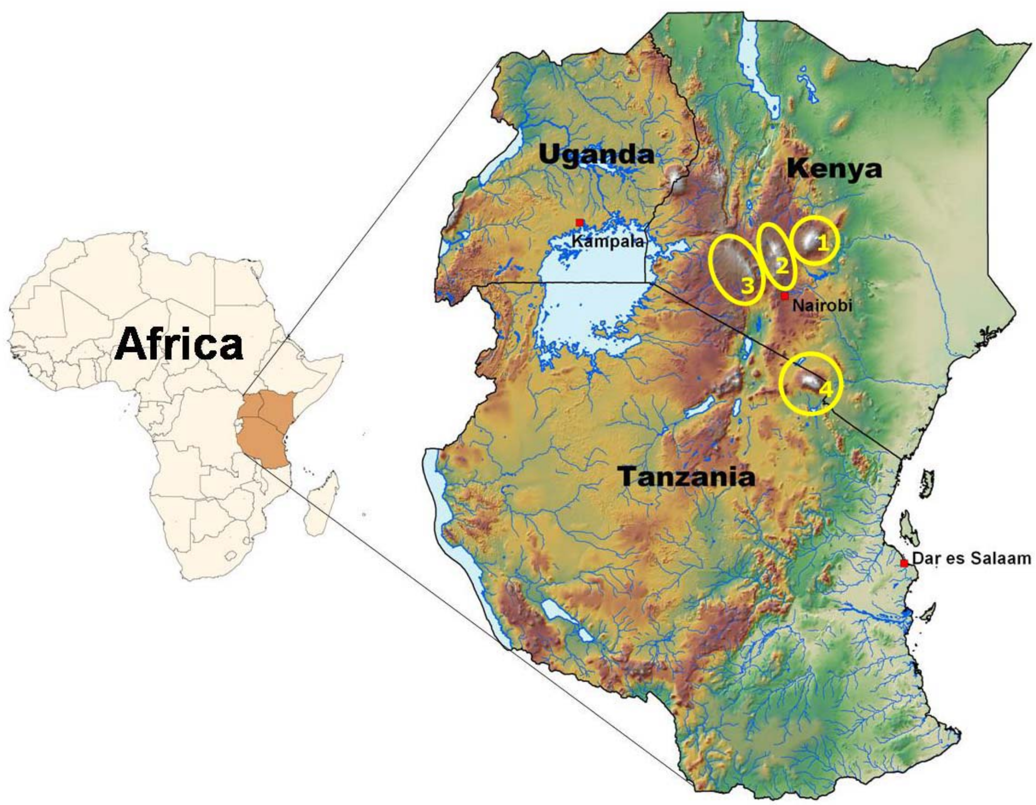


Figure 5: Major water towers and drainage system of East Africa, *Note:* (1). Mt. Kenya, (2) Aberdares Escarpment, (3) Mau Escarpment, (4) Mt. Kilimanjaro and Mt. Elgon (source: www.lvbcom.org)

However, East Africa is experiencing increased pressure on available water resources (EAC 2010). Due to rapidly growing population, the available water resources will reduce as users and uses increase and demand keeps growing. This will result in declining per capita water availability (Table 2). It is obvious from the statistics that Kenya is in a precarious situation, having about 681 cubic meters per capita per year (Republic of Kenya 2013), which compares poorly with the globally recommended 1,000 cubic meters per capita per year. Moreover, due to increasing population, water availability is projected to decline to

235 cubic meters by 2025,[1] meaning the country will be severely water stressed in a decade's time. Rwanda and Burundi face similarly severe water scarcity now and in the future (UNEP GEO report 2000).

Table 2: Per Capita Water Availability in Kenya, Tanzania, and Uganda

Water availability per capita	1990	2006	2025
Plenty (Exceeding 2,500 m^3/yr)	Uganda, Tanzania		
Vulnerable (1,700–2,500 m^3/yr)		Uganda, Tanzania	
Stress (1,000–1,700 m^3/yr)			Uganda, Tanzania
Scarcity (less than 1,000 m^3/yr)	Kenya, Rwanda, Burundi	Kenya, Rwanda, Burundi	Kenya, Rwanda, Burundi

Source: EAC 2011.

1.2.2 Groundwater

In East Africa, groundwater resources are an important source of water, particularly in arid and semi-arid areas. Their occurrence depends on geology, geomorphology, and effective rainfall (both current and historic). Thus, groundwater storage is highly variable in the EAC Partner States. Estimates show that Burundi and Rwanda have the lowest groundwater storage estimated at 47 and 49 cubic kilometers respectively, while in comparison, Uganda has 339 cubic kilometers, Tanzania has 5,250 cubic kilometers (MacDonald et al. 2012), and Kenya has 55.973 cubic kilometers (NWMP 2003). However, groundwater resources are poorly developed in the region and their full potential remains unmapped, and thus unknown.

1.3 Access to Water Resources

1.3.1 Global

Access to water and sanitation is recognized as a human right and has long been a central aim of international development policies and targets. The MDGs sought to "halve the proportion of the population without access to safe drinking water and basic sanitation" between 1990 and 2015 (UNGA 2001). Great strides have been achieved over the past two decades: about 2.3 billion people gained access to an improved drinking water source and about 1.9 billion had access to an improved sanitation facility (World Health Organization and UNICEF 2014). Although the MDG target on access to safe drinking water was met in 2010, this progress was not able to keep up with the rapid population growth and urbanization. Of those gaining access to drinking water, some 1.6 billion use a higher level of service, that is, a piped water supply on premises. However, much still needs to be done, as about 748 million people do not use an improved source of drinking water and 2.5 billion still do not use an improved sanitation facility (WWAP 2015). Moreover, not all of those using improved facilities have clean water: an estimated 1.8 billion people drink contaminated water (Bain et al. 2014).

Even with these gains, the gap between freshwater supplies and demand continues to widen due to climate change and increasing consumption of water by a growing human population. The Vision 2050 for world water resources management (WWAP 2015) has been proposed as a way to meet that challenge (Box 2).

1 www.informaworld.com/smpp/content~db=all~content=a917971133

Box 2: Vision 2050: Water in a Sustainable World

- "In a Sustainable World that is achievable in the near future, water and related resources are managed in support of human well-being and ecosystem integrity in a robust economy.
- Sufficient and safe water is made available to meet every person's basic needs, with healthy lifestyles and behaviors easily upheld through reliable and affordable water supply and sanitation services, in turn supported by equitably extended and efficiently managed infrastructure.
- Water resources management, infrastructure and service delivery are sustainably financed.
- Water is duly valued in all its forms, with wastewater treated as a resource that avails energy, nutrients and freshwater for reuse.
- Human settlements develop in harmony with the natural water cycle and the ecosystems that support it, with measures in place that reduce vulnerability and improve resilience to water-related disasters.
- Integrated approaches to water resources development, management and use and to human rights are the norm.
- Water is governed in a participatory way that draws on the full potential of women and men as professionals and citizens, guided by a number of able and knowledgeable organizations, within a just and transparent institutional framework."

Source: WWAP The U.N. World Water Report 2015.

1.3.2 East Africa

Access to water influences the economic development and social welfare of communities (Allan 2002). Although access to safe drinking water has markedly improved in East Africa over recent years, a considerable proportion of the population is still without access to safe and adequate water supply (IUCN 2010). Though access varies among the EAC Partner States, none has achieved the drinking water target of 100 percent in access and quality. Basic access to drinking water is 20 liters per capita per day for rural areas and 50 liters per capita per day for people living in urban areas with flushing toilets (Howard and Bartram 2003). Further, in all the Partner States, less than 75 percent of the rural population has access to safe drinking water. Clean water availability is not keeping pace with population growth, hampering progress toward achievement of the 2015 MDGs, and the post-2015 Sustainable Development Goals.

All of the region's countries face an enormous water supply and infrastructure challenge. Most of the urban poor and the rural population rely on springs and boreholes, which are not fully developed, easily contaminated, and in some cases over-abstracted. Water distribution is also not equal as some places have high volumes of water while others face drought with low levels of water. Supply and access to safe water is poor in most of the EAC countries. Uganda, the exception, has almost met its 2015 MDG targets due to the recent reforms. However, there are discrepancies in the percentage of water accessed in rural and urban areas.

Access to safe water supplies throughout Uganda is 65 percent. Although the number of people with access to safe water and sanitation has improved over the past 10 years, many communities (rural and urban) still rely on contaminated water sources, such as streams and open wells. The rapidly growing populations in the EAC Partner States and migrations to urban areas have resulted in the need to establish centralized water systems to supply potable water to residents. Further, climate change, affluence, and population growth have resulted in increasing water demand for domestic, industrial, and agricultural use.

The EAC Partner States are a long way from meeting the drinking water target of 100 percent. Further, less than 75 percent of the rural population in the region has access to safe drinking water, with the least coverage—less than 60 percent—in Kenya. Table 3 shows an increasing trend in access to and probable increase in consumption of water for the period 2001–2011 in all the East African countries, thereby putting more pressure on readily available water resources.

Table 3: Access to Water in East Africa

Indicator partner	State/years	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Rural	Burundi	43	43	49	49	49	49	55	55	55	55	55
	Uganda	50	53	53	54	56	56	57	58	59	59	59
	Tanzania	50	51	54	57	61	59	64	64	70	70	-
	Kenya	-				48	48	48	48	48	48	48
	Rwanda	-				59	59	59	59	59	59	59
	EAST AFRICA	-	-	-	-	-	-	-	-	-	-	-
Urban	Burundi	95	89	89	89	85	85	88	88	88	88	88
	Uganda	66	67	73	76	78	80	80	80	80	80	80
	Tanzania	55	60	63	65	87	87	87	87	92	92	
	Kenya	-	-	-	-	83	83	83	83	83	83	83
	Rwanda	-	-	-	-	87	87	87	87	87	85	85
	EAST AFRICA	-	-	-	-	-	-	-	-	-	-	-
Overall	Burundi	52	66	66	66	67	67	72	72	72	72	72
	Uganda	-	56	56	57	68	68	68	68	74	74	74
	Tanzania	54	56	56	57	68	68	68	68	74	74	-
	Kenya	-	-	-		57	57	57	57	57	57	57
	Rwanda	-	-	41	43	47	57	63	74	74	74	74
	EAST AFRICA	-	-	-	-	-	-	-	-	-	-	-

Source: Partner States as adapted from EAC Facts and Figures 2012.

1.4 Aquatic Ecosystems

1.4.1 Global

An ecosystem is a community of organisms that live and interact within a particular environment. An aquatic ecosystem is an environment in a body of water that supports a group of organisms that interact with each other. Examples of aquatic ecosystems include rivers, streams, ponds, lakes, oceans, bays, swamps, marshes, and their associated organisms. Aquatic ecosystems are diverse and very productive.

They provide several tangible and intangible good and services to humans. However, these critical ecosystems are threatened worldwide by human activities. For instance, some ecosystems have been converted to other uses, while others have been degraded. Declines in the biodiversity of freshwater ecosystems have been suggested to be rapid, especially because freshwater ecosystems support disproportionately high levels of biodiversity compared to their spatial coverage (Ricciardi and Rasmussen 1999, Xenopoulos et al. 2005).

Aquatic biodiversity includes aquatic plants, insects, mollusks, crustaceans, fishes, reptiles, water birds, and mammals (Reaka-Kudla 1997). This rich biodiversity supports a large fisheries sector, both commercial and artisanal, providing income and food security to a large portion of the poorer communities. The fisheries sector is the leading supplier of dietary household animal protein and the only viable source for key micronutrients critical in addressing malnutrition and "hidden" hunger for most of the countries. World food fish aquaculture production expanded at an average annual rate of 6.2 percent over 2000–2012 (9.5 percent in 1990–2000) from 32.4 million to 66.6 million tons.

Wetlands are among the most biologically productive ecosystems. Because of this, they are under great pressure. Studies estimate that approximately 44,000 of the world's 1,868,000 described species come from freshwater ecosystems. These ecosystems occupy only 0.8 percent of the Earth's surface. Aquatic biodiversity includes aquatic plants, insects, mollusks, crustaceans, fishes, reptiles, water birds, and mammals (Reaka-Kudla 1997). Globally, a total production of 148.5 million tons was realized in 2010 with a per capita fish supply of 18.6 kilograms, 86 percent of which was used for direct human consumption (Porter et al. 2014). In Africa per capita fish consumption, at 6.7 kilograms, is the least globally. Africa contributes less than 1 percent of the global aquaculture supply and most of that is represented by a handful of countries—Egypt alone accounts for over 80 percent.

1.4.2 Africa

Aquatic habitats and their biodiversity are under serious threats at global levels. African aquatic biodiversity is highly diverse and of great importance to the continent's livelihoods and economies. In Africa, fishes and plants are regarded as the most important aquatic biodiversity resources. Considering all aquatic resources that are harvested annually, it is estimated that 45 percent are fishes, and 58 percent are plants (Darwall et al. 2011). The well-known aquatic biodiversity resources in Africa mainly consist of species with economic value. However, species of little or no economic value are still poorly known. The assessment of the status of some of aquatic biodiversity in African freshwater habitats by International Union for Conservation of Nature (IUCN) in 2010 indicated that about 90 percent are endemic to the continent. This endemism is strictly linked to aquatic plants, freshwater mollusks, and freshwater crabs. A significant amount of freshwater biodiversity is also considered to be under threat. For instance, it was estimated that 12 percent of birds, 19 percent of mammals, and 26 percent of amphibians are under threat (Darwall et al. 2011). The ever-increasing water demands and expected climatic change will exacerbate the threats on endangered aquatic biodiversity.

1.4.3 East Africa

East African aquatic ecosystems are internationally recognized for their high levels of species richness and endemism. The freshwater fisheries, for example, have one of the greatest endemism of cichlid species resulting from adaptive radiation. To date, many of these species have not been described. This rich biodiversity supports a large commercial and artisanal fisheries sector, providing income and food security to a large portion of the poorer communities. Additionally, freshwater ecosystems provide immense benefits to local, national, and regional economies and provide the basis for indigenous medical practices, food, energy, shelter, crafts, and various raw materials.

Eastern Africa's potential both in the oceans and inland waters in this regard remains largely untapped (Mwanja and Signa 2012). Areas with many resources derived directly from ecosystems tend to attract populations using those resources (EAC 2011).

Wetlands provide water and primary productivity upon which countless species of plants and animals depend for their survival. They support high concentration of birds, mammals, reptiles, amphibians, fish, and invertebrates. People depend on wetlands mainly for grazing their animals, food, water, and medicine, as well as for papyrus for roofing and making mats. Lake Victoria, for instance, provides proteins for approximately 8 million people and supports over 100,000 fishermen (Darwall et al. 2005).

1.5 Lake Victoria Basin

1.5.1 Extent and Hydrography

The transboundary Lake Victoria Basin (LVB) is at the heart of East Africa, covering an area of 194,200 square kilometers, of which 7 percent is in Burundi, 22 percent in Kenya, 11 percent in Rwanda, 44 percent in Tanzania, and 16 percent in Uganda (Figure 6).

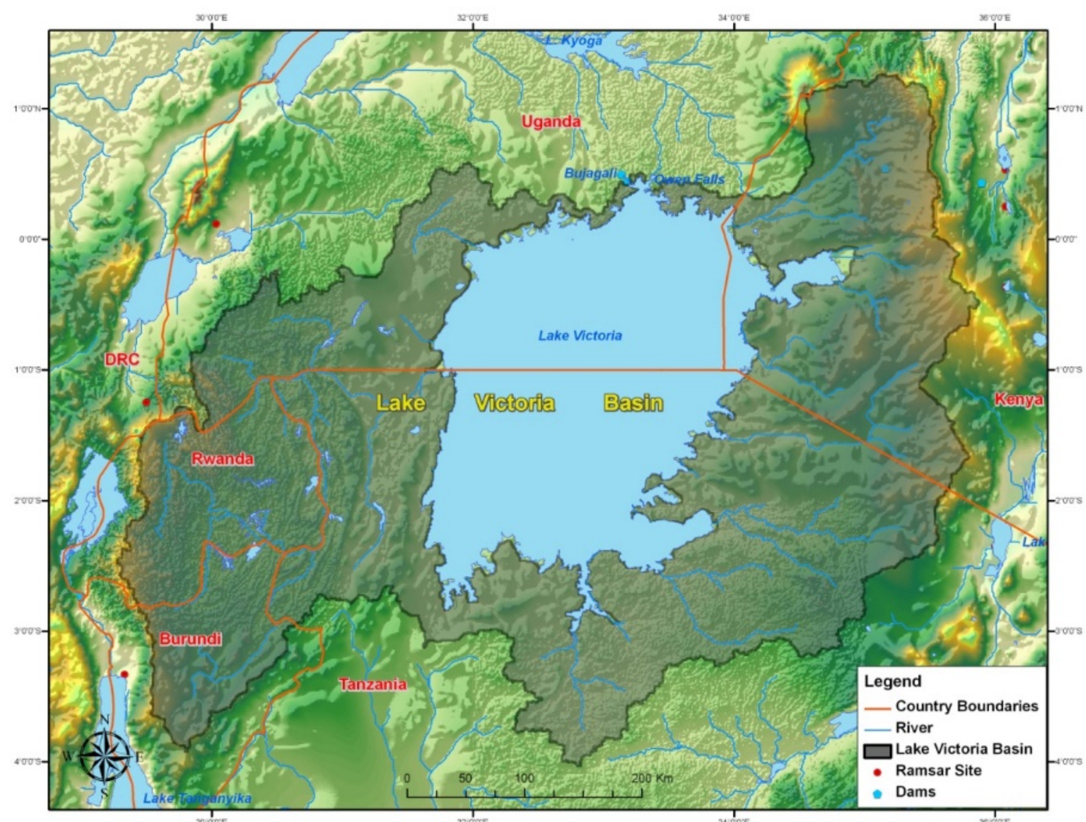


Figure 6: Map of Lake Victoria Basin (source: www.lvbcom.org)

The basin includes Lake Victoria, the second largest lake in the world with an area of 68,800 square kilometers and a number of satellite lakes and rivers. The lake has a shoreline of approximately 3,450 kilometers long, demarcated among the riparian countries (Table 4). The main lake and satellite lakes are fringed in many places by extensive wetlands. About 35 million people with a population density estimated at 174 persons per square kilometer (Tolo et al. 2012). About 30 percent of the entire population of East Africa is estimated to live and derive their livelihood directly or indirectly from the basin.

The main economic activities in LVB include agriculture, fishing, quarrying and mining, and trade. Agriculture is the dominant economic activity, supporting over 80 percent of the population, of which 60 percent practice rain-fed agriculture, which generates 30–40 percent of GDP. Lake Victoria also supports freshwater fishing with estimated annual fish yields of about 500,000 tons, which contributes significantly to both local consumption and export earnings in the region.

Table 4: Lake Victoria Surface Area, Catchment, and Shoreline Statistics

Country	Lake surface area		Catchment area		Lake shoreline length	
	Square kilometers	Percent	Square kilometers	Percent	Kilometers	Percent
Kenya	4,128	6	42,724	22	550	16
Uganda	29,584	43	31,072	16	1,750	51
Tanzania	35,088	51	85,448	44	1,150	33
Burundi	0	0	13,594	07	0	0
Rwanda	0	0	21,362	11	0	0
Total	68,800	100	194,200	100	3,450	100

Source: EAC Regional Transboundary Diagnostic Analysis 2007

1.6 CLIMATE

The LVB has an equatorial hot and humid climate with a biannual rainfall pattern, where the long rains are experienced from March to May and short rains from October to December (Nicholson 1998, Yin and Nicholson 1999). July is the coolest month of the year and the warmest month is variable and fluctuates in the period from October to February. Rainfall varies considerably from one part of the basin to another. The mean annual rainfall is on the order of 1200–1600 millimeters, but it exceeds 3,000 millimeters on Nabuyonge Island, in the center of the lake (Sutcliffe 2013). Most of the rainfall occurs at night and is generally associated with strong thunderstorms. On the northern and western shores, the effects of rainfall do not extend more than 40 kilometers inland. The distribution of mean annual rainfall in the basin is shown in Figure 7. The basin's climate also is influenced by seasonal winds (Figure 8).

In the months of January to February and June to September, the wind pattern is predominantly east-west, parallel to the equator, with origins from the western parts of Kenya and Tanzania (Sutcliffe 2013). These winds pick up moisture while crossing the lake and subsequently deposit it on the western catchments, especially Bukora catchment, Uganda. During March to May and October to December, the wind pattern shifts toward the northern parts of the lake. The diurnal lake/land breeze system interacts with the mountain/valley breezes and the large-scale winds in such a way that strong wind convergence occurs over the western half of the lake at night but over the eastern half of the lake during the day.

The temperature in the LVB countries reaches maximum in February, just before the March equinox and reaches its minimums in July after the June equinox maximum and range from 28.6°C to 28.7°C. The minimum temperature ranges from 14.7°C to 18.2°C. Comparison of temperatures records for the period 1950–2000 to 2001-2005 shows that maximum temperatures have increased by an average of 1°C (EAC 2005, Anyah and Semazzi 2004).

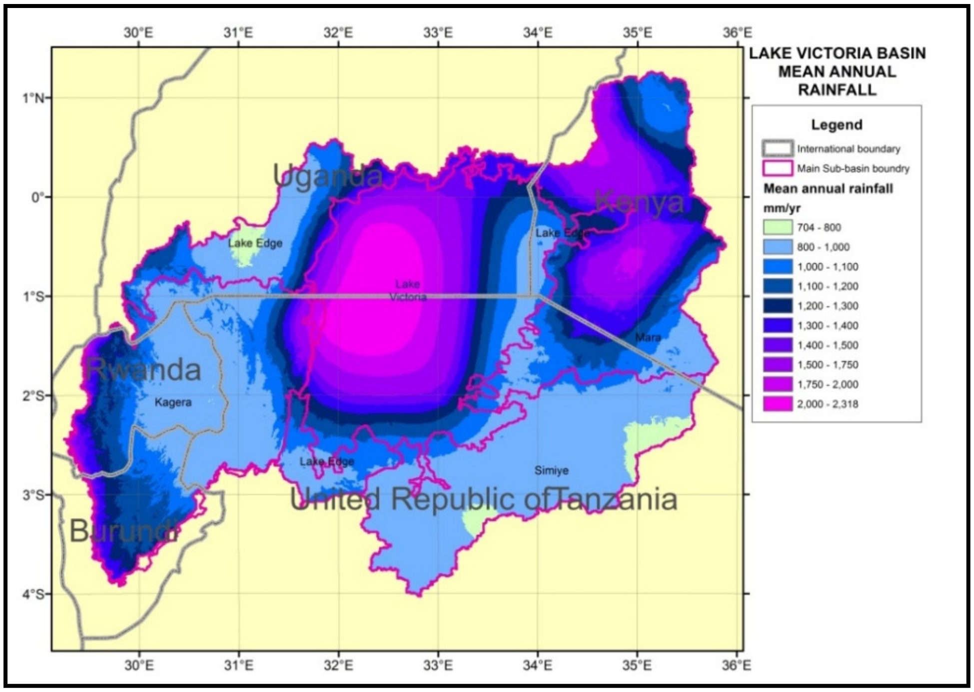


Figure 7: Lake Victoria Basin: Mean Annual Rainfall, mm/yr (source: Sutcliffe 2013)

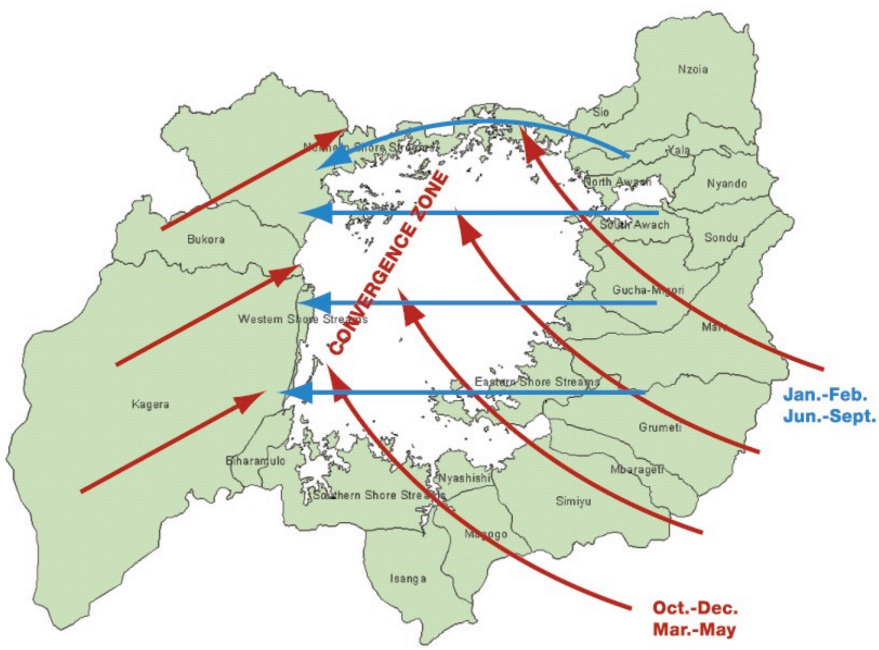


Figure 8: Seasonal wind patterns of the Lake Victoria Basin (source: Sutcliffe 2013)

1.6.1 Drainage System of LVB

The surface drainage into Lake Victoria consists of rivers, streams, and wetlands. The lake receives inflow from 17 tributaries contributing about 13 percent of the water entering the lake annually; the remaining 87 percent comes from rainfall. The White Nile is the only outflow of Lake Victoria exiting the lake at Jinja, in Uganda (north of the lake). The two sub-basins of Lake Victoria with the largest flows are the

Kagera and the Nzoia with about 33 percent and 15 percent of total inflows to the lake (Sutcliffe 2013). Streams and rivers along the lake edge constitute some 11 percent of inflows.

Two rivers are transboundary, namely Kagera (Burundi, Rwanda, Tanzania, and Uganda) and the Mara (Kenya and Uganda). However, several tributaries, especially in Uganda, enter the lake through swamps that are estimated to have a total area of 2,600 square kilometers. The other major rivers of the basin are: Bukora and Katonga, which originate in Uganda; the Nzoia, Sio, Mara, Yala, Awach, Gucha, Migori, and Sondu, which originate from Kenya; and the Mori, Simiyu, Grumeti, Mbalageti, Magogo-Moame, and other small streams originating from Tanzania (Figure 9 and Table 5).

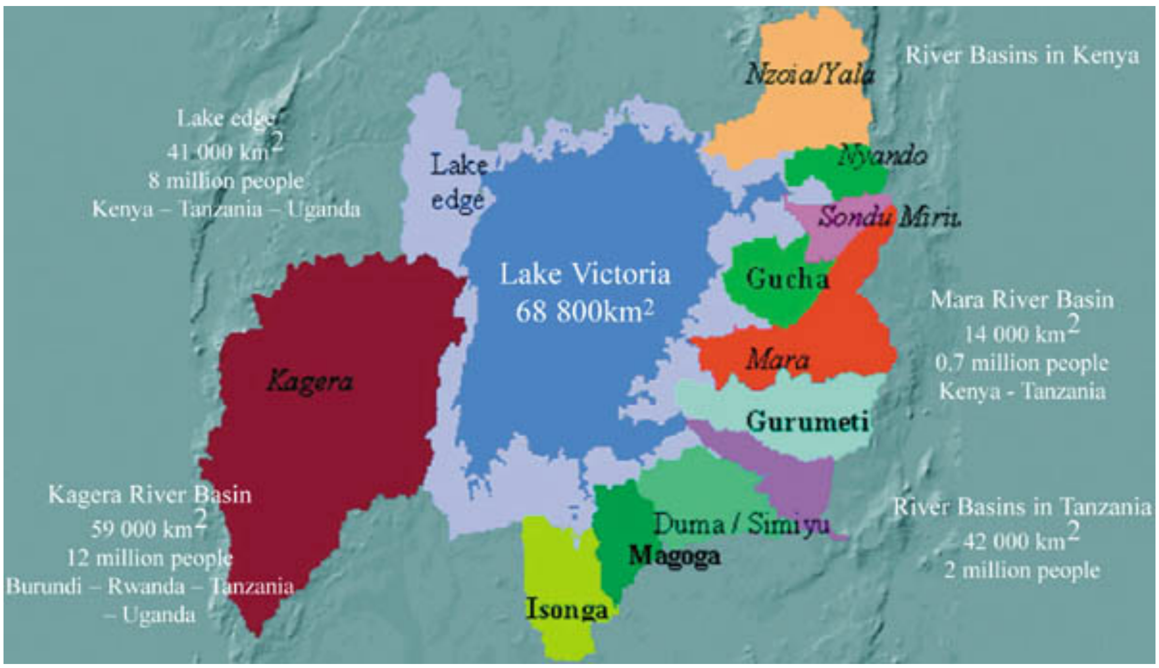


Figure 9: Sub-Basins of the Lake Victoria Basin (FAO 2010)

Table 5: Drainage of Lake Victoria Basin

Country	River basin	Flow in cumecs	Percent
Kenya	Sio	11.4	1.4
	Nzoia	116.7	14.5
	Yala	37.7	4.7
	Nyando	18.5	2.3
	North Awach	3.8	0.5
	South Awach	5.9	0.7
	Sondu	42.2	5.2
	Gucha-Migori	58.0	7.2
Tanzania	Grumeti	11.5	1.4
	Mbalageti	4.3	0.5
	Eastern Shore streams	18.6	2.3
	Simiyu	39.0	4.8
	Magogo-Maome	8.4	1.0
	Nyashishi	1.6	0.2

Country	River basin	Flow in cumecs	Percent
	Issanga	31.0	3.9
	Southern Shore streams	25.7	3.2
	Biharamulo	17.8	2.2
	Western Shore streams	20.7	2.6
Uganda	Bukora	3.1	0.4
	Katonga	5.1	0.6
	Nothern Shore streams	25.6	3.2
Shared rivers	Kagera	261.1	32.4
	Mara	37.5	4.7
	Total	**805.3**	**100**

Source: Integrated Water Quality and Limnology Study of Lake Victoria LVEMP 2005.

Evaporation is also a key element of the water balance of Lake Victoria and changes in rate of evaporation are very critical for performance of the water sector. Changes in temperature affect evaporation and evapotranspiration rates and impact water availability. The monthly evaporation over Lake Victoria is shown in Figure 10.

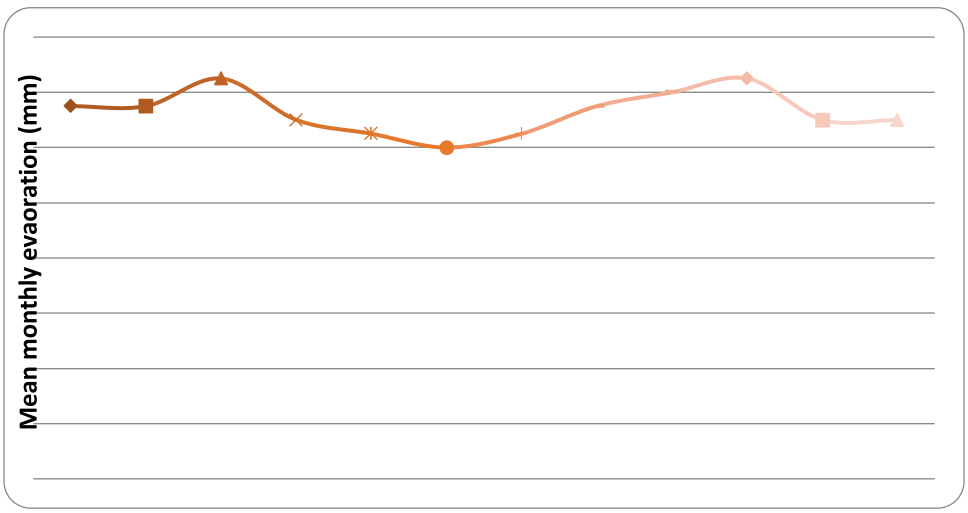


Figure 10: Estimated Monthly Evaporation in Lake Victoria Basin (source: LEVMP 2005)

1.6.2 Water Balance Model of Lake Victoria

Yin and Nicholson (1998) developed a simple water balance for Lake Victoria expressing the balance between its inputs and outputs. The model is as follows:

$\Delta H = P_w + Inflow - (E_w + Outflow)$

where ΔH is a change in lake level, while the inputs to the lake are the lake rainfall (P_w) and inflow from the 17 tributaries, and the outputs are the lake evaporation (E_w) and the outflow via the White Nile at Jinja. The results from the water balance assessments indicate that Lake Victoria has a net water storage averaging 33 cubic meters per second (Table 6).

Table 6: Average Inflows and Outflows from Lake Victoria

Type of flow	Flows (m^3/s)	Percentage (%)
Inflows		
❖ Rain over lake	3,631	82
❖ Basin discharge	778	18
Outflows		
❖ Evaporation from lake	-3,330	76
❖ Nile River	-1,046	24
Balance	+33	

Source: COWI 2002.

1.6.3 Aquatic Ecosystems

The LVB reflects the diversity of the region's natural resources; freshwater lakes, wetlands, mountains, forests, woodland, rolling plains, and grassland. Wetlands of the basin include swamps, marshes, seasonally inundated grasslands, swamp forests, floodplains, and riparian wetlands (at the edges of lakes and rivers). These provide critical ecosystem functions such as buffering the impacts of the strong seasonal variations in rainfall patterns, storing floodwaters, and helping to maintain river flows even during dry spells. They also trap sediments and purify agricultural, industrial, and urban wastewater.

The LVB has a multispecies fish diversity of over 500 endemic species. Three main species support the current fishery: Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*), and dagaa, also known as omena (*Rastineobola argentea*). Both Nile perch and Nile tilapia were introduced into the LVB in the late 1950s to 1960s and have flourished, though with significant ecological effects and impacts on other species (Nyingi 2012). Apart from diverse species of fish, LVB is a host to various bird species, some of which are endemic to certain wetlands. The common species include a variety of gulls, terns, papyrus yellow warbler (*Chloropeta gracilirostris*), white-winged warbler (*Bradypterus carpalis*), and papyrus gonolek (*Laniarus mufumbiri*).

Numerous phytoplankton communities support the fisheries of the LVB, the common ones being *Aulacoseira* sp. and *Microcystis* sp. The zooplankton community is mainly represented by copepods, cladocerans, and rotifers species (Mavuti 1989, Opiyo 1991). On the benthic level, burrowing nematodes, chironomids, *Chaoborus* sp., and swamp oligochaetes (*Alma emini* and *Limnodrilus* sp.) are common (Mavuti 1989). Bivalves (particularly *Sphaerium nyanzae* (Smith 1802) and *Coelatura monceti* (Bourguignat 1883)) and gastropods (*Bellamya unicolor* (Olivier 1804) and *Melanoides tuberculata* (Muller 1774)), have been shown to be the most abundant benthic macro-invertebrates in sections of the LVB. The gastropods are common in inshore waters and mollusks in offshore waters. Swamp vegetation and other aquatic macrophytes that are common in the lakes include *Commelina africana*, *Ludwigia leptocarpa,* and *Phragmites* sp. These macrophytes harbor a rich community of other plants and animals (Opiyo 1991).

All five East African countries have significant wetlands within the LVB. In Kenya, key wetlands include the Yala Swamp (17,500 hectares), which includes Lake Kanyaboli (1,050 hectares), Lake Sare (500 hectares), Lake Namboyo (1 hectare), the Nyando Swamp (15 by 6 kilometers); the Sondu- Miriu wetland (10,000 hectares); the Saiwa Swamp (20 kilometers long) and the Kimandi River wetland (4,800 hectares).

2. SECTOR TRENDS FOR THE WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE SECTOR IN EAST AFRICA

2.1 TRENDS IN WATER AVAILABILITY, ACCESS, AND QUALITY

Water availability, quantity, and quality in the LVB faces several challenges associated with increasing population and intensified socioeconomic activities that exert pressure on water resources. These include the over-abstraction of water for irrigation and urban uses, as well as human encroachment on the catchment areas through settlement, cultivation, over-grazing, and bush fires.

2.1.1 Availability

East Africa is experiencing increased pressure on available water resources (EAC 2010). Due to a rapidly growing population, the available water resources will reduce as users and uses increase and demand keeps growing. The net result is declining per capita water availability as shown in the previous chapter and in Table 7.

Table 7: Per Capita Water Availability in Kenya, Tanzania, and Uganda

Water availability per capita	1990	2006	2025
Plenty (exceeding 2,500 m^3/yr)	Uganda, Tanzania		
Vulnerable (1,700–2,500 m^3/yr)		Uganda, Tanzania	
Stress (1,000–1,700 m^3/yr)			Uganda, Tanzania
Scarcity (less than 1,000 m^3/yr)	Kenya, Rwanda, Burundi	Kenya, Rwanda, Burundi	Kenya, Rwanda, Burundi

Source: EAC 2011.

In addition, many aquifers in semi-arid and arid regions are overexploited because abstractions exceed recharge rates, causing environmental problems, increasing pumping costs, and the loss of the resource for future generations. Non-renewable resources are locked in deep aquifers with insignificant recharge and are being mined when abstracted, raising concerns about sustainability for the future (Margat et al. 2006). At the national level, groundwater availability and use is summarized below.

- In **Burundi,** not much is documented regarding the groundwater resources. However, estimates indicate that groundwater constitutes about 48 percent of the total renewable water resources in the country (Green facts 2015). The domestic groundwater supply is based on about 25,000 springs with different discharge rates that provide water through local gravity systems.

- **Kenya** has 55.973 billion cubic meters per year of groundwater. Given a sustainable groundwater yield is 10 percent of the groundwater recharge, the available water resource in 2010 was estimated at 26.2 billion cubic meters per year (Republic of Kenya 2013). Groundwater is used for several purposes including domestic consumption, crop production, and livestock and wildlife watering. Public water supply in the coastal strip is almost entirely dependent on groundwater. Some towns rely largely or exclusively on groundwater for public and private water supply. These include Wajir, Mandera, and Lodwar. In addition, groundwater resources are extensively used by industry, especially in Nairobi, Nakuru, and Thika.

- In **Rwanda**, there is little documentation on groundwater and aquifers. Available information estimates that groundwater discharge is about 66 cubic meters per second, with about 22,000 recognized sources, which have a total discharge of 9.0 cubic meters per second (REMA 2009). Rwanda groundwater storage is estimated to be 49 cubic kilometers (Macdonald et al. 2012). However, groundwater accounts for 86 percent of safe drinking water supply for rural areas in the eastern and southern provinces where boreholes are the major source of water supply. Large numbers of boreholes and shallow wells have been constructed in the eastern parts of the country since the 1990s. National statistics in 2009 indicated that there are at least 400 boreholes and wells in various parts of the country (Ministry of Natural Resource, Rwanda, 2011-2015).

- In **Tanzania**, groundwater supplies more than 25 percent of the domestic water consumption (JICA 2002). It is mostly used for drinking, irrigation, and industrial activities. It is also the main source of water for most rural areas of Tanzania and urban areas of Arusha, Dar es Salaam, Dodoma, Manyara, Shinyanga, Simiyu, and Singida (Kashaigili 2012). These resources are also commonly used in the peri-urban fringes where there is no supply distribution network and in areas with unreliable piped water supply. There are over 5,000 recorded deep boreholes drilled both as exploratory and production wells throughout the country. Since 1997, more than 10,000 groundwater supply sources have been developed in Dar es Salaam alone (Mjemah et al. 2012, Mtoni et al. 2013).

2.1.2 Access

Table 7 shows an increasing trend in access to and probable increase in consumption of water for the period 2001–2011 in all the East African countries, thereby putting more pressure on readily available water resources.

Table 7: Access to Water in EAC Partner States

Indicator	Partner state	Percentage coverage of access to water each year										
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Rural	Burundi	43	43	49	49	49	49	55	55	55	55	55
	Uganda	50	53	53	54	56	56	57	58	59	59	59
	Tanzania	50	51	54	57	61	59	64	64	70	70	-
	Kenya	-				48	48	48	48	48	48	48
	Rwanda	-				59	59	59	59	59	59	59
Urban	Burundi	95	89	89	89	85	85	88	88	88	88	88
	Uganda	66	67	73	76	78	80	80	80	80	80	80
	Tanzania	55	60	63	65	87	87	87	87	92	92	
	Kenya	-	-	-	-	83	83	83	83	83	83	83
	Rwanda	-	-	-	-	87	87	87	87	87	85	85
Overall	Burundi	52	66	66	66	67	67	72	72	72	72	72
	Uganda	-	56	56	57	68	68	68	68	74	74	74
	Tanzania	54	56	56	57	68	68	68	68	74	74	-
	Kenya	-	-	-		57	57	57	57	57	57	57
	Rwanda	-	-	41	43	47	57	63	74	74	74	74

Source: EAC Facts and Figures 2012.

Access to safe water supplies throughout Uganda is 65 percent. Although the number of people with access to safe water and sanitation has improved over the past 10 years, many communities (both rural and urban) still rely on contaminated water sources such as streams and open wells. The rapidly growing populations in the EAC Partner States and migrations to urban areas have resulted in the need to establish centralized water systems to supply potable water to residents. Further, climate change, affluence, and population growth have resulted in increasing demand of water for domestic, industrial, and agricultural use. Access and consumption of safe potable water for the East African Partner States between 2001 and 2012 is shown in Table 8. Climate change will increase irrigation demand due to the combination of decreased rainfall in certain regions and increased evapotranspiration, placing additional pressure on irrigation systems that are in many cases already under-performing. Soil erosion from increased rainfall intensity (episodic rainfall) could affect watershed sustainability and lead to sedimentation in reservoirs, affecting the operation of multipurpose facilities. Extreme variability or reduced supplies could stretch the infrastructural and institutional limits of systems that manage water across sectors. Reduced availability of water for irrigation could threaten food security, rural development, and the economies of East Africa for which agriculture is the economic backbone. Some rivers will be adversely affected as they arise from glacial melts, hence the loss of those glaciers would reduce water for hydropower generation and decrease electricity grid reliability, with consequent effects on the economy. Sedimentation (particularly serious in the LVB catchment) will affect supply and quality of water with consequent impacts on the larger economy. Issues on competition over limited water resources have been raised and have the potential to cause conflicts.

Table 8: Water Usage by Sector within East African Countries

Country	Year	Irrigation (%)	Domestic municipal supply (%)	Industry (%)
Burundi	2000	77.1	17.0	5.9
Kenya	2003	79.2	17.1	3.7
Rwanda	2000	68.0	24.0	8.0
Uganda	2002	40.0	43.3	16.7
Tanzania	2012	92.9	6.1	1.0

An overview of the water access situation in the EAC shows the following:

- A large share of the population in Burundi has no access to clean drinking water. Natural springs are the main sources of water supply. These groundwater-fed sources provide approximately 90 percent of all drinking water (UNEP 2010). However, the proportion of the population supplied with drinking water has risen from about 50 percent in 2008 to 60 percent in 2012. In other words, over a million more people have access to drinking water. However, access to adequate sanitation is extremely low at 13 percent in rural areas and 33 percent in urban areas (2012), which means that the water quality is still negatively affected.

- Most of the population in Kenya lacks potable household water. According to the national population census of 2009, only about 28 percent of the population had piped water while 37 percent obtained their water from springs, wells, or boreholes that were either improved or unimproved (Government of Kenya 2009). Furthermore, over 29 percent of the population gets water directly from sources such as streams, lakes, ponds, and other sources that are considered unsafe. The lack of or constraints on water supplies consumers face are not primarily due to absolute shortages in the natural endowments, but rather, the infrastructure is underdeveloped.

- In Rwanda, 25 percent of the population is unable to access safe drinking water, while 26 percent has no access to improved sanitation facilities. Rural areas are more affected. Urban settlements without adequate sanitation have increased pollution of surface water and groundwater pollution due to fewer sewer structures and treatment networks. While rich mineral resources boost the national economy, mining activities have led to increased river water contamination and sedimentation. Agriculture, which accounts for 37 percent of GDP, is another contributor to water pollution through inappropriate application of fertilizers and pesticides. On the other hand, in the urban populations access to water is at 80 percent and access to sanitation is 24 percent.

A summary of trends in the EAC Partner States is presented below.

- **Burundi** is endowed with plentiful surface water resources, however industrial and domestic activities in the urban centers affect the quality of incoming water. In 2000, 70 percent of the population had access to improved drinking water and this improved to 75 percent in 2012. Most of the water withdrawn is used in agriculture. In the year 2000 the sector used 77 percent of the water, 17 percent went to domestic water supply and 5.9 percent was used by industries.

- In **Kenya**, about 13 million people lack access to an improved water supply while 19 million lack access to improved sanitation (NEMA 2015). This is much higher than in other African low-income countries, where only one-third of the population relies on surface water (WHO/UNICEF 2014). It should be noted that the relatively high proportion of water used by agriculture and irrigation is due to the low levels of developed infrastructure for water supplies, rather than absolute water availability.

- **Rwanda** has a relatively high abundance of water resources. The country is located within the watersheds of both the Nile and Congo rivers. The surface waters cover over 8 percent of the country's area (FAO 2005). However, access to potable water remains a challenge. An estimated 35 percent of Rwanda's approximately 10 million people have no access to an improved drinking water source (FAO 2005). Since 1994, Rwanda has invested heavily to provide safe water to the population. In this regard, the goal has been to increase improved drinking water coverage from 65 percent in 2008 to 85 percent in 2015 and increase access to improved sanitation from 54 percent to 65 percent in 2015. Between 2000 and 2012 sanitation coverage improved from 47 percent to 64 percent overall and from 45 percent to 64 percent in rural areas (WHO/UNICEF 2014). However, meeting the MDG target for the provision of clean water was a challenge due to poorly developed wastewater systems (UNEP 2010).

- In **Tanzania,** the total water withdrawal was estimated at 4,975 cubic meters in 2012 (WHO/UNICEF 2014). Agriculture takes the biggest share at 93 percent, while municipal use accounts for 6 percent and industrial use 1 percent. Access to water and sanitation remains low. In 2000, 54 percent of the population had access to improved drinking water, this dropped to 53 percent in 2012. Access to unimproved water sources took a negative trend moving upward from 27 percent to 30 percent between 2000 and 2012.

- **Uganda** has ample water resources and successful reforms have enabled the country to increase access to improved drinking water coverage from 56 to 75 percent, between 2000 and 2012, becoming the highest in the five East African countries. In the same period, access to drinking water for the urban population increased from 85 to 95 percent. However, 17 percent of the rural population still lacks access to improved drinking water and 40 percent lacks access to improved sanitation (FAO/WHO 2014). Industrial consumption of water is high compared to the other EAC Partner States. In 2002, the industrial usage of the total water withdrawn was about 17 percent. Agriculture accounts for 40 percent of water withdrawal. Industrial and agrochemical pollution of water is rising. In the last three decades the population has more than tripled, but urban infrastructure has not developed at the same rate and most of the urban population lives in unplanned, underserviced slums, which lack piped water.

In general, in rural areas 45 percent had access to improved water while 32 percent had access to an unimproved water source (Figure 11).

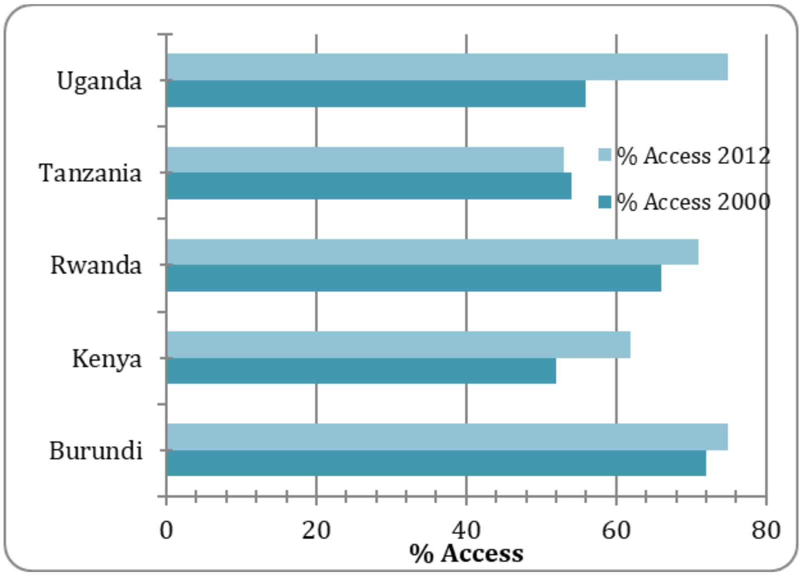


Figure 11: Access to Improved Drinking Water Sources (source: WHO/UNICEF 2014)

2.2 WATER QUALITY

Considerable changes in the physical, chemical, and biological properties of water sources within the basin have been observed over a period of 50 years (EAC 2007). The changes are particularly due to increasing and considerable pressure from a variety of interlinked human activities in the catchment; such as industrial and municipal activities within urban centers, wetlands degradation, and deforestation. The major urban centers of Kampala, Entebbe, Masaka, and Jinja in Uganda; Mwanza and Musoma in Tanzania; Kisumu in Kenya; and Kigali in Rwanda are hotspots for point and nonpoint sources of pollution within the basin (Figures 12 and 13). Pollutants from the urban centers originate from manufacturing industries, inefficient wastewater treatment facilities, and dumping of solid wastes (LVEMP 2005, Kiwango and Wolanski 2007). In addition, sediment loading from degraded catchments is an important source of nutrient and sediment loads, which are transported by rivers and streams into gulfs, bays, and some near-shore areas within the basin (Table 9). High concentrations are recorded in the north and southern sections of the lake (LVEMP 2005).

Among the most significant impacts from pollution is the increase in nutrient input in the form of nitrogen and phosphorus, hence widespread eutrophication with massive proliferation of algal blooms. Compared to historical data, phosphorus concentrations in Lake Victoria have increased 4-8 fold, from 0.02–0.047 milligrams per liter (Talling 1957) to 0.078–0.140 milligrams per liter (LVEMP 2005). In some sections of the lake, such as inner Murchison Bay, the concentrations are currently 4 milligrams per liter (LVEMP II, 2014). Relatively high levels of total phosphorus of greater than 1 milligrams per liter were also observed within the Mara River Basin (Kilonzo et al. 2013). Similarly, nitrogen concentrations show an increasing trend with levels greater than 1 milligrams per liter in open waters within Mara River Basin and inner Murchison Bay.

Table 9: Annual External Nutrient Loading into Lake Victoria

Pollution Source	Loading to Lake Victoria (t/y)		
	BOD Load	Nitrogen Load	Phosphorus Load
Domestic Waste (including urban runoff)	17,938	3,505 (1.68%)	1,624 (4.24%)
Industrial Sources	5,606	414 (0.21%)	342 (0.89%)
River Basin	25,122	49,509 (23.78%)	5,693 (14.86%)
Runoff from Cultivated Land	...	22,966 (11.03%)	2,297 (6.00%)
Runoff from Non-cultivated Land	...	29,615 (14.23%)	3,949 (10.31%)
Atmospheric Wet Deposition	...	62,601 (30.08%)	11,831 (30.89%)
Atmospheric Dry Deposition	...	39,550 (18.99%)	12,567 (32.81%)
Total	48,666	208,160 (100%)	38,303 (100%)

Source: LEVMP 2003.

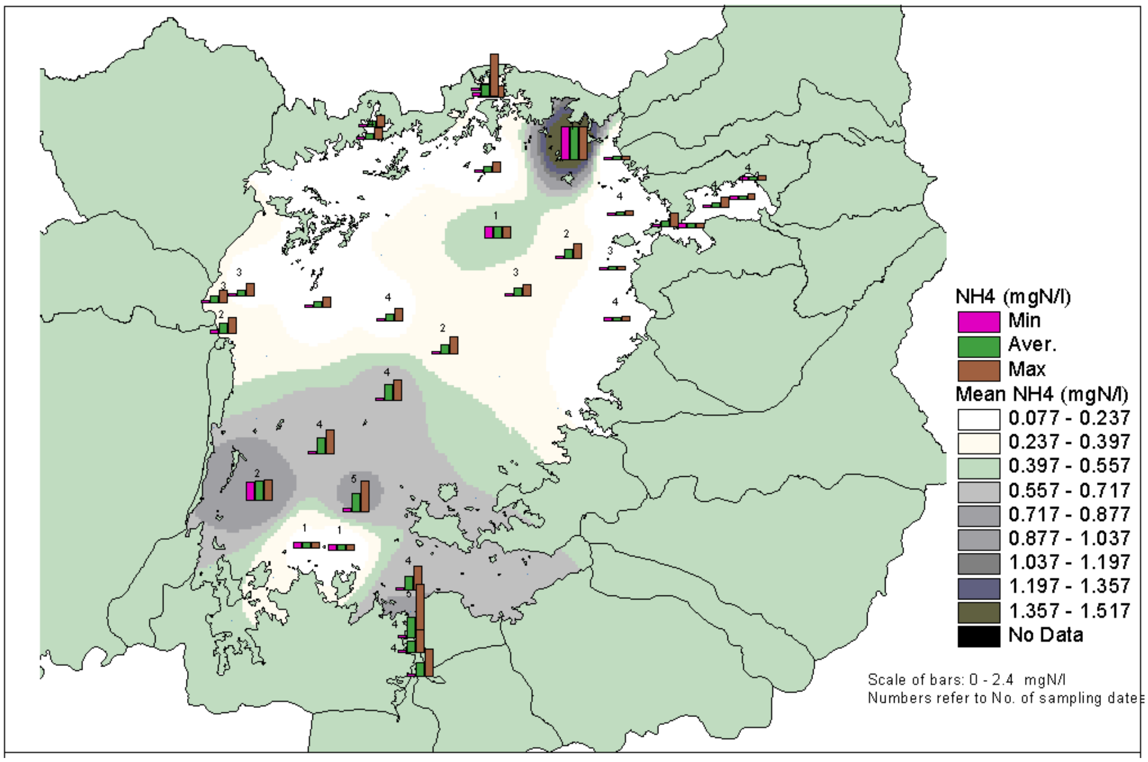


Figure 12: Ammonium Concentrations over Lake Victoria Basin

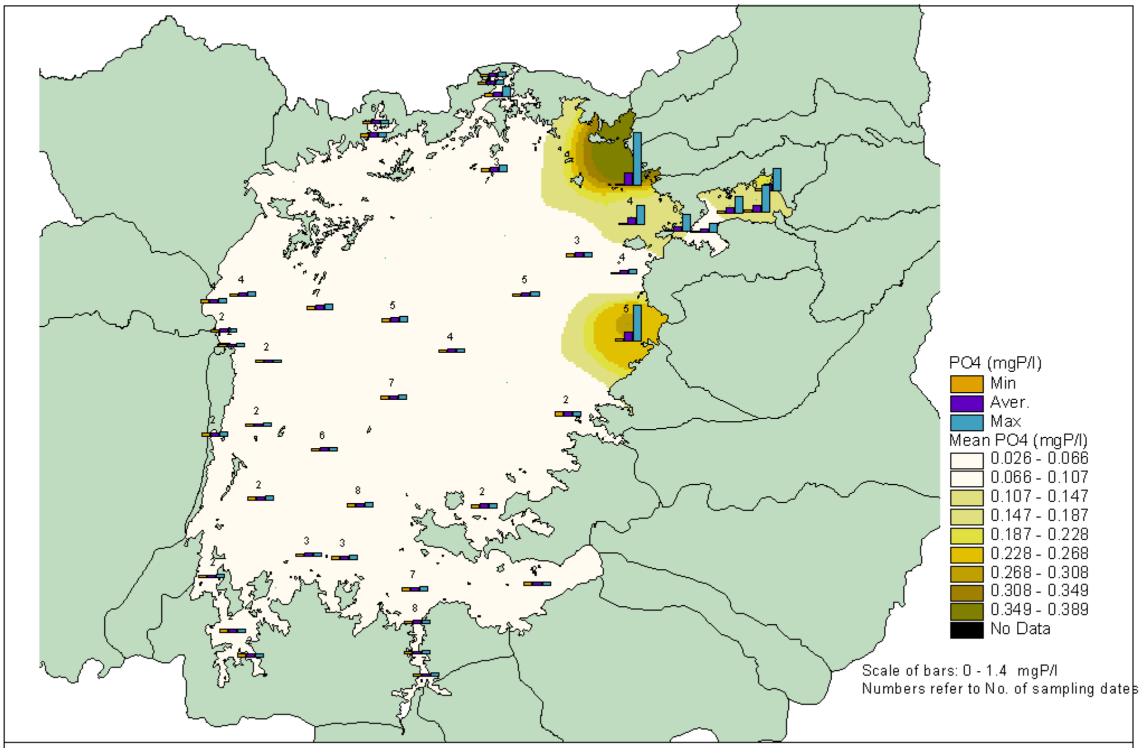


Figure 13: Phosphate Concentrations over Lake Victoria Basin, Note: High phosphate values are recorded on the northeastern part of the lake where the Kenyan rivers enter the lake (LVEMP 2005)

Algal blooms affect the dissolved oxygen content of the water leading to anoxic conditions. Kiwango and Wolanski (2007) reported declining levels of oxygen spreading across larger parts of Lake Victoria. Within the inner Murchison Bay of Lake Victoria dissolved oxygen levels of 0–2 milligrams per liter have been reported for a big part of the year (LVEMP II 2014). In recent years many of the bays around the shore have been invaded by water hyacinth (*Eichhornia crassipes*); the influence of the species on the lake water balance will depend on its extent.

Sediment yield from degraded catchments within the basin have affected water quality in terms of suspended solids, turbidity, and nutrient concentrations (GLOWS 2007). High nutrient loads have been attributed to agricultural runoff, which accounts for as much as 75 percent of the nitrogen flow into the lake (Kiwango and Wolanski 2007). About 6,511,950 tons of total suspended solids per year are entering the lake from the catchment drainage.

2.3 AQUATIC ECOSYSTEMS

A significant proportion of populations in East Africa rely on ecosystems for the provision of goods such as fresh water, food (meat and fish), building materials, and energy sources (timber, biomass, etc.). Areas with many resources derived directly from ecosystems tend to attract the populations using those resources (EAC 2011). As a result, most of the natural habitats have been modified in some way by human activities, for instance through crop farming, grazing, tourism development, and sand and clay mining. According to the 2005 Millennium Ecosystem Assessment, 15 of 24 ecosystems services upon which people directly rely are at risk of further degradation relative to current status. It is predicted that climate change will have a strong negative impact on already degraded ecosystems.

The aquatic ecosystems within the LVB are fragile. A wide range of socioeconomic activities constrain their management and development. These ecosystems have come under increasing stress, which is raising conservation concerns, among them increased pressure on resources, losses of habitats and biodiversity, increased water pollution, and degradation of the environment. Competing land use and land and ecosystem degradation has been identified as one the most important factors affecting the persistence of biodiversity, ecosystems, and ecosystem services.

Aquatic ecosystems in Burundi and Rwanda are mainly threatened by degradation of the riverbanks while those in Kenya, Uganda, and Tanzania face additional threats from pollution, sedimentation, loss of wetlands, eutrophication, and water hyacinth. These challenges have had serious effects leading to loss of critical habitats and consequently to negative impacts on biodiversity. Reduction of "spongy-like" effect of wetlands has also been affected leading to floods such as those witnessed in Nyando (Kenya) (EAC 2007).

Among the major threats to the biodiversity in the Lake Victoria are habitat loss or modification due to increasing human population, deforestation, farming, over-grazing, human settlements, illegal hunting, infrastructure development, and tourism. Over-abstraction of water and alteration in river flow regimes pose particular threats to biodiversity and livelihoods in semi-arid regions. Deforestation and discharge of agro-chemicals, waste, and refuse to water bodies pollutes the water and results in decreased fish biodiversity and altered food webs. More recently, water hyacinth is believed to be a major reason for the alteration of many communities of aquatic and terrestrial species associated with the lake. These changes are also strongly affecting the harvesting of aquatic resources. In addition, inputs of nitrogen and phosphorus from atmospheric deposition and nutrients applied to the land and carried into the LVB by tributaries result in excessive nutrients in the water, which is detrimental to aquatic life.

In **Rwanda,** wetlands fringe most of the river systems and lakes in the basin. The entire aquatic system within the LVB consists of a vast wetland comprising of riverine swamps and shallow lakes, most less than four meters deep. Wetlands in Rwanda are categorized into upland and floodplain types. Upland wetlands occur mostly in the mountainous western and northern zones of the country perched in the valleys along tributaries of the Nyabarongo, Akanyaru, and the Maziba rivers. The floodplain wetlands stretch several kilometers straddling the border between Rwanda and Burundi where it is marked by the Akanyaru and Akagera rivers. Extensive floodplains of the Nyabarongo and Akanyaru rivers in southern Rwanda and the Akagera River are found along the country's eastern border with Tanzania.

Tanzania accounts for the largest area of wetlands in the basin with a total of 422,000 hectares of wetlands in 28 distinct sub-basins. The major wetlands include Mara, Rubana, Simiyu, Magogo, and Kagera, among others. An estimated 57,000 hectares of total wetland area is classified as permanent swamp.

In **Uganda,** wetlands cover 13 percent of total surface area of the basin and have been categorized as swamp (8,392 square kilometers), swamp forest (365 square kilometers), and zones with impeded drainage (20,392 square kilometers). They include Nabugabo Wetland, Mabamba, Sango Bay, and Lutembe. They form areas of seasonally flooded grasslands and swamp forest (such as Sango Bay), permanently flooded papyrus, grass swamp, and upland bog. Most wetlands in the country fall into two broad categories, namely those associated with lakes (lacustrine) and those that lie along rivers. These include wetlands that border the bays of Berkeley at the Kenya/Uganda border, Macdonald, Hannington, and Napoleon Gulf; as well as Murchison, Waiya, and Bunjako bays. The islands of Kalangala also have extensive fringes of wetlands. Lacustrine wetlands are often permanently flooded.

2.3.1 Fisheries and Aquaculture

The fisheries sector contributes about 4 percent to the regional GDP in East Africa. This production offers direct support to an estimated population of over 5 million people. The region is the leading producer of freshwater fish in Africa based largely on production from Lake Victoria (FAO 2014). This situation has been made more complex by dominance of Nile perch fisheries, which have been linked to dramatic reduction of biodiversity in the region while also contributing to increased export earnings and employment.

Lake Victoria alone produced 804,000 tons of fish over 10 years ago, an increase of nearly 30 percent compared to year 2000 and 50 percent compared to 1980. Fishing effort increased substantially during 2000–2005: the number of fishermen increased by 52 percent, fishing craft were up by 63 percent, and motorization was up 211 percent (Figure 14).

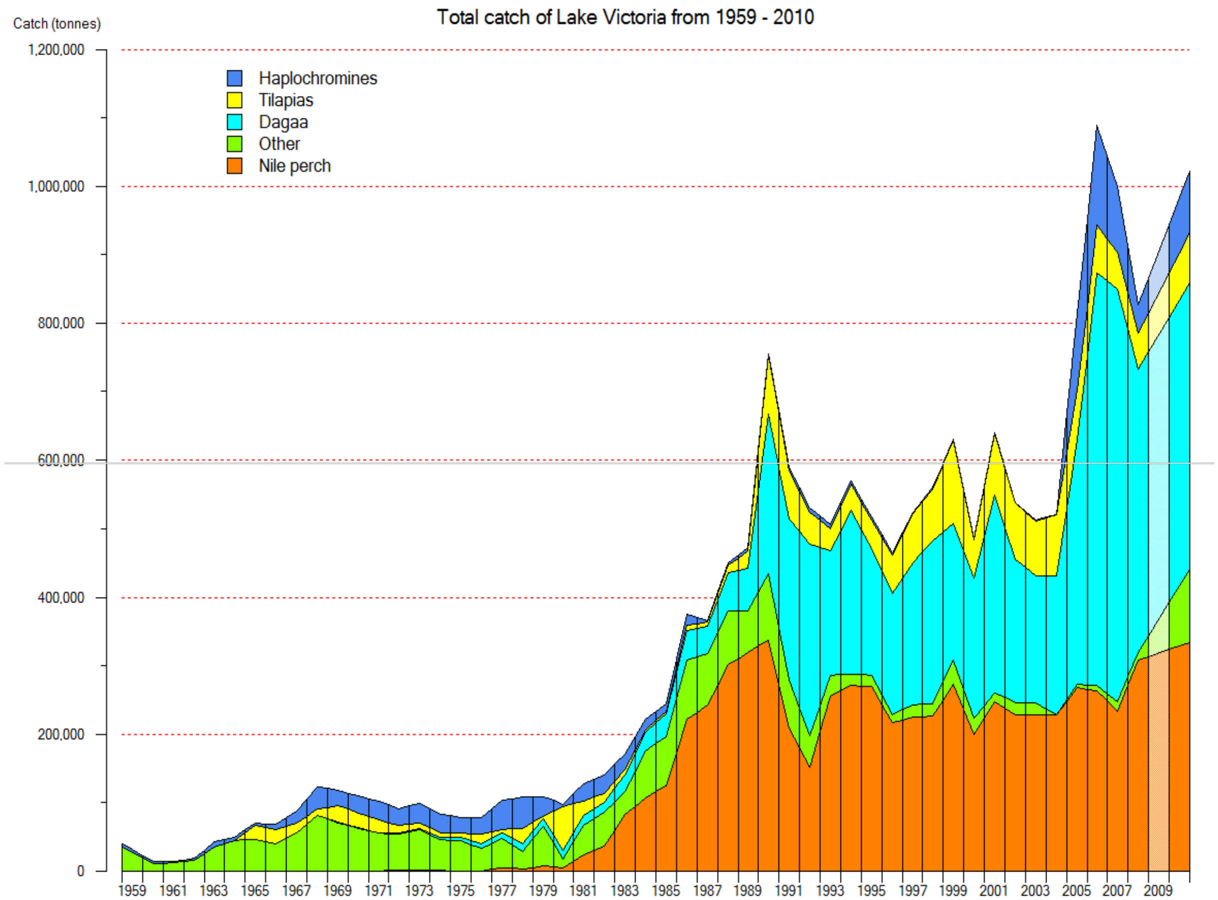


Figure 14: Total Annual Fish Catches (tons) from Lake Victoria, 1959–2010 (source: Kolding et al. 2014)

Currently, Lake Victoria fisheries are estimated to produce 1 million tons per year of which about 67 percent is from the Tanzanian part of lake, followed by 19 percent from Uganda and 15 percent from Kenya (Regional Catch Assessment Survey Synthesis Report 2005–2011) based on three commercial species: Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*), and dagaa (*Restrineobola argentea*) (LVFO 2013). This is a change from a diverse multispecies fishery of the 1980s.

The fishery provides food security to a large segment of the population throughout the region but specifically supports over 3 million livelihoods (LVFO 2009). According to LVFO (2013), there are over 200,000 fishers (20 percent Kenya, 31 percent in Uganda, and 49 percent in Tanzania) and about 600,000 people involved in fish processing and fish meal industries around the lake.

The fishery contributes 2 percent of GDP for Kenya and 3 percent for both Tanzania and Uganda (World Bank 2009). The state of fisheries is of major concern to the riparian states and there has been a general view that fish catches are declining and that the fishery may be in danger of collapse (LVFO 2014). This is due to environmental degradation within the catchment that increases the silt load in the waterways and overfishing.

The introduction of alien species like the Nile perch is estimated to have reduced the number of fish species by 200 (Kaufman 1992). Rapidly increasing fishing effort in recent years may have reduced biodiversity further. Biodiversity loss affects the ecosystem functioning with potential consequences for the resilience of ecosystem functions that humans depend on. There are also indications that overfishing of Nile perch has been beneficial for biodiversity in the lake by reducing predation pressure on other fishes.

The increased value of fish owing to the expanded local, regional, and international fish trade has led to stagnation and collapse of many of the key natural fisheries stocks across the region. The EAC has a per capita fish supply under 8.0 kilograms of which less than 5.0 kilograms is consumed locally (Table 10).

Table 10: Fish Production and Consumption in EAC Countries (in 2014)

	Burundi	Kenya	Rwanda	Tanzania	Uganda	Total
Inland waters (km^2):	2,180	13,400	1,390	>61,500	36,330	114,800
Marine waters (km^2):	N/A	230,0000	N/A	287,300	N/A	517,300
Major inland waters and percent share	L. Tanganyika	L. Victoria 6%	L. Kivu – >50% R. Kagera – source	Lake Victoria > 90%	L. Victoria 73% Lakes. Albert, Kyoga, Edward R. Nile (27%)	
Marine coastline km	N/A	536	N/A	424	N/A	960
EEZ (km^2)	N/A	142,400	N/A	230,000	N/A	372,400
Inland fish production	12,309	156,860	19,475	372,257	407,638	968,269
Inland aquaculture	160	21,488	516	9,917	95,906	127,987
Marine production (t)	N/A	10,000	N/A	15,000	N/A	25,000
Total fish production (t)	12,469	188,348	19,991	397,174	503,544	1,121,526
Population	9,850,000	43,178,000	11,458,000	47,783,000	36,346,000	148,615,000
Per capita supply kg/yr	1.3	4.4	1.8	8.3	13.9	7.6
Per capita consumption kg/yr	1.0	3.1	1.6	6.5	8.5	4.0
Production value USD/yr	783,000	250,000,000	25,000,000	500,000,000	800,000,000	1,575,783,000
Imported fish value (USD/yr)	104,000	8,300,000	10,000,000	250,000	1.600,000	48,538,000
Direct employment (jobs)	4,000	65,500	40,000	202,654	400,000	557,552
Indirect employment (jobs)	120,000	300,000	200,000	600,000	1,100,000	2,441,748
Estimated livelihoods	300,000	1,600,000	1,000,000	2,000,000	2,800,000	8,652,000
Leading source of fish	Inland fisheries	Inland fisheries	Imported fish	Inland fisheries	Inland fisheries	Inland fisheries

Source: FAO Yearbook of Fishery and Aquaculture Statistics - Commodities Summary Tables (PDF) 2014.

The upsurge in East Africa's aquaculture production has been remarkable: Uganda aquaculture expanded from a paltry 285 tons in 1999 to nearly 100,000 per year and Kenya is reporting over 40,000 tons in annual aquaculture production, up from less than 2,000 tons in 2007. Tanzania is producing nearly 10,000 tons (7,000 from sea and 3,000 from farmed fish), up from less than 3,000 tons in 2005. Rwanda has expanded from less than 500 tons to over 1,500 tons annually and Burundi, which is currently reporting nearly 500 tons of farmed fish annually, has increased from less than 200 tons in 2010. The trend is projected to continue upward toward aquaculture production becoming the main supply of fish in EAC within 10 to 15 years.

3. ASSESSING AND MAPPING CURRENT VULNERABILITY AND HOTSPOTS IN THE LVB FOR WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE SECTOR

3.1 MAPPING VULNERABILITY HOTSPOTS FOR THE WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE SECTOR

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) notes that the vulnerability to current climate variability and future climate change particularly threatens the development of poor and marginalized people (Fritzsche et al. 2014). Vulnerability assessments are therefore useful to identify climate change impact hotspots and to provide input for adaptation and development planning at local, national, and regional levels. They provide a framework for identifying and prioritizing adaptation interventions to target those systems that will be most affected by adverse climate change impacts. In planning climate change adaptation, the concept of "vulnerability" can help in understanding what lies behind adverse climate change impacts and to identify communities or ecosystems that are most at risk.

The conceptual framework used to determine the sector vulnerability analysis is shown in Figure 15. This approach is based on the widely used definition provided by the IPCC (in AR4). The adopted from de Sherbinin (2013) was used for the vulnerability mapping of Mali. It refers to vulnerability as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is also a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC Parry et al. 2007).

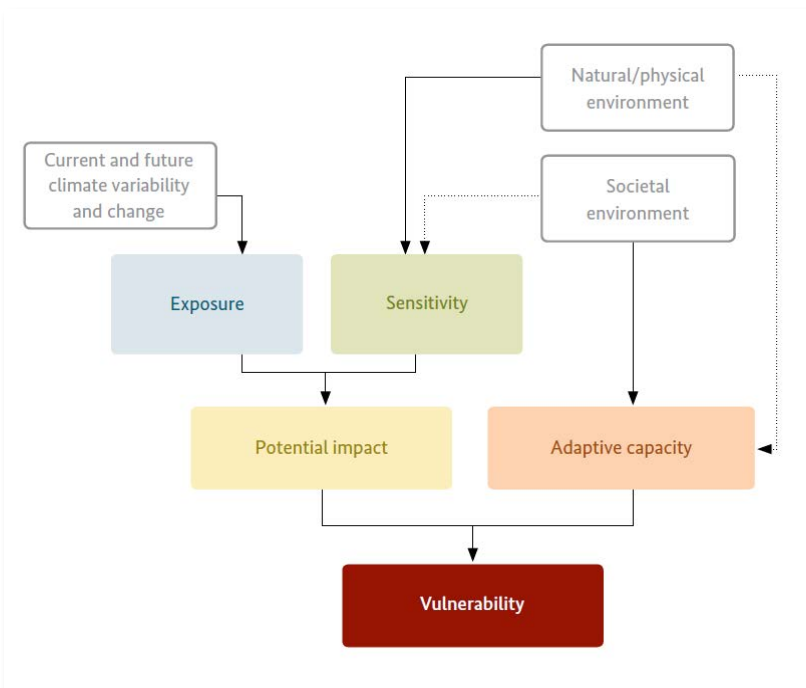


Figure 15: The Vulnerability Framework (source: Fritzsche et al. 2014)

Based on this definition, four components are recognized as determinants of vulnerability: exposure, sensitivity, potential impact, and adaptive capacity. However, vulnerability to impact also depends on the system's adaptive capacity. The four components of the system are described in Box 3.

Box 3.1: Components of Vulnerability

1. **Exposure** is directly linked to climate parameters, that is, the character, magnitude, and rate of change and variation in the climate. Typical exposure factors include temperature, precipitation, evapotranspiration, and climatic water balance, as well as extreme events such as heavy rain, floods, and meteorological drought. Changes in these parameters exert major additional stress on systems.
2. **Sensitivity** is the degree to which a system is adversely or beneficially affected by a given climate change exposure. Sensitivity is typically shaped by natural or physical attributes of the system. It also includes human activities, which affect the physical constitution of a system, such as water management and population pressure.
3. **Potential impact** of climate change is determined by a combination of exposure and sensitivity.
4. **Adaptive capacity**, as described in the IPCC's AR4 is "the ability of a system to adjust to climate change (including climate variability and extremes)."

Source: Fritzsche et al. 2014

3.1.1 Identification and Selection of Indicators

The approach used a spatial vulnerability index consisting of 29 indicators grouped into three vulnerability components: climate exposure, sensitivity, and adaptive capacity resulting in 12 unique spatial indicators (shown in Table 11). Selection of indicators was guided by the literature on factors known to contribute to each component of vulnerability, as well as consultations with stakeholders and data availability.

Data availability and quality was a critical determinant, the regional extent presented challenges in spatial and temporal resolution. For climate exposure indicators we relied on FEWS NET historical climate data (Funk et al. 2012) (PPTAV, PPTCV, TTREND, TMPCV, TMPTREND). Each data layer was justified based on its conceptual proximity or closeness to the three vulnerability components (Hinkel 2011).

Table 11: Indicators Used to Assess Vulnerability Components

Sector	Component	Data set	Code	Source
Water	Exposure	Annual average Precipitation	PPT_AVG, MAM_PPT_AVG, SOND_PPT_AVG,	CHIRPS blended satellite-station precipitation
		Coefficient of Variation in Annual Precipitation	PPT_CV, MAM_ PPT_CV, SOND_ PPT_CV	CHIRPS blended satellite-station precipitation
		Long-Term trends in Precipitation	PPT_TREND, MAM_ PPT_TREND, SOND_ PPT_TREND	CHIRPS blended satellite-station precipitation
		Annual average Land Surface Temperature	TMIN_AVG, TMAX_AVG	Climate Hazards Group (CHG) Land surface Temperature

Sector	Component	Data set	Code	Source
		Coefficient of Variation in Maximum Annual Land Surface Temperature	TMAX_CV, MAM_TMAX_CV SOND_TMAX_CV	Climate Hazards Group (CHG) Land surface Temperature
		Long-Term trends in Land Surface Temperature	TMAX_TREND, TMIN_TREND, MAM_TMIN_TREND, SOND_TMIN_TREND	Climate Hazards Group (CHG) Land surface Temperature
		Flow accumulation	FLOW_ACC	SRTM DEM
		Flood Frequency	FLOOD_FREQ	UNEP GRID
	Sensitivity	Population trends	POP_TREND	GPW
		Poverty Index	POVI	DHS
		Water Stress	WATER_STRESS	WRI (Water Resource Institute)
	Adaptive Capacity	Digital Elevation Model (SRTM)	DEM	JPL

Note: CV = Coefficient of Variability, LULC = Land use/Land cover

3.1.2 Data Processing

Data was processed in ArcGIS Spatial Analyst to rasterize and standardize the spatial resolution and the projection as indicated in Figure 16.

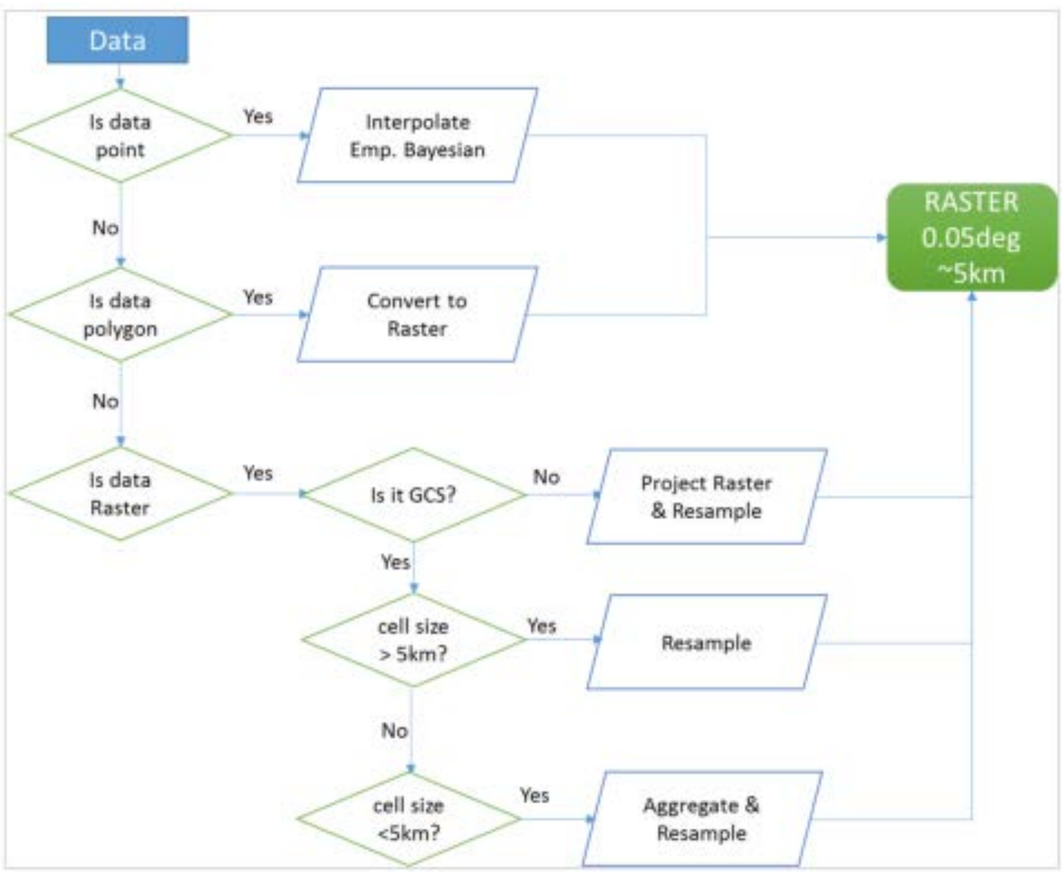
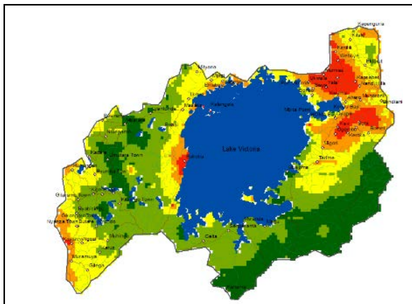
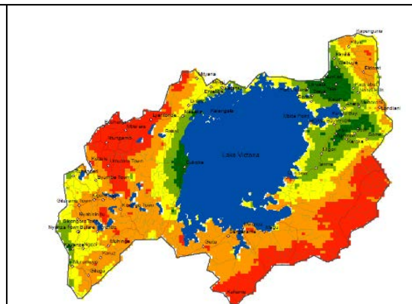
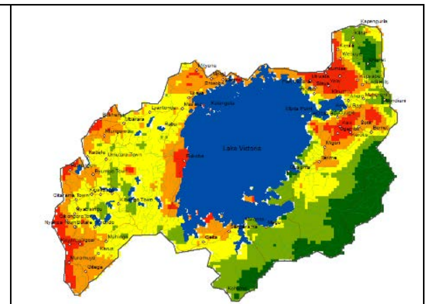
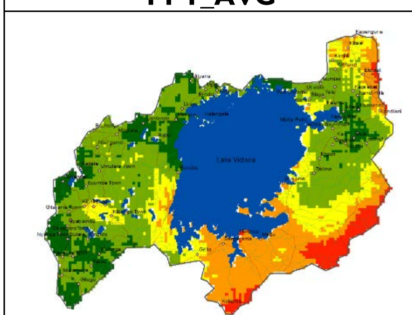
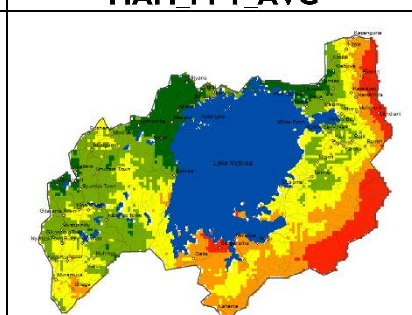
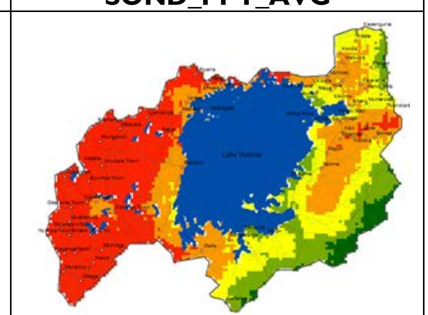
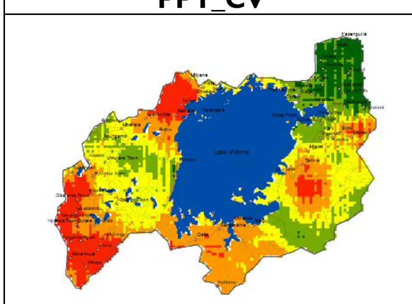
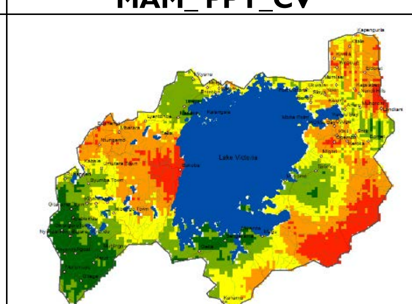
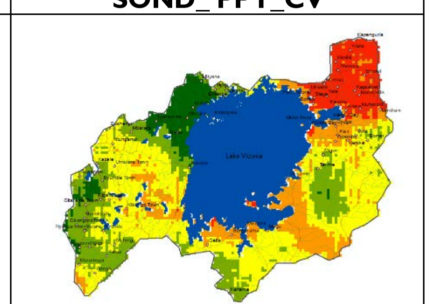


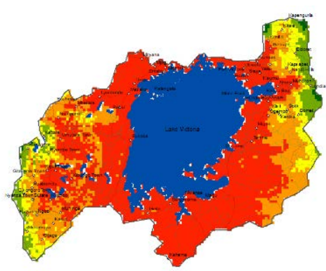
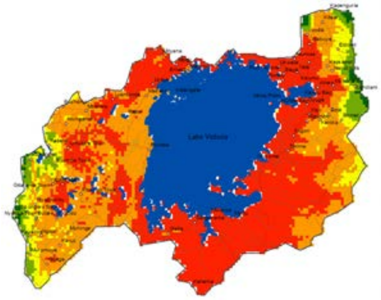
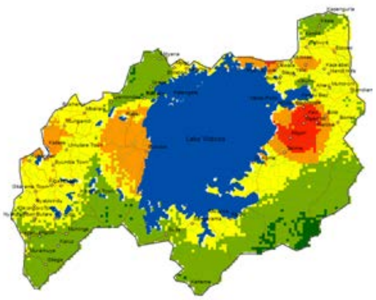
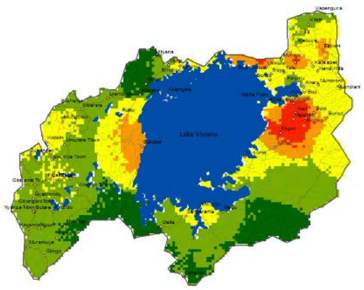
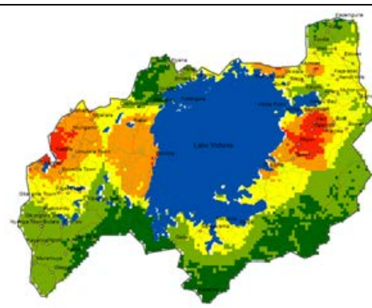
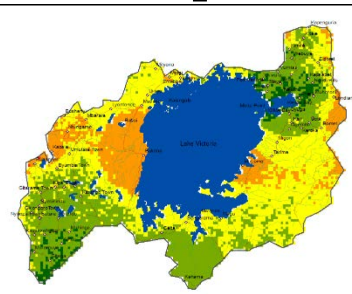
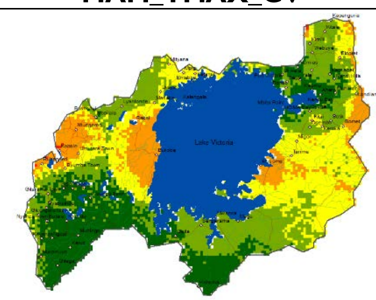
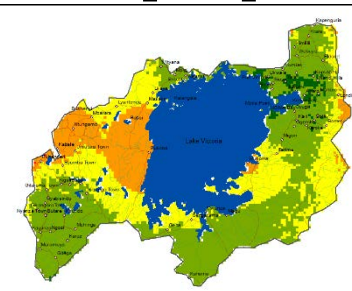
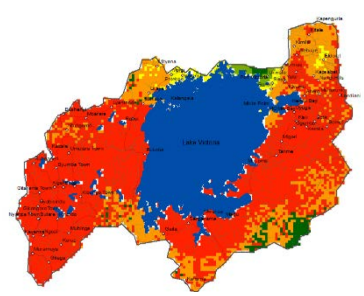
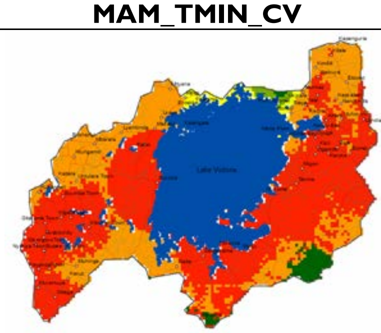
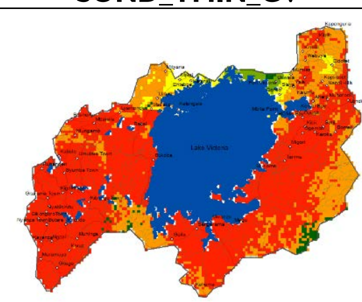
Figure 16: Data Processing Steps

Each data set was considered individually and its influence on vulnerability was evaluated. The data sets were then recoded based on expert judgment and the spread of data from the histograms. To allow comparison across all the different layers and components, the data sets were normalized on a scale of 1 to 100 using the raster calculator in Arc Map Spatial Analyst. In the development of the vulnerability components (exposure, sensitivity, and adaptive capacity), the component data sets were combined using a weighted sum in Arc Map's Spatial Analyst and normalized to a scale of 1 to 100. Similar steps were implemented to derive the overall vulnerability map for the water sector for the LVB.

3.1.3 Exposure

Climate stressors were processed and normalized. Rainfall Trends (PPT_TREND) and Average Rainfall (PPT_AVG) exhibited an inverse relationship to vulnerability and were normalized accordingly. Minimum and maximum temperature variables were provided. All the other climate variables exhibited a direct relationship to vulnerability in the water sector. LVB exhibited high average temperatures especially around Lake Victoria. The overall sensitivity was mainly influenced by temperature trends. Bukoba, Migori, Tarime, Rakai, and Ogembo exhibited very high vulnerability to climate stressors.

		
PPT_AVG	**MAM_PPT_AVG**	**SOND_PPT_AVG**
		
PPT_CV	**MAM_ PPT_CV**	**SOND_ PPT_CV**
		
PPT_TREND	**MAM_ PPT_TREND**	**SOND_ PPT_TREND**

		
TMIN_AVG	**TMAX_AVG**	
		
TMAX_CV	**MAM_TMAX_CV**	**SOND_TMAX_CV**
		
TMIN_CV	**MAM_TMIN_CV**	**SOND_TMIN_CV**
		
TMAX_TREND	**MAM_TMAX_TREND**	**SOND_TMAX_TREND**

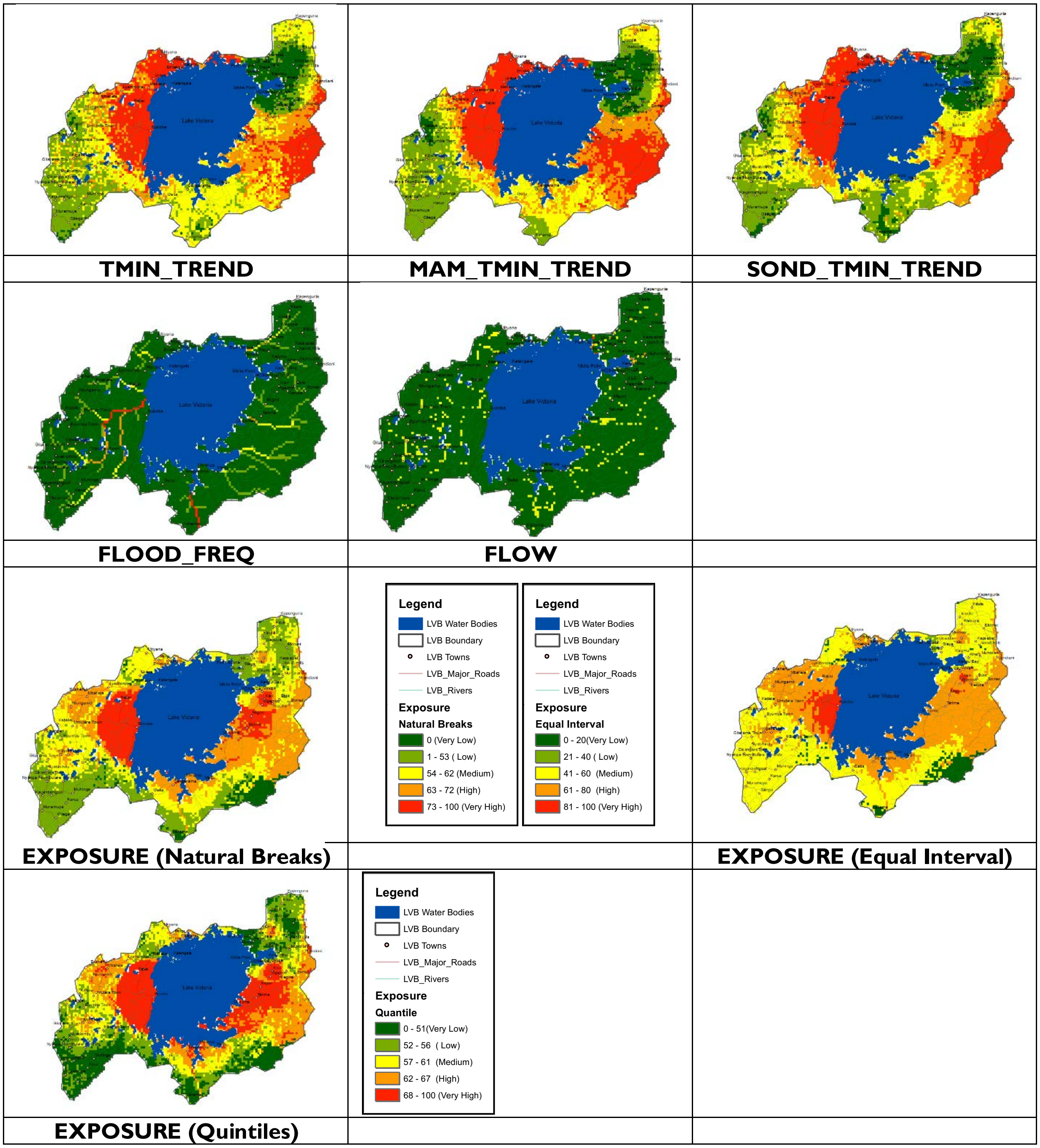


Figure 17: Maps indicating climate exposure in the LVB

3.1.4 LVB Sensitivity Layers

The overall sensitivity was highly influenced by the water access and poverty layers. The areas around Bukoba, Musoma, Tarime, Sengerama, Kahama, Bukoba, and Mbarara, exhibited high sensitivity due to these two factors. Pockets of medium to high sensitivity occurred around towns in the northern parts of Lake Victoria due to an increasing population trend.

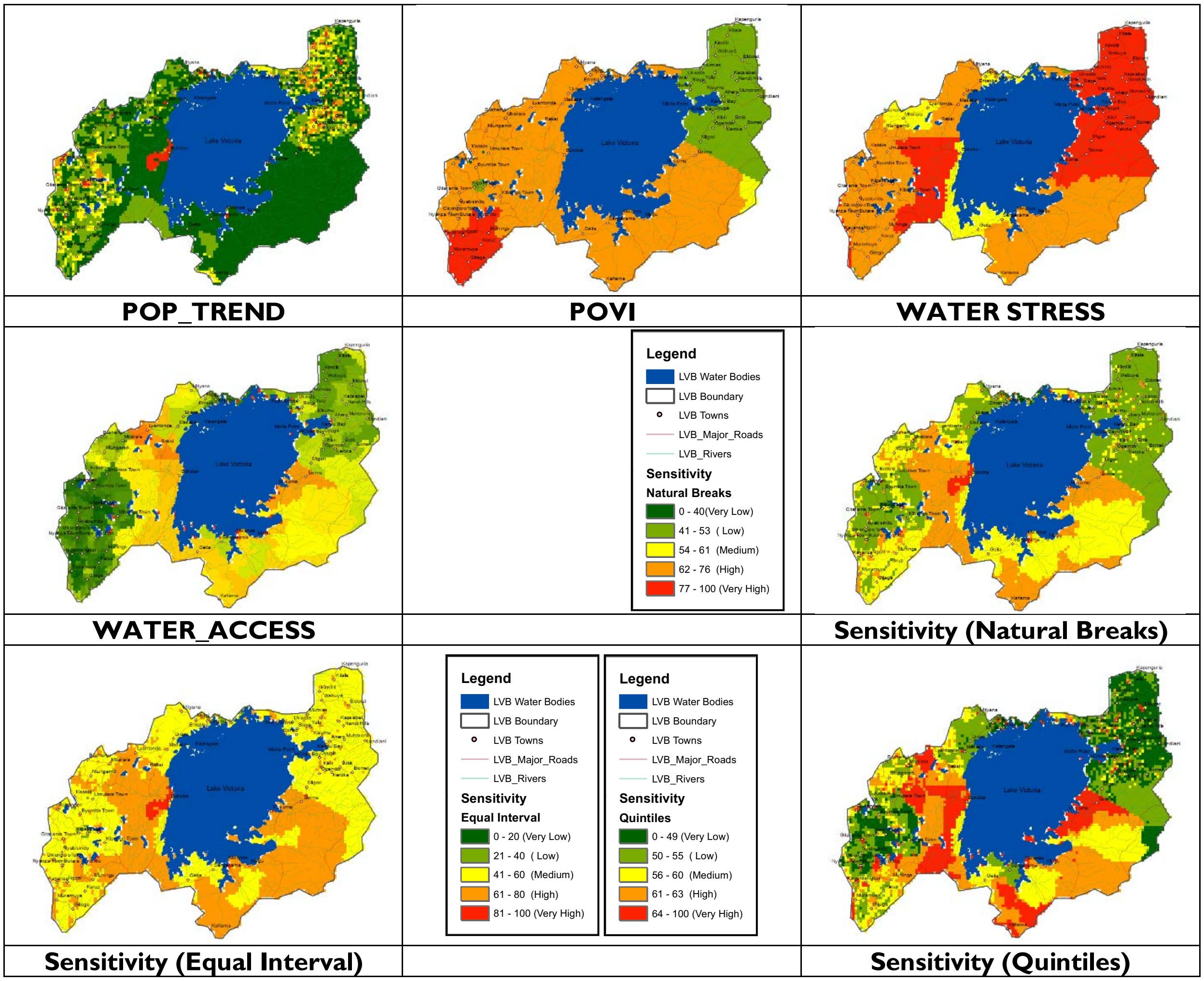
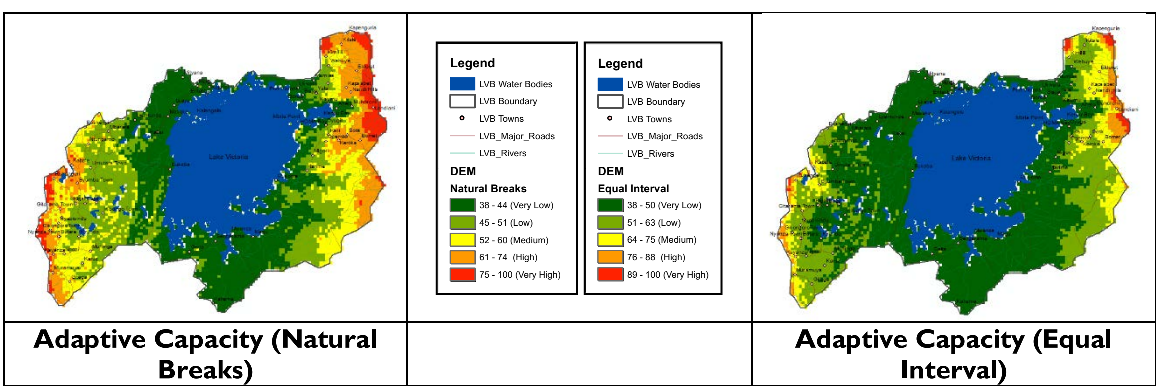
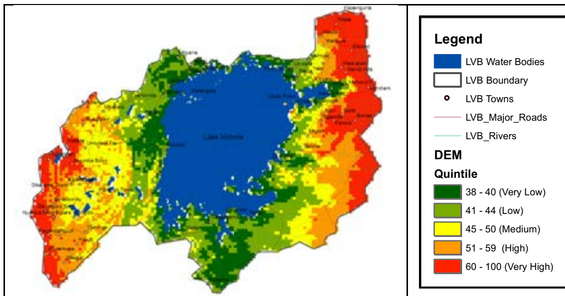


Figure 18: Maps indicating the sensitivity of water resources to climate change

3.1.5 LVB Adaptive Capacity Layers

The adaptive capacity component revealed a pattern low to high vulnerability with increase in elevation levels due to lesser water availability from perennial water bodies. Areas around Kitale, Eldoret, Nandi Hills, and Bomet in the east of the LVB and Gitega, Ruhengeri, and Kabale in Rwanda and Burundi exhibited high vulnerability.





Adaptive Capacity (Quintiles)

Figure 19: Maps indicating the adaptive capacity of water resources to climate change

3.1.6 Overall Vulnerability

The exposure and adaptive capacity layers had a greater influence on the overall vulnerability of the LVB region with areas around Bukoba, Tarime, Mwanza, Migori, Ogembo, Tarime, Bomet, Londiani, Kakamega, Rakai, and Mbarara experiencing high vulnerability.

Hotspots are critical regions in which water resources have higher sensitivity to global climate change than other regions (Alcamo and Henrichs 2002). The climate-related impacts projected in these hotspots include increase in water stress at the watershed level due to increased water withdrawals or decreasing availability of water, the fragile nature of the ecosystems, resource availability, socioeconomic factors, and climate variability (UNEP 2013).

In addition to the vulnerability mapping, this study undertook analysis of seasonal rainfall data for the period 1981–2014, using rainfall extracted from GEOCLIM data set. The result reveals that four areas within the LVB are experiencing significant climate variability and hence from a water perspective may experience major impacts. These are:

1. Lake Cyohoha, where seasonal rainfall trends have significantly decreased during both SOND and MAM seasons.
2. Lake Navugabo, where there is significant decrease in SOND season rainfall.
3. Southwestern Mau and Mwanza Gulf experience high variability and increasing trends in the MAM season rainfall.

The Cyohoha, Navugabo, and Mwanza gulfs were thus identified as potential hotspots as was the southwest of Mau, which is the location of the Mara River headwaters where the main perennial tributaries, the Amala and the Nyangores rivers, drain from the western Mau Escarpment into the Mara.

Based on the above results, a review of the LVB climate change vulnerability maps produced by RCMRD, and previous studies—such as those identified as priority Biological Sensitive Areas (BSAs) by the PREPARED Ecosystem Profile Assessment for the LVB—the following sites were identified through a scoring of various criteria as potential hotspots for the sector (summarized in Table 11). Additional criteria included the following:

- Criticality for water quantity and quality at local and national level
- Transboundary extent
- Habitat for threatened species or species of conservation concern
- Socioeconomic concerns, especially expected impacts on aquatic biodiversity and fisheries.

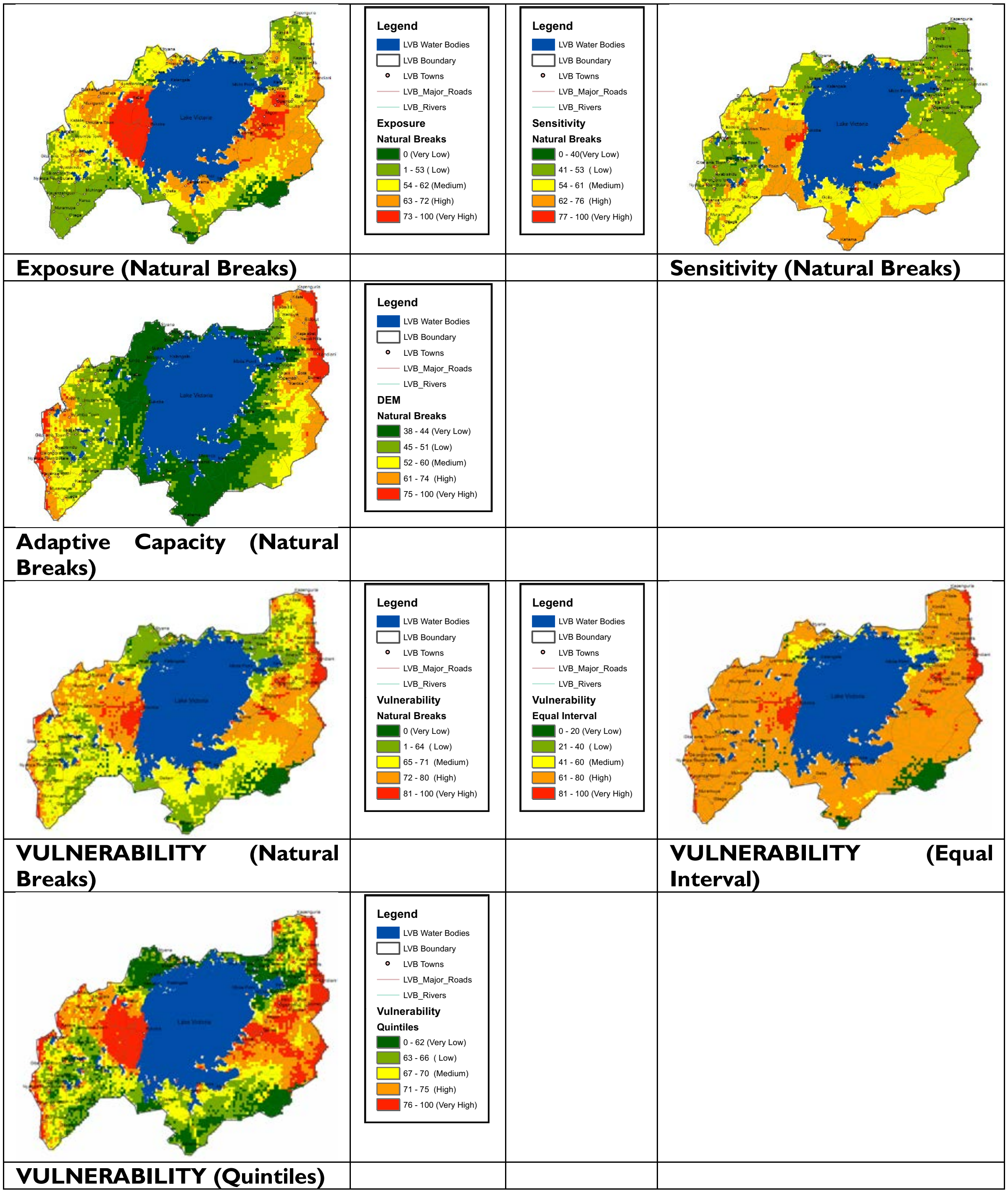


Figure 20: Maps indicating vulnerability of water resources to climate change

The process also considered opportunity for synergies with the agriculture sector (fisheries), energy sector (water quantity and quality for hydropower generation), health sector (water-borne diseases, malaria), and terrestrial ecosystems (critical species and habitats/ecosystem function).

Three transboundary priority hotspots were identified, as well one hotspot for each EAC Partner State. A brief description of the selected sites follows.

Transboundary Sites

- **Chohoha Lake (Rwanda/Burundi).** Lake Chohoha Sud (also known as Tshohoa South) is south of Kigali in the Bugesera district on Rwanda's border with Burundi. The district, in the southeastern part of Rwanda, is a region of high temperature and poor rainfall. It also has many lakes, making it the major source of water, especially wetlands that are exploited for agricultural purpose. The near total conversion of wetlands, forests, and savanna woodlands into agricultural farms has negatively affected the supply of direct ecosystem services, such as water and fuel wood. This has also been blamed for the changing micro-climate, the most visible effect being the disappearance of Lake Cyohoha North, which depended on surrounding wetlands for water. Ninety percent of the diseases in Bugesera are water-borne due to poor water quality. Access to water (especially safe water) is one of the main concerns in Bugesera. Irrespective of its source or quality, the cost of water in Bugesera—whether expressed in monetary or other values—has skyrocketed in recent years.

- **Mara River Basin (Kenya/Tanzania).** The Mara River Basin covers an area of 13,325 square kilometers and is transboundary between Kenya and Tanzania. The 400-kilometer-long river originates in the forested Mau Escarpment along the western rim of the Eastern Great Rift Valley in Kenya. Between 1973 and 2005 the Mau Forest lost more than 8,214 hectares of cover. The forest loss is critical for the Mara, Molo, Naishi, Makalia Nderit, Njoro, and Sondu rivers and will result in ecological and hydrological changes that threaten the sustainable future of areas downstream (UNEP 2009). The Mara River is the main source for the Mara Wetlands. Water requirements for upstream economic activities have led to a reduction in available water to communities and water quality, which affects the integrity of the wetland. Meanwhile, decreased hydrological input is likely to reduce the wetland's ability to regulate the timing and magnitude of water to affected communities (UNEP 2009). The Mara River Basin continues to face serious environmental and water resources problems, primarily from intensive settlement and cultivation leading to loss of vegetation cover, widespread soil erosion, decreased water infiltration capacity, decreased soil fertility, and increased sedimentation and water pollution in the rivers.

- **Sango Bay (Uganda/Tanzania).** Located in southern Uganda and covering an area of approximately 55,110 hectares, Sango Bay harbors the Minziiro Forest Reserve, a groundwater-fed forest in the Kagera region of northwestern Tanzania. The wetland swamps are a source of water for both domestic use and livestock consumption. High human population densities and reliance on subsistence agriculture are reflected in the heavy dependency of the neighboring community on the Sango Bay ecosystems. In particular, wetlands have been drained for sugarcane and food crop production (PREPARED 2014). Various exotic species of floating plants, mostly invasive species such as water hyacinth, water fern, and water lettuce, are also present and are becoming a problem as they crowd out other small emergent water plants in other parts of East Africa. As a result, water quality in the lake has been compromised threatening the availability of fresh water to communities and endangering endemic fish species, Sitatunga (PREPARED 2014).

National Sites

- **Rwegura River (Burundi).** The Rwegura Catchment is in the Kibira National Park and has an estimated area of 231.5 square kilometers. It has two major inlets—Kitenge and Mwokora. The catchment has rainfall during the major part of the year from September to May with a short dry season. Abstraction of water for hydropower generation on the Kitenge River and for irrigation has led to water stress for the users. There have been problems with decreased water levels in the reservoir leading to challenges in water allocation and power shortages. Priority has been given to hospitals, followed by industries; residences rarely get power, which has become an issue of concern (Norbert et al. 2011).

- **Yala Swamp (Kenya).** Yala Swamp is the third-largest wetland in the country after Lorian and Tana Delta. The swamp covers an estimated area of about 175 square kilometers. It is located along the northeastern shores of Lake Victoria and falls within Siaya and Busia counties of Kenya. It stretches from the Yala River to the south and encompasses Lake Kanyaboli, the lower Nzoia floodplain, and all the lakeshores south of Ugowe Bay (Hughs and Hughes 1992). The swamp sits at the point where the Yala and Nzoia rivers enter Lake Victoria, arising from the backflow of the lake as well as the rivers' flood waters. The swamp is a delicate ecosystem and biodiversity conservation habitat for both indigenous and endangered species of fish, birds, and mammals. For instance, the swamp provides important breeding habitat for fish and acts a refuge for important fish species such as the critically endangered Singidia tilapia (*O. esculentus*). Additionally, the swamp is considered an Important Bird Area due to its endemic papyrus bird species. Yala Swamp is currently threatened by large-scale commercial development within the wetland. Large amounts of agricultural activities upstream in the rivers draining into the swamp have also led to increased sediment load entering the wetland. Similarly, increase in other associated contaminants has led to eutrophication of the wetland. This has led to loss of the wetland's ability to purify water and hence to siltation of Lake Kanyaboli, resulting in great concern over loss of available freshwater for communities and reduction of fish stocks, especially endemic species (Norbert et al. 2011).

- **Nyabugogo Swamp (Rwanda).** The Nyabugogo Catchment is in the central eastern part of Rwanda. The catchment drains a total area of about 1,647 square kilometers. The major land use activity in the catchment is agriculture, which occupies about 897 square kilometers (about 54 percent) of the catchment. The climate of the catchment is mostly temperate and equatorial with average temperatures between 16°C and 23°C, depending on the altitude (Nhapi et al. 2011). The Nyabugogo River traverses the City of Kigali and has many tributaries, such as the Marenge, Mwange, and Rusine rivers on its upstream portion. Other rivers feed into it from the urbanized part of Kigali, such as the Mpazi, Ruganwa, Rwanzekuma, and Yanze rivers thus providing freshwater for the populace. However, there are major pollution-generating activities identified in the catchment, including flower farming and the Kabuye sugar works sugarcane plantation upstream, legumes and rice cultivation, and quarrying and mining activities along the Nyabugogo River (Nhapi et al. 2011). There are also many other industries concentrated in the Kigali industrial area that discharge liquid wastes into the Ruganwa River. The Utexrwa textile industry also discharges its effluent into the Rwanzekuma River. It is thus observed that the water in the Nyabugogo River system is polluted as far as physical parameters are concerned with the monitored chemical parameters showing consistently high levels of pollution, warranting urgent attention to arrest further deterioration of water quality in the Nyabugogo River.

- **Mwanza Gulf (Tanzania).** Mwanza Gulf is a large gulf at the southern end of Lake Victoria. The gulf extends 60 kilometers southward with an average width of 5 kilometers and a surface area of approximately 500 square kilometers (Kishe and Machiwa 2003). The gulf has an average depth of 6 meters with the deepest depth (25 meters) near the entrance of the gulf (Akiyama et al. 1977). The main rivers discharging into the gulf are the Issanga (seasonal), Mirongo, and Nyashishi (perennial). Mwanza Gulf harbors a number of fish and macrophyte species and was identified as breeding area and nursery grounds for various fish species including Nile perch (Sangara) and tilapiines (Sato) (EAC 2005). This supplies cheap animal protein, income for domestic/local and foreign/regional markets to achieve food security, and alleviation of poverty. Mwanza Gulf has extensive wetland vegetation and macrophytes, which helps to purify its waters, hence minimizing water treatment costs and making water prices relatively affordable for most of the low-earning population. The macrophytes also are economically useful in making domestic furniture (chairs, tables), mats, and fences. Mwanza Gulf is a source of water supply for domestic, industry, and institution uses in areas around Mwanza region and neighboring regions of Shinyanga (Shinyanga and Kahama Districts) and plans are under way to pump the waters to some districts in Tabora region (Igunga, Nzega). Mwanza Gulf is facing both climatic and non-climatic impacts. Other challenges include waste discharge (from processing industries, as well as domestic and municipal effluents). Domestic and hotel wastewater is drained into the lake through underground percolation as well as surface runoff during rainy seasons, soil erosion, clearing of peripheral wetlands, water abstraction, water pollution (from domestic uses, including beach bathing and washing). These practices are threatening the quality of the water and consequently the health of the entire community through water-borne diseases such as bilharzias (COWI 2002). Human settlements and hotels and associated recreational activities along the beaches create challenging environmental threats.

- **Lake Nabugabo (Uganda):** Nabugabo is a shallow freshwater "satellite lake" of Lake Victoria in south-central Uganda. It is about 8.2 kilometers long and 5 kilometers wide with a maximum depth of 5 meters, separated from the main lake by a sand bar about 1.2–3 kilometers wide. It is near the rapidly expanding town of Masaka (approximately 15 kilometers from the city center) and about 4 kilometers from the main lake's shoreline. It is connected to several wetlands and three other (but much smaller) satellite lakes that together make up the Lake Nabugabo Complex. These include Birinzi (formerly Kayanja), Kayuga, and Manywa and covering approximately 3,500 hectares (PREPARED 2014). High human population densities and reliance on subsistence agriculture are reflected in the heavy dependency of the neighboring community around Lake Nabugabo on the lake ecosystem. Poor agricultural practices have adversely affected the water quality, reducing access to freshwater for consumption and use (PREPARED 2014).

4 SECTOR POLICY, LEGAL, AND INSTITUTIONAL PREPAREDNESS FOR CLIMATE CHANGE IN WATER, AQUATIC ECOSYSTEMS, AND WATER SUPPLY INFRASTRUCTURE

4.1 Policies, Institutions, and Principles Governing Water Resources

A wide range of regional organizations have a mandate for governance and management of water resources and aquatic ecosystems in East Africa. These include the EAC, Common Market for Eastern and Southern Africa (COMESA), Nile Basin Initiative (NBI), New Partnership for Africa's Development (NEPAD), Intergovernmental Authority on Development (IGAD), African Ministers' Council on Water (AMCOW), and Lake Victoria Basin Commission (LVBC), which serves as an overall institution for the management of issues related to the LVB.

4.1.1 EAC Overall Policy Framework

In 2005, the EAC published its "Vision and Strategy Framework for Management and Development of Lake Victoria Basin," which established a shared vision and a long-term strategic plan for the sustainable management and development of the LVB. Further, the EAC has developed the Climate Change Policy and Master Plan as well as strategies to address the adverse impacts of climate change in the region and harness any potential opportunities posed by climate change within the principle of sustainable development. The East African Community Climate Change Policy (EACCCP) is aimed at addressing issues of climate based on an integrated, harmonized, and multisectoral framework. The policy is in tandem with various regional and sub-regional development policies, strategies, plans, and programs. These include the Treaty for the Establishment of EAC, the Protocol on Environment and Natural Resources Management, the Protocol for Sustainable Development of the Lake Victoria Basin and the Regional Environmental Impact Assessment, Guidelines on Shared Ecosystems, and the EAC Development Strategy (2011–2015) among others. In addition, Articles 23 and 24 of the Protocol on Environment and Natural Resources Management (under negotiation) has a provision for joint actions to address climate change and environmental disasters in the region.

Policies established by EAC are complimentary to various multilateral environmental agreements as well global and regional, legal, and policy frameworks on water and natural resources. These include the Rio Convention, namely United Nations Framework Convention on Climate Change (UNFCCC) with its Kyoto Protocol; United Nations Convention to Combat Desertification, Convention on Biological Diversity (CBD), as well as Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) and the Ramsar Convention on Wetlands of International Importance, among others. Four Partner States (Burundi, Rwanda, Tanzania, and Uganda) have also developed National Adaptation Programs of Action (NAPAs) that are in various stages of implementation. Kenya, on the other hand, has prepared a National Climate Change Response Strategy, which spells out the priority areas for both adaptation and mitigation activities in the country.

4.2 EAC Policy Push for Water Resources Management

4.2.1 The East African Community: Extent and Strategic Visions

Each of the five Partner States of the EAC has a Strategic Vision that guides its national plans and development (Table 12). Water is one of the most important natural resources and is fundamental for the sustainable development of the region. Water is a necessity for the domestic, agricultural, industrial, commercial, and socio-cultural needs of society and ecosystems. Water availability in adequate quantities and good quality will affect the attainment of these strategies.

Table 12: EAC Partner States Strategic Visions

Partner state	Time frame	Strategic vision	Priority areas
Kenya	Vision 2030	Globally competitive and prosperous Kenya with a high quality of life	To achieve sectoral objectives including meeting regional and global commitments
Uganda	Vision 2035	Transform Ugandan society from peasant to a modern prosperous country	Prominence being given to knowledge-based economy
Tanzania	Vision 2025	High quality of life anchored on peace, stability, unity, and good governance, rule of law, resilient economy, and competitiveness	Inculcate hard work, investment, and savings culture; knowledge-based economy; infrastructure development; and private sector development
Rwanda	Vision 2020	Become a middle-income country by 2020	Reconstruction, human resources development, and integration to regional and global economy
Burundi	Vision 2025	Sustainable peace and stability and achievement of global development commitments in line with MDGs	Poverty reduction, reconstruction and institutional development

Source: 4th EAC Development Strategy (2011/12–2015/16).

The EAC states, after signing the EAC Treaty in 1999 declared the LVB an Economic Growth Zone and committed to develop the basin in a coordinated and sustainable manner. The EAC Treaty (1999), Article 114 on Management of Natural Resources, 1(c) stipulates that the Partner States shall "adopt common regulations for the protection of shared aquatic and terrestrial resources." Furthermore, the Protocol for Sustainable Development of Lake Victoria Basin (1999) in Article 25 on Water Resources Monitoring, Surveillance, and Standard Setting states:

- The Partner States shall establish and harmonize their water quality standards.
- The Partner States shall, in their respective territories, establish water quality and quantity monitoring and surveillance stations and water quality and quantity control laboratories.
- The Partner States shall exchange water quality and quantity data in accordance with guidelines to be established by the Partner States.

Under Article 94 (p), the signatories promise to jointly tackle inland water pollution with a view to achieving effective monitoring and control of pollution. In addition, the EAC's Vision and Strategy Framework for Management and Development of Lake Victoria Basin (2011) under the Sector Strategies for Water Resources Management has listed among others, the requirement to "Promote water quality and quantity monitoring." Thus, the EAC integration and cooperation is cognizant of a regional approach, while also being sensitive to country-specific concerns.

4.2.2 Harmonization of Water Policies by EAC Partner States

The governments of the five EAC Partner States are making serious efforts to address water resources issues in their respective countries as well as to use the transboundary water resources for the social and economic benefit of the region. These efforts have included developing and strengthening national policies, institutional frameworks, and laws and regulations that are essential to meet the existing and emerging water resources challenges. They also have proposed to strengthen regional cooperation to jointly address transboundary threats and challenges and seek opportunities for enhancing sustainable management of shared water resources. Burundi is developing its national water policy, while Rwanda's policy of 2011 is in the final stages of approval. Kenya developed Sessional Paper No. 1 of 1999 on National Water Policy on Water Resources Management and Development. Uganda had its National Water Policy in 1997; and Tanzania replaced its 1991 Water Policy with National Water Policy 2002. All these polices promote comprehensive water resources management and a development framework.

4.2.2 Policy and Institutional Framework at the National Level

Water is factored into many national development plans and strategies. Some relevant national policy and legal instruments include National Water Acts in the individual EAC countries. The focal national agencies are listed in Table 13.

Table 13: Lead Agencies for Water Sector in Each EAC Country

EAC Partner State	Focal agency	Other key agencies
Burundi	The General Directorate of Water Resources and Sanitation	The General Directorate of Forestry and Environment, National Commission for the Environment, Environment Directorate
Kenya	Ministry of Water, Environment, and Natural Resources	Directorate of Environment, National Environmental Management Authority
Rwanda	Ministry of Natural Resources	Rwanda Natural Resources Authority, Rwanda Environment Management Authority, Ministry of Infrastructure, Water and Sanitation Corporation
Tanzania	Ministry of Water and Irrigation	Vice Presidents Office, Department of Environment, National Environment Management Council
Uganda	Ministry of Water and Environment	National Environment and Management Authority

Following is a summary, by country, of the main policy documents related to water.

Burundi has the Water Resource Management Decree Law No. 1/41. The Ministry of Water, Energy and Mines (MWEM), through its Directorate General for Water and Energy (DGEE), is responsible for leading the overall policy formulation and administrative functions of the central government as they relate to the water supply and sanitation sector. The Directorate of Water Resources (DRH) within DGEE is responsible for developing strategies for sustainable development of the country's water resources, developing and maintaining the country's National Water Master Plan, and maintaining the water tariff policy for rural and urban areas. In rural areas, the Directorate General of Rural Water and Electricity (DGHER) oversees and coordinates drinking water and sanitation.

The Water and Electric Authority (REGIDESO) of Burundi is an autonomous public utility operating under the supervision of MWEM, and 34 Communal Water Authorities (RCEs) undertake actual service provision. REGIDESO is responsible for catchment, treatment, and distribution of drinking water in urban areas while RCEs supply drinking water to the rural areas. Municipal Engineering Services (SETEMU) is responsible for sewerage and wastewater treatment services, but currently Bujumbura is the only city being serviced. Other cities and towns do not have sewerage systems, and sanitation facilities in rural areas are very limited.

The DGHER hopes to help address drinking water needs in the rural areas through RCEs. District User Committees manage the RCEs, while the DGHER provides central government support of the RCEs. As of 2005, only 16 of the country's 34 administrative districts (called communes in Burundi) had functioning RCEs.[8] Of these RCEs, only half collected household water fees. The others relied on income from fixed sales of water for private connections. Significant amounts of financial, managerial, and technical assistance are needed to scale up the RCEs' ability to manage their systems and promote better hygiene in rural areas.

The government has been working to reform water supply and sanitation institutions to extend service, improve quality, and improve financial sustainability. In 2000, Burundi adopted a law that both liberalized the sector and created a new regulatory framework. The law defines the conditions for private sector participation and allows for establishment of a regulatory entity for water supply and energy and a development fund for the sector. It stated that REGIDESO no longer had a monopoly over public drinking water and electricity supply. The provisions of the law, including establishment of a regulator, have yet to be fully implemented.

A national water sector policy development process has begun, which includes the implementation of the National Water Master Plan (PDNE). The new policies aim to increase coverage through improved coordination. Specifically, Burundi has defined its current priorities as follows: (i) rehabilitation of drinking water supply systems, which could considerably increase access to this commodity; (ii) reduce regional disparities in water availability; (iii) integrated management of the country's water resources through integrated multipurpose information systems; (iv) improved hygiene and sanitation; and (v) encouraging the private sector to invest in the sector to ensure its sustainability. The government is also working to better manage its watersheds to protect water sources and increase available supply for domestic purposes, through the development of an Integrated Water Resources Management (IWRM) plan.

Kenya's water policies are in transition, as a raft of laws, bills, policies, strategies, and institutional and regulatory structures are under development, while existing ones are being reviewed and revised to align with the new Constitution (2010), the Kenya Vision 2030, and other emerging policy changes. The Water Act 2002 is currently under review, with the process having passed the first reading in Parliament as the Draft Water Bill (2014). The Water Bill, is a "Bill for An Act of Parliament to provide for the regulation, management and development of water resources, water and sewerage services; and for other connected purposes." Most of the regulations in Water Act 2002 have been retained. For instance, the right to clean and safe water is in the Water Bill, which states, "Every person in Kenya has the right to clean and safe water in adequate quantities and to reasonable standards of sanitation as stipulated in Article 43 of the Constitution of Kenya." Regarding ownership of water resources, **the Water Bill states that: "**Every water resource is hereby vested in and shall be held by the National Government in trust for the people of Kenya." The bill further espouses the administrative and regulatory structures to support water resources management, including the appointment of various office holders. Water Resources Users Associations are retained in the bill. The use of water catchment areas (rather than counties) as the basic planning unit is also stipulated in the proposed bill.[2]

In Rwanda, the National Policy for Water Resources Management was developed in 2004 and reviewed in 2012. The National Water Resources Master Plan was adopted in 2014, while the current framework is being implemented under the Water Resources Management Sub-Sector Strategic Plan (2011–2015). The overall goal of the National Policy for Water Resources Management is "to manage and develop the water resources of Rwanda in an integrated and sustainable manner, so as to secure and provide water

2 Republic of Kenya 2014. Water Bill 2014 (released by Parliament).

of adequate quantity and quality for all social and economic needs of the present and future generations with the full participation of all stakeholders in decisions affecting water resources management."

Rwanda's policy objectives are to:

- Provide a comprehensive and suitable policy framework that will strengthen the government's ability to conserve and protect water resources.
- Provide a legal and institutional framework for water resources conservation and management throughout the country and at transboundary level.
- Promote partnerships, incentives, and benefit sharing to enhance water resources conservation and management.
- Provide a framework for equitable allocation of water resources and the sharing of benefits derived from that resource.
- Promote positive attitudes toward water resources conservation and management.

Rwanda's policy tenets have provisions for water that include (i) water is a finite resource; (ii) water is a human right; (iii) water resource is an economic good; (iv) water is a social good. The policy aims to manage water through (i) Integrated Water Resources Management (IWRM); (ii) participatory management; (iii) catchment-based water resources management; (iv) climate change resilience; (v) internationally shared water resources.

In **Tanzania,** the government instituted water sector reforms in the early 2000s as articulated in the National Water Policy (2002). The Tanzania Water Resources Management Policy (2002) ensures the development of a comprehensive framework for water management. The overall objective of the reforms, as coordinated by the Water Sector Development Programme, is to strengthen sector institutions for IWRM and improve access to clean and safe water supply and sanitation services. Several instruments have been established since then to facilitate efficient and effective implementation of the reforms. Key among them are the National Water Sector Development Strategy (2006–2015), Water Resources Management Act No. 11 of 2009, and Water Supply, and Sanitation Act, No. 12 of 2009.

The growing water resources development and management concerns include inadequate water storage infrastructure that is impeding the nation's ability to deal with climate variability and its impact on food, energy, water, and environmental security. Climate change is going to further stress the nation's water resources. Inadequate investments in reliable water infrastructure and the low capacity of water resources management institutions are contributing to water insecurity and stress, perpetuating local and regional water-use conflicts and imposing losses on the economy.

For basins to manage water resources efficiently and to address issues of water availability as well as to improve water security, the government of Tanzania is undertaking several initiatives in collaboration with development partners and other stakeholders. The initiatives include preparation and implementation of IWRM plans that will address sustainable allocation and conservation of water resources. It also includes strengthening of basin water boards to carry out their mandated tasks through provision of equipment for data collection and monitoring for informed decision making, rehabilitation, and building of Basins Water and Laboratory offices. Finally, it includes implementation of a water pollution control strategy and strengthening of water resources management institutions and formation of new ones according to the WRMA 2009.

In **Uganda**, the legal and policy framework for the water sector is guided by the Constitution (1995) through which the government recognizes the role of water in development. In the National Water Policy (1999), water is considered a social and economic good, while the Water Act (1995) postulates the rational management and use of the waters of Uganda. The Environmental Act (1995) dwells on sustainable environmental management and other relevant regulations. The water policies were developed under two distinct categories (i) water resources management (covering policy objectives, principles and strategies for monitoring, assessment, allocation, and protection of the resource and management framework), and (ii) water development and use (covering policy objectives, principles, and strategies for the development and use of water for domestic water supply, water for agricultural production, and other water uses including industry, hydropower, recreation, and ecosystem needs). The water statute also provides for the formation of Water and Sanitation Committees, Water User Groups, and Water User Associations as community-level organizations with a mandate to ensure the sustainability of water supply and sanitation facilities through proper management, operation, and maintenance.

The National Water Policy for Uganda provides for integrated and sustainable development, management and use of water resources with full participation of all stakeholders, regulated use of all water other than for domestic use, sustainable provision of clean safe water, development and efficient use of water in agriculture, improved collaboration and coordination among stakeholders, and equitable access and use of the Nile waters (transboundary water resource). The Directorate of Water Resources Management is responsible for developing and maintaining national water laws, policies, and regulations; managing, monitoring, and regulating of water resources through issuing water use, abstraction, and wastewater discharge permits; IWRM activities; coordinating Uganda's participation in joint management of transboundary water resources and peaceful cooperation with Nile Basin riparian countries. The directorate consists of three departments: the Department of Water Resources Monitoring and Assessments, Department of Water Resources Regulation, and Department of Water Quality Management.

Through the Ministry of Water and Environment and water and environment sector development partners the government has an objective to support the sector to achieve its targets and improve its efficiency in line with the goals and targets of the National Development Plan (NDP, 2010/11 to 2014/15), the country's overarching national planning framework. Uganda's approach to the water and sanitation MDGs and related NDP targets aim at providing access to safe water supply to at least 3.4 million Ugandans (2.5 million rural and 0.9 million in small towns and rural growth centers), and increasing access to improved sanitation for the same populations.

A wide range of international and nongovernment organizations, donors, and civil society organizations are working in this sector at regional, national, and local levels in the EAC Partner States. These include the Department for International Development (DFID), USAID, European Union, UNICEF, United Nations Development Programme (UNDP), African Development Bank (AfDB), United Nations Environment Programme (UNEP), Economic Community of the Great Lakes Region (CEPGL), Lake Kivu and Rusizi River Basin Authority (ABAKIR), World Bank, Japan International Cooperation Agency (JICA), International Fund for Agricultural Development, Food and Agriculture Organization (FAO), Nile Basin Capacity Building Network (NBCBN), United Nations Educational, Scientific and Cultural Organization (UNESCO), Germany Development Cooperation (GIZ), and the Dutch government, among others.

4.3 Lake Victoria Basin Policy and Institutional Framework

4.3.1 Lake Victoria Basin Commission

The LVBC is a specialized institution of the East African Community (EAC) that is responsible for coordinating the sustainable development agenda of the Lake Victoria Basin. The EAC established the commission, formerly known as the Lake Victoria Development Programme, in 2001 as a mechanism for coordinating the various interventions on the lake and its basin and serving as a center for promotion of investments and information sharing among the stakeholders. The program is the driving force for turning the Lake Victoria Basin into a real economic growth zone. The commission envisages a broad partnership of the local communities around the lake, the EAC, and its Partner States, as well as development partners. The commission's activities focus on the following:

- Harmonization of policies and laws on the management of the environment in the lake and its catchment area
- Continuation of the environmental management of the lake, including control and eradication of water hyacinth
- Management and conservation of aquatic resources, including fisheries
- Economic activities in the development of fishing, industry, agriculture, and tourism
- Development of infrastructure, including revamping the transport system on and around the lake.

The commission further emphasizes poverty eradication and the participation of local communities. It is expected to make a significant contribution toward reducing poverty by lifting the living standards of the people of the lake region. This is to be achieved through economic growth, investments, and sustainable development practices that are cognizant of the environment.

4.3.2 Lake Victoria Fisheries Organization

The Lake Victoria Fisheries Organization (LVFO) was formed through a convention signed in 1994 by Kenya, Tanzania, and Uganda to coordinate management of the fisheries resources of Lake Victoria. The organization's aim is to harmonize, develop, and adopt conservation and management measures for the sustainable use of the living resources of Lake Victoria to optimize socioeconomic benefits from the basin for the three countries. The LVFO is implementing fisheries co-management on the lake by legally empowering fisheries communities to become equal and active partners with government in fisheries management and development. The LVFO is guiding, supporting, and implementing the capacity building of communities to participate in management.

These principles are also enshrined in the Nile Basin Cooperative Framework and the Lake Victoria Protocol. In particular, Article 112(2) (b) of the EAC Treaty obliges the Partner States to conserve the environment and natural resources of East Africa. Among the obligations accepted by the states is the conservation of water resources and the prevention of pollution. Article 112(2) (b) (vi) specifically provides for the protection of Lake Victoria and its water resources. Some of the key principles include the following:

- Sustainable utilization
- Equitable use between the states sharing the watercourse
- The prevention of significant harm to other watercourse states
- Prior notification, exchange of information, and consultation regarding planned measures
- Assessment of the potential impacts of planned measures
- Preservation of environmental integrity of the watercourse, including prevention of pollution
- Integrated management of water resources
- Basin management and the community of interest of all states that share the watercourse.

4.3.3 Key Principles of Shared Waters in Lake Victoria Basin

The Key Legal Principles of Transboundary Water Resources Management are included in the United Nations Convention on the Non-Navigational Uses of International Water Courses of 1997, and in the Protocol for the Sustainable Development of the Lake Victoria Basin, 2003. They are:

i. *The principle of international cooperation,* which refers to undertakings on international water resources which are governed by two or more states.

ii. *The concept of an international watercourse,* which is a system of surface waters and ground waters constituting, by virtue of their physical relationship, a unitary whole, parts of which are in different states and normally flowing into a common terminus.

iii. *The principle of equitable utilization* of the water resources in shared watercourses.

iv. *The obligation not to cause significant harm to co-riparian.* In using the resources, states are required not to cause significant harm to the interest of other states by pollution or other conduct.

v. *The protection of present reasonable and beneficial uses of the water.* International law favors the protection of present beneficial uses of shared waters and discourages wasteful uses.

vi. *Notification and information sharing*: The 1997 Convention and general international law require states to cooperate and share information regarding the development of shared water resources. The principle of prior notification requires that each of the riparian states should notify other basin states of planned measures or activities within its territory that may have adverse effects upon those other states.

vii. *The principle of regular exchange of data and information,* which is essential for confidence building, and basis upon which states can build a reliable and comprehensive knowledge base.

viii. *The principle of the prevention, minimization, and control of pollution* of watercourses so as to minimize adverse effects on freshwater resources and their ecosystems, including fish and other aquatic species, and on human health.

ix. *The principle of the protection and preservation of the ecosystems of international watercourses* whereby ecosystems are treated as units, all components of which are necessary to their proper functioning, that are protected and preserved.

x. *The principle of community of interest in an international watercourse* whereby all states sharing an international watercourse system have an interest in the unitary whole of the system.

xi. *The principle that water is a social and economic good* (The Rio-Dublin Principles 1992).

4.4 KEY WATER SECTOR STAKEHOLDERS, CAPACITIES, AND INITIATIVES

4.4.1 Water Sector Stakeholders

Key stakeholders for the water and climate change sector include governmental, institutional, private sector, and nongovernmental organizations, as well as and development partners. Each of these categories has a role in the development, management, and funding of water and climate-related projects or activities. Public institutions include ministries of water, environment, natural resources, finance, agriculture, local government, education, and trade. A wide range of regional, local, and community-based initiatives, as well as site-focused projects, seek to address the impacts of climate change. Key stakeholders at the regional level include institutions such as:

- The AMCOW, a specialized technical committee of the African Union that promotes cooperation on water and sanitation.
- The LVBC, which serves as an overall institution for the management of issues related to the Lake Victoria Basin.
- Climate Prediction and Applications Centre (ICPAC) a specialized institution of the IGAD working with the National Meteorological Services, World Meteorological Organization, and other partners to address regional challenges of climate risks including climate change.

Several United Nations and donor agencies also support regional efforts to avert climate change impacts including through provision of technical and financial support, research, and knowledge sharing. These include UNDP, UNEP, UNICEF, FAO, UNESCO, USAID, GIZ, Danish International Development Agency, World Bank, Canadian International Development Agency, Belgian Development Agency (BTC), and AfDB.

There are also sectoral ministries of water and/or irrigation for integration and water resource management. In Uganda, for example, the Climate Change Department under the Ministry of Water and Environment coordinates the implementation and monitoring of national climate change actions in different sectors.

A couple of international nongovernmental organizations (NGOs) also are involved in climate change–related programs. These include:

- CARE International, which works in Ethiopia, Tanzania, Uganda, and more widely across East Africa through its Global Water initiative focusing on developing evidence that highlights solutions to the challenges of water management and use in smallholder agriculture, including climate change vulnerability.[3]

- ActionAid is working with communities in the region to help them deal with climate change. They also campaign for change at the global level.

- Mercy Corps is helping vulnerable communities cope with the rising incidence of climate-related disasters, such as flooding and drought, and leveraging the global focus on climate change adaptation.[4] The organization is also working on climate care through cutting carbon, conducting education campaigns, and providing safe water by distributing filters to households in western Kenya. The gravity-driven point-of-use filters require no electricity or consumables.[5]

Other local organizations include:

i. *RECOR (Rwanda Environmental Conservation Organization) is a national environmental conservation NGO working on climate change, biodiversity conservation, renewable energy, education for sustainable development, forestry, agroforestry, water, hygiene, and sanitation. It involves local communities in looking for suitable and sustainable solutions to local environmental challenges.*

ii. *The National Association of Professional Environmentalists* in Uganda promotes environmental awareness, biodiversity conservation, water and waste management, enhancement of community participation, research, publication, and dissemination of information. It also carries out lobbying and advocacy and networking.

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3 http://globalwaterinitiative.org/gwi-in-east-africa/

4 http://www.mercycorps.org/research-resources/climate-change

5 http://climatecare.org/our-projects/lifestraw-carbon-for-water/

iii. The Swedish Society for Nature Conservation focuses on energy, freshwater resource management, biodiversity conservation, and waste management.[6]

iv. The Climate Change Network of Kenya seeks to influence and participate in the development and implementation of appropriate sustainable development climate change–sensitive policies, projects, and activities to minimize the vulnerability of people to climate change and work collectively with other actors toward inclusive sustainable development.[7] Programs include water resources harvesting and management.

6 http://www.worldlakes.org/uploads/Africa_NGO_Directory_7Mar04.pdf

7 http://ccnkenya.org/aboutus/?flag=aboutus&abt=1

5. ONGOING PROGRAMS AND INITIATIVES

Several initiatives already exist in East Africa as commitments and efforts toward responding to the emerging challenges of climate change. Some these are:

- The Lake Victoria Environmental Management Project (LVEMP) is a comprehensive regional development program that covers the whole of Lake Victoria and its catchment areas. The project aims to collect information on the environmental status of the lake and its catchment, as well as the practices being used by the communities living around the lake. It supports institution establishment, capacity building, actions to deal with environmental problems, water hyacinth control, improving water quality and land use management, and sustainable use of the wetlands for both their buffering capacity and the products they contain.

- The Nile Basin Initiative (NBI)/The Nile Equatorial Lakes Subsidiary Action Program is a partnership among the Nile riparian states that seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security. Having begun as a dialog among the riparian states it resulted in a shared vision to achieve sustainable socioeconomic development through the equitable use of, and benefit from, the common Nile Basin water resources.

- The Nile Equatorial Lakes Subsidiary Action Program is one of two NBI investment programs—the other being the Eastern Nile Subsidiary Action Program (ENSAP)—that promote investments in power development and trade, water resources management, management of lakes, fisheries, and watersheds, as well as agricultural trade and productivity.

- The Global Water Partnership, with its regional headquarters in Uganda, is a working partnership among all actors involved in water management: government agencies, public institutions, private companies, professional organizations, multilateral development agencies, and others committed to the Dublin-Rio principles.

- The Programme on Climate Change Adaptation and Mitigation in the COMESA-EAC-SADC region is a five-year initiative that started in 2010. It aims to inject Africa's Unified Position on Climate Change into the post-2012 UNFCCC global agreement and to unlock resources for promoting strategic interventions that sustain productivity and livelihood improvements for millions of climate-vulnerable people in the region. The program is linked to the AU-NEPAD Climate Change Adaptation-Mitigation Framework and its Investment Platform for Climate-Smart Agriculture.

5.1 Gaps in Institutional Capacities for Adaptation

The following gaps in institutional capacity and capability may compromise design, implementation, and monitoring of adaptation measures at local and national levels:

- Human technical capacity in water resources management is limited, which compromises effective design and implementation of adaptive measures and actions. This situation is compounded by lack of financial and technological resources at the national and local levels. Most of the projects in the region are implemented by international agencies with limited technology transfer.

- Gaps in meteorological infrastructure and data hinder much-needed coordinated and enhanced meteorological research, as well as the ability to channel such information to where it is most needed.

- The impacts of climate change on gender and marginalized groups is underappreciated. Gender, age, and disability are important determinants of adaptive capacity. In most cases, women, elders, youth, and children make up a large proportion of the poor in communities that are highly dependent on local natural resources for their livelihood and are disproportionately vulnerable to and affected by climate change. Women in rural areas have responsibility for household water supply, energy for cooking and heating, and food security. As a result, they are negatively affected by drought, uncertain rainfall, and deforestation. Because of their roles, unequal access to resources, and limited mobility, women in many contexts are disproportionately affected by natural disasters, such as floods, fires, and mudslides. In addition, other persons residing in regions prone to drought and floods, as well as the handicapped, elderly, and other marginalized persons are also at greater risk of climate change and climate variability.[8]

- The institutional capacity and capability to assess and quantify the impact of climate change on different sectors and systems, the socioeconomic consequences of ecosystem losses and economic activities, and mitigation and adaptation to climate change are also limited.

5.2 EXAMPLES OF CURRENT EFFORTS TO SUPPORT ADAPTATION TO CLIMATE CHANGE

(a) Water Resources

Improved water stress management requires strategies to address risks related to flow regimes, including floods and drought, and to health and poverty since they are linked to future water resource conditions. Water management measures must target the reduction of wastewater, improved storage, and the balance of green and blue water under various climate change–induced water demand levels. Technological innovations and water-use efficiency remain priorities, especially in land use planning, crop production technologies, and other forms of withdrawals. Emphasis should be on information to support adaptation through forecasting, prediction and early warning, traditional knowledge, and raising awareness. Improved water governance and cross-country and basin-wide cooperation will continue to be instrumental in addressing water-use conflicts, policy support needs, and equitable water and water benefit sharing and trade.

- Kenya has incorporated climate change adaptation strategies in its national planning documents. Short-term measures include implementing a duty waiver on imported maize, conserving water, irrigation, and constructing cattle troughs in various parts of the country. Long-term measures include sensitizing communities to efficient and effective use of water, supporting and encouraging the use of rainwater harvesting techniques, de-silting or building new water pans/dams, and adopting energy-saving technologies.[9]

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[8] Disability and Climate Change: Understanding vulnerability and building resilience in a changing world http://www.cbm.org/article/downloads/54741/Disability_and_Climate_Change.pdf

[9] FAO 2014. Adapting to climate change through land and water management in Eastern Africa Results of pilot projects in Ethiopia, Kenya and Tanzania

- Rwanda, through the Africa Adaptation Programme, has established the Rwanda Environment and Climate Information System by acquiring and installing a variety of modern meteorological and information technology equipment and training 50 people from Rwanda's Meteorological Agency and Environmental Management Authority (REMA) on climate modeling and forecasting and disaster management preparedness. An enormous range of capacity has been built through these interventions: a database of climate change data and information and a geographic information system have been established; an atlas of vulnerability to likely impacts of climate change and a map of risk zones were created; vulnerability and risk assessments were carried out; and the National Adaptation Plan of Action was amended to include an early warning system (EWS), with representatives from 11 institutions that were trained on modeling, forecasting, and preparedness now constituting the EWS Disaster Management Steering Committee and professionals from other agencies trained on the deployment and use of early warning information. A series of agriculture and water-related pilot projects also provided key information on adaptation opportunities.[10]

- In Tanzania, the water sector has been the focus of significant reform and investment with support from a US$800 million fund to implement the Water Sector Development Programme. The program focuses on infrastructure investment and provision for urban and rural water supply and sanitation alongside implementation of a reformed water resource management regime. The funding through the Water Resource Management function of the Ministry of Water and nine semi-autonomous basin water offices by donors has been key in prioritizing the needs of the environment and poor communities over water needed for industry and production. Nonetheless, a fully functional system of water resource regulation and administration, including scaled responses to drought events that prioritize vulnerable users, is imperative if Tanzania is to be resilient to climate shocks (Nepworth 2010).

- In Uganda, the Directorates of Water Resources Management and Water Development within the Ministry of Water and Environment take the lead for vulnerability and adaptation responses. As a result, a National Assessment and Strategy in Water Resources has been put together and is being used to incorporate climate change into strategic planning for water resources. Meanwhile, the Joint Water and Sanitation Sector Programme Support saw a total commitment of US$150 million from 2007 to 2012 in improving the management of water resources and delivery of water services to reduce Uganda's vulnerability to climate change. The World Bank has supported Uganda to develop a Water Resources Assistance Strategy 2011 that aims to assist the government in identifying priority actions for building on successful outcomes, tackling remaining challenges, and exploiting the water sector (Nepworth 2010).

(b) Aquatic Ecosystems

Studies by Ogutu-Ohwayo et al. (2011) indicated that the local population within the LVB lack sufficient understanding of the possible impacts of climate change on water resources, aquatic ecosystems, resources, and their livelihoods. This lack of knowledge exposes the already vulnerable ecosystems to the effects of climate change. Since most of the households in LVB rely on rain-fed farming, their food sufficiency depends on their success in farming. Thus, anything that affects farming, such as drought and flooding, would ultimately affect household food sufficiency. This makes the populations in LVB vulnerable to the effects of climate change, with negative impacts on aquatic biodiversity (LVBC 2011).

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[10] https://www.undp-aap.org/countries/rwanda

Adaptations by populations within the LVB are necessary to respond to opportunities and threats to resources and livelihoods caused by climate change. Small-scale fishermen and riparian communities within the LVB have responded by adjusting and taking on other livelihood occupations, such as diversifying to crops, livestock, forestry, and other income-generating activities; changing and diversifying fisheries operations; migrating to less-affected areas; or resorting to social capital and community support (Ogutu-Ohwayo et al. 2011).

Other adaptations put in place by local communities include planting drought-tolerant crops, timely planting of crops, use of organic pesticides to control diseases, and irrigation during dry seasons. Water security has been enhanced through water harvesting and storage, support by NGOs to construct tanks, drilling of shallow wells, and enacting by laws (LVBC 2011). Promotion of aquaculture through an Economic Stimulus Plan to reduce pressure on the dwindling catches from natural fisheries is another adaptive measure that has been employed (Manyala 2011).

Further adaptation measures proposed include the need to collectively identify, agree, and prioritize the most appropriate locally available and affordable strategies, improve on them, and provide early warning systems to increase resilience and sustain livelihoods (Ogutu-Ohwayo et al. 2011).

5. CONCLUSION

Water security is a priority for the livelihoods and economic development of rural and urban communities in EAC Partner States. Water demand (for domestic, commercial/industrial uses or energy) already far outstrips available supply, with or without the impacts of climate change. Climate change will further complicate the challenge of balancing demand and supply. The climate variables critical for the performance of this sector are temperature and precipitation variations, sea level rise, and increase in extreme weather events that affect the sector, particularly floods and droughts.

In general, lakes, rivers, and wetlands in East Africa provide major economic benefits as follows:

(a) *Domestic and industrial water uses*. While domestic, industrial, and commercial water use are the primary economic uses of water resources, wetlands are important for cleaning up water in by removing pollutants such as phosphorous, heavy metals, and toxins that are trapped in the sediments, thereby reducing the cost of water treatment.
(b) *Hydroelectric power generation*. National and transboundary hydropower projects are being implemented to meet increasing demand for energy in the EAC Member States using technologies such as run-of-river hydropower, storage hydropower, and pumped storage hydropower.
(c) *Agriculture, livestock, and food security*. With growing demand for agricultural production, EAC Partner States are shifting from a rain-fed agriculture to the intensification and expansion greatly increasing water abstraction for irrigation and livestock management.
(d) *Fisheries*. Fisheries are an important source of income, employment, food, and foreign exchange for East Africa. Lake Victoria alone produces a fish catch of over 800,000 tons annually, currently worth about US$590 million for Kenya, Tanzania, and Uganda. The lake fisheries support almost 2 million people with household incomes and meet the annual fish consumption needs of almost 22 million people in the region.

In addition, water resources provide crucial services in EAC Partner States including the following:

(a) *Trade—transport and communications*. Lake Victoria constitutes the main area for inland water transport in the region, but its tributaries provide the means of transport for populations in the riparian countries.
(b) *Tourism—employment and biodiversity*. The rivers, wetlands, and lakes of the EAC region are important tourism and recreation sites and support local employment while wetlands and freshwaters provide habitats for many key species and provide ecosystem services.
(c) *Change control and flood mitigation*. Wetlands play a great role in flood control and climate regulation, as well as in climate adaptation and mitigation; the water bodies also influence micro-climates in the region.

However, high population, poverty, agricultural intensification, and degradation of aquatic ecosystems is increasing pressure on water quantity and quality. Various initiatives, plans, and policies seek to address the potential impacts of climate change and climate variability on water resources, water infrastructure, and aquatic ecosystems in East Africa. Given the significance of this sector, it is imperative that strategic options are developed for communities to cope with the likelihood of water stress in the future especially in the context of climate change and climate variability. The VIA studies in selected hotspots should increase understanding of these systems and help to build the resilience of the communities that depend on water resources for their livelihoods. In addition, measures need to be put in place to secure priority aquatic ecosystems, address potential threats to aquatic biodiversity, and sustain ecosystem function. Climate change and variation are expected to reduce water supplies. As water becomes scarce, competition for access to and use of water sources will intensify. As a result, conflicts are more likely to occur as a struggle to use this scarce resource increases.

Fortunately, the EAC and the five Partner States have a robust policy and legal framework at national and regional levels and a framework for shared transboundary water resources and aquatic ecosystems is emerging. However, the institutional framework is not robust enough to cope with the potential challenges of climate change and in as much as there are some national-level experiences in adaptation for this sector, a major and accelerated investment is needed at human, technical, technological, and institutional levels.

REFERENCES

Aerts, J., H. Renssen, P.J. Ward, H. De Moel, E. Odada, L.M. Bouwer, and H. Goosse, 2006: "Sensitivity of global river discharges under Holocene and future climate conditions." *Geophys. Res. Lett.* 33.

African Union, 2015: The 2014 Africa Water and Sanitation Sector Report. Securing Sanitation in Africa Department of Rural Economy and Agriculture. African Union, Twenty-Fourth Ordinary Assembly of the Union. 30–31 January 2015, Addis Ababa, Ethiopia.

Agrawal, A., and K. Redford, 2009: "Place, conservation, and displacement." *Conservation Society*, vol. 7, pp. 56–58.

Alcamo, J., and T. Henrichs, 2002: "Critical regions: A model-base estimation of world water resources sensitive to global changes." *Aquat. Sci.* 64, 352–362.

Allan, J.A., 2002: "Water resources in semi-arid regions: Real deficits and economically invisible and politically silent solutions," in A. Turton and R. Henwood, (eds.), *Hydropolitics in the developing world – A southern African perspective*, African Water Issues Research Unit, Pretoria, 23–36.

Allan, J.D., M. Palmer, and N.L. Poff, 2005b: "Climate change and freshwater ecosystems" in T.E. Lovejoy and L. Hannah (eds.), *Climate Change and Biodiversity*: pp.274–290. Yale University Press, New Haven, CT.

Aloo, P.A., 2003: "Biological diversity of the Yala Swamp lakes, with species emphasis on fish species composition, in relation to changes in the Lake Victoria Basin (Kenya): threats and conservation." B*iodiversity and Conservation* 12: 902–920.

AMCOW, 2011: Country Status Overview of water supply and sanitation.

Anger, G., J. Seitz, and W. Nyangena, 2009: Economic Impact of Climate Change in the East African Community (EAC).

Anthony, D., 2007: Traditional environmental management systems related to changes and variations of water resources in semi-arid Tanzania: a case of the Mara River Basin, unpublished PhD thesis, University of Dar es Salaam.

Anyah, R.O., and F.H.M. Semazzi, 2004: "Simulation of the sensitivity of Lake Victoria basin climate to lake surface temperatures." *Theoretical and Applied Climatology* 79:55–69.

Ayieko, M.A, M.F.O. Ndon'ga, and A. Tamale, 2010: "Climate change and the abundance of edible insects in the Lake Victoria region." *Journal of Cell and Applied Biology* 4: 112–118.

Bain, R., R. Cronk, R. Hossain, S. Bonjour, K. Onda, J. Wright, H. Yang, T. Slaymaker, P. Hunter, A. Prüss-Ustün, and J. Bartram, 2014: "Global assessment of exposure to faecal contamination through drinking water based on a systematic review." *Tropical Medicine and International Health*, 19(8): 917–927.

Balian, E.V., H. Segers, C. Lévêque, and K. Martens, 2008: "The freshwater animal diversity assessment: an overview of the results." *Hydrobiologia* 595:627–637.

Bertahas, I., E. Dimltriou, S. Laschou, and I. Zacharias, 2006: "Climate change and agricultural pollution effects on the trophic status of a Mediterranean lake." *Acta Hydroch Hydrob* 4:349–359.

Bogardi, J.J., D. Dudgeon, R. Lawford, E. Flinkerbusch, A.Meyn, C. Pahl-Wostl, K. Vielhauer, and C. Vörösmarty, 2012: Water security for a planet under pressure: interconnected challenges of a changing world call for sustainable solutions, Curr Opin Environ Sustain (2012), doi: 10.1016/j.cosust.2011.12.02.

Bouchaou, L., T. Tagma, S. Boutaleb, M. Hssaisoune, and Z.E. El Morjani, 2012: "Climate Change and its Impacts on Groundwater Resources in Morocco: the Case of the Souss-Massa Basin" in H. Treidel, J.L. Martin-Bordes, and J. J. Gurdak (eds), *Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations.* Taylor & Francis.

CBM, 2012: Disability and Climate Change: Understanding vulnerability and building resilience in a changing world: http://www.cbm.org/article/downloads/54741/Disability_and_Climate_Change.pdf.

Chiew, F.H.S., and T.A. McMahon, 1996: "Trends in historical streamflow records" in J.A.A. Jones, C. Liu, M.K. Woo, and H.T. Kung (eds), *Regional Hydrological Response to Climate change,* Kluwer Academic Publishers. pp. 63–68.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Koli, W.-T. Kwon, R. Laprise, V.M. Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton, 2007: Regional climate projections. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.), Cambridge University Press, Cambridge, 847–940.

COWI Consulting Engineers, 2002: Integrated Water Quality/Limnology study for Lake Victoria. Lake Victoria Environmental Management Project, Part II Technical Report.

Darwall, W.R.T., K. Smith, T.,Lowe, and J.-C. Vié, 2005: The Status and Distribution of Freshwater Biodiversity in Eastern Africa. IUCN SSC Freshwater Biodiversity Assessment Programme. IUCN, Gland, Switzerland and Cambridge, UK.

Darwall, W.R.T., K. Smith, T.,Lowe, and J.-C. Vié (eds.), 2005: The Status and Distribution of Freshwater Biodiversity in Eastern Africa. viii, 36. Occasional Paper of the IUCN Species Survival Commission 31. IUCN, Gland, Switzerland and Cambridge, UK: IUCN SSC Freshwater Biodiversity Assessment Programme.

Darwall, W.R.T., Smith, K.G., Allen, D.J., Holland,R.A, Harrison, I.J. and Brooks, E.G.E. (eds) (2011). The Diversity of Life in African Freshwaters: Under Water, Under Threat. An analysis of the status and distribution of freshwater species throughout mainland Africa. Cambridge, UK and Gland, Switzerland: IUCN.

de Sherbinin, Alex. (2013). Climate change hotspots mapping: What have we learned?. Climatic Change. 123. 23-37. 10.1007/s10584-013-0900-7.

Diop, S., 2012. Water Resources Availability and Sectorial Analysis for Sustainable Development in Africa. Paper presented at the international symposium on Enhancing water management capacity in a changing world, June 25-28, 2012, Sao Paulo, Brazil, 28, 2012.

Dudgeon, D., A.H. Arthington, M.O. Gessner, Z.-I. Kawabata, D.J. Knowler, C. Lévêque R.J. Naiman, A.-H. Prieur-Richard, D. Soto, M.L.J. Stiassny, and C.A. Sullivan, 2005: "Freshwater biodiversity: importance, threats, status and conservation challenges." *Biological Research* 81:163–182.

EAC (East African Community), 1999: EAC Treaty. East African Community, Arusha.

——————, 2004: The East African Community Five Years Meteorological Development Plan and Investment Strategy.

——————, 2005: Policy brief on the environment and natural resources sector of the East African Community. http://www.eac.int/lvdp/Policy_brief_04_2006.pdf.

——————, 2007: Regional Transboundary Diagnostic Analysis of the Lake Victoria Basin. Lake Victoria Basin Commission.

——————, 2007: Strategic Action Plan for the Lake Victoria Basin. Lake Victoria Basin Commission.

——————, 2010: East African Community Climate Change Policy. EAC secretariat, Arusha, Tanzania.

——————, 2011: 4th EAC Development Strategy (2011/12 – 2015/16): One People, One Destiny. Deepening and Accelerating Integration.

——————, 2011: Vision and Strategy Framework for Management and Development of Lake Victoria Basin. Arusha, Tanzania.

——————, 2011: EAC Development Strategy 2011/12-2015/16: Deepening and Accelerating Integration.

——————, 2011: East African Community Climate Change Master Plan.

——————, 2011: East African Community Climate Change Policy (EACCCP). EAC secretariat, Arusha, Tanzania.

——————, 2012: Facts and figures. Arusha, Tanzania.

——————, 2013: Lake Victoria Basin Commission secretariat: strengthening meteorological services on the lake.

——————, 2013: EAC Partner States @50: Commissioner paper. International Symposium on Agriculture, November 05–07, 2013; Kampala, Uganda.

——————, 2014: Lake Victoria Basin ecosystem profile assessment report.

East Africa Community Secretariat, 2005: The State of the Fisheries Resources of Lake Victoria and their management. Proceeding of the regional stakeholder's conference, Entebbe, Uganda.

EAGLON (East African Great Lakes Observatory Network), (undated): Modeling Data. Available at: http://websibn78.seventyeight.axc.nl/index.php.

Economic Commission of Africa (ECA), African Union, African Development Bank 2000: Africa Water Vision 2025: Equitable and Sustainable Use of Water for Socioeconomic Development

Edmunds, W.M.E., 2009: "Paleoclimate and groundwater evolution in Africa—implications for adaptation and management." *Hydrol. Sci. J.* 54, 781–792.

Elshamy, M.E., and H.S. Wheater, 2009: "Performance assessment of a GCM land surface scheme using a fine-scale calibrated hydrological model: an evaluation of MOSES for the Nile Basin." *Hydrological processes* 23, 1548–1564.

Emerton, L., L. Lyango, P. Luwum, and A. Malinga, 1999: *The present economic value of Nakibubo urban wetland, Uganda.* IUCN East Africa Regional Office, Nairobi, Kenya.

FAO (Food and Agriculture Organisation), 2005: Rwanda country report, in *Irrigation in Africa in figures,* AQUASTAT Survey 2005, FAO, Rome, Italy. ftp://ftp.fao.org/agl/aglw/docs/wr29_eng.pdf.

__________, 2010: Case Three – TransVic: Improved Land Management Across the Lake Victoria Basin retrieved from: http://www.fao.org/wairdocs/tac/y4953e/y4953e07.htm

—————, 2011: *Climate change, water and food security.* FAO, Rome. http://www.fao.org/docrep/014/i2096e/i2096e.pdf.

—————, 2014: Adapting to climate change through land and water management in Eastern Africa Results of pilot projects in Ethiopia, Kenya and Tanzania.

Ficke, A.D., C.A. Myrick, and L.J. Hansen, 2007: "Potential impacts of global climate change on freshwater fisheries." *Rev. Fish. Biol. Fisheries,* 17: 581–613.

Flynn, K.C., 2001: "Urban agriculture in Mwanza, Tanzania." *Africa: Journal of the International African Institute* 71(4), pp. 666–691.

Fritzsche, K., Schneiderbauer, S., Bubeck, P., Kienberger, S., Buth, M., Zebisch, M. & Kahlenborn, W. (2014). Vulnerability Sourcebook: Concept and guidelines for standardized vulnerability assessments. Bonn and Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Funk, C.; Michaelsen, J.; Marshall, M. Mapping recent decadal climate variations in precipitation and temperature across Eastern Africa and the Sahel. In Remote Sensing of Drought—Innovative Monitoring Approaches; Wardlow, B., Anderson, M., Verdin, J., Eds.; CRC Press: Boca Raton, FL, USA, 2012; pp. 331–358

Data Integration for Climate Vulnerability Mapping in West Africa (PDF Download Available). Available from: https://www.researchgate.net/publication/284177802_Data_Integration_for_Climate_Vulnerability_Mapping_in_West_Africa [accessed Feb 13 2018].

Gasse, F., 2002: "Kilimanjaro's secrets revealed," *Science*, 298: 548–549.

Geheb, K., and K. Crean, 2003: "Community-level access and control in the management of Lake Victoria's fisheries." *Journal of Environmental Management* 67(2): 99–106.

Georgakakos, A., H. Yao, and A. Tidwell, 2005: Study on Water Management of Lake Victoria Technical Report 10 Climate Change Impact Assessment. Uganda Ministry of Energy and WREM International Inc.

Global Environment Outlook (GEO 2000): UNEP retrieved from http://www.grid.unep.ch/geo2000/english/index.htm

GLOWS-FIU, 2007: Water Quality Baseline Assessment Report, Mara River Basin, Kenya/Tanzania. Global Water for Sustainability Program, Florida International University. 61 pp. ISBN.

Government of Kenya, 2009: Population and housing census. Ministry of Planning and Vision 2030.

Green, T.R., M. Taniguchi, H. Kooi, J.J. Gurdak, D.M. Allen, K.M. Hiscock, H. Treidel, and A. Aureli, 2011: "Beneath the surface of global change: Impacts of climate change on groundwater." *Journal of Hydrology* 405: 532–560.

Greenfacts, 2015: Water Availability Information for Burundi. http://www.greenfacts.org/en/water-resources/figtableboxes/aquastat29.html.

GWSP, 2005: The Global Water System Project: Science Framework and Implementation Activities. Earth System Science Partnership.

Hanson, C., J. Ranganathan, C. Iceland, and J. Finisdore, 2008: The Corporate Ecosystem Services Review: Guidelines for Identifying Business Risks and Opportunities Arising from Ecosystem Change. Washington, DC, World Resources Institute.

Hanson, R.T., M.D. Dettinger, and M.W. Newhouse, 2006: "Relations between climatic variability and hydrologic time series from four alluvial basins across the southwestern United States." *Hydrogeol. J.* 14 (7), 1122–1146.

Heck, S., J. Ikwaput, C.T. Kirema-Mukasa, C. Lwenya, D.N. Murakwa, K. Odongkara, P. Onyango, J.P. Owino, and F. Sobo, 2004: *Cross-border Fishing and Fish Trade on Lake Victoria:* IUCN.

Heino, J., R. Virkkala, and H. Toivonen, 2009: "Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions." *Biol. Rev.* 84: 39–54.

Hinkel, J. "Indicators of vulnerability and adaptive capacity": Towards a clarification of the science—policy interface. Glob. Environ. Chang. 2011, 21, 198–208.

Howard, G., and J. Bartram, 2003: Domestic Water Quantity, Service Level and Health. World Health Organization.

Hughes, R.H., and J.S. Hughes, 1992: A directory of African wetlands. IUCN, Gland, Switzerland and Cambridge, UK.

Hulme, M., R. Doherty, T. Ngara, M. New, and D. Lister, 2001: "African climate change: 1900–2100," *Climate Research* 17,145–168.

Iglesias, A., S. Quiroga, and A. Diz, 2011: "Looking into the future of agriculture in a changing climate." *European Review of Agricultural Economics* 38(3), 427–447. European Environment Agency, Copenhagen.

IPCC (Intergovernmental Panel on Climate Change), 2001: Assessment on climate change, 52.

——————, 2007: IPCC Fourth Assessment Report. Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability. IPCC, Geneva.

——————, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hansen (eds.), Cambridge University Press, Cambridge, UK.

——————, 2014a: Freshwater resources. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Cambridge University Press, Cambridge, United Kingdom and New York, NY, pp. 229–269.

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

IUCN (International Union for Conservation of Nature), 2010: Situation Analysis for Water and Wetlands Sector in Eastern and Southern Africa, Nairobi, Kenya.

JICA (Japan International Cooperation Agency), 2002: Study on the National Irrigation Master Plan in the United Republic of Tanzania. Master Plan, vol 1—Main Report. Ministry of Agriculture and Food Security. Nippon Koei Company, Limited.

Kashaigili, JJ 2012 Tanzania. In: Pavelic P Giordano M, Keraita B, Ramesh V, Rao T (eds.) Groundwater availability and use in Sub-Saharan Africa: A review of 15 countries. International Water Management Institute

Kaufman, L. 1992: Catastrophic Change in Species-Rich Freshwater Ecosystems: The lessons of Lake Victoria, *BioScience*, Volume 42, Issue 11, 1 December 1992, Pages 846–858,

Kilonzo, F., F.O. Masese, A.V. Griensven, W. Bauwens, J. Obando, and P.N.L. Lens, 2013: "Spatial–temporal variability in water quality and macro-invertebrate assemblages in the Upper Mara River Basin, Kenya." *J. Phys. Chem. of the Earth* 67–69: 93–104

Kishe, M.A., and J.F. Machiwa, 2003: "Distribution of heavy metals in sediments of Mwanza Gulf of Lake Victoria. Tanzania." *Environmental International*, 28: 619–625.

Kiwango, Y.A., and E. Wolanski, 2007: Papyrus wetlands, nutrients balance, fisheries collapse, food security, and Lake Victoria level decline in 2000–2006. Wetlands Ecology Management.

Kolding J, Medard M, Mkumbo O, Zwieten PAM. Status, trends and management of the Lake Victoria Fisheries. In: Welcomme RL, Valbo-Jørgensen J, Halls AS, editors. Inland fisheries evolution and management—case studies from four continents. FAO Fisheries and Aquaculture Technical Paper 579; 2014.

Kundzewicz, Z.W., and P. Döll, 2009: "Will groundwater ease freshwater stress under climate change?" *Hydrol. Sci. J.* 54(4), 665–675.

LVBC (Lake Victoria Basin Commission), 2007: Regional transboundary diagnostic analysis of the Lake Victoria Basin. East African Community.

——————, 2011: Vulnerability assessment to climate change in Lake Victoria Basin. Lake Victoria Basin Commission, Kisumu, Kenya.

LVBC and WWF-ESARPO, 2010: Biodiversity Strategy and Action Plan for Sustainable Management of the Mara River Basin. Nairobi and Kisumu, Kenya.

LVEMP (Lake Victoria Environmental Management Programme), 2005: Water Quality Synthesis Report.

LVFO. (2014a). Regional catch assessment survey synthesis report, june 2005 to april 2014. Lake Victoria Fisheries Organization. Jinja

MacDonald, A.M., H.C. Bonsor, B.É.Ó. Dochartaigh, and R.G. Taylor, 2012: "Quantitative maps of groundwater resources in Africa Environ." *Res. Lett.* 7 024009.

MacDonald, A.M., H.C. Bonsor, R.C. Calow, R.G. Taylor, D.J. Lapworth, L. Maurice, J. Tucker, and B.É.Ó. Dochartaigh, 2011: Groundwater resilience to climate change in Africa. British Geological Survey Open Report, OR/11/031. 25 pp.

MacDonald, A.M., R.C. Calow, D.M.J. MacDonald, W.G. Darling, and B.É.Ó. Dochartaigh, 2009: "What impact will climate change have on rural water supplies on Africa?" *Hydrological Sciences Journal,* 54: 690–703.

Mahé, G., 2009: "Surface/groundwater interactions in the Bani and Nakambe rivers, tributaries of the Niger and Volta river basins, West Africa." *Hydrol. Sci. J.* 54(4), 704–712.

Maitima, J.M., P.C. Kariuki, S.M. Mugatha, and L.W. Mariene, 2009: Adapting East African Ecosystems and productive systems to climate change: an ecosystem approach towards costing of climate change adaptation in East Africa. Report for the economics of climate change adaptations in Africa.

Manabe, S., P.C.D. Milly, and R. Wetherald, 2004: "Simulated long-term changes in river discharge and soil moisture due to global warming," *Hydrol. Sci. J.* 49(4), 625–642.

Manyala, J.O., 2011: Fishery value chain analysis: Background report–Kenya.

Margat, J., S. Foster, and A. Droubi, 2006: Concept and importance of non-renewable resources. In: Non-Renewable Groundwater Resources: A Guidebook on Socially-Sustainable Management for Water Policy Makers (ed. by S. Foster and D. P. Loucks), 13–24. IHP-VI, Series on Groundwater no. 10, UNESCO, Paris, France.

Mati, B.M., S. Mutie, P.,Home, F. Mtalo, and H. Gadain, 2005: "Impacts of land use change on the hydrology of transboundary Mara River" in *Proceedings of the 11th World Lakes Conference*, 31st October -4th November 2005, Nairobi, Kenya, O. Odada, D.O. Olago, W. Ochola, M. Ntiba, S. Wandiga, N. Gichuki, and H. Oyieke, H. (eds). Ministry of Water and Irrigation and the International Lake Environment Committee. Volume 2: 432–439.

Mato, R.R.A.M., 2000: Groundwater Quality Deterioration in Dar es Salaam City, Tanzania. A paper presented to the Groundwater: Present and future Challenges workshop, 26 Nov–1 December, Cape Town, South Africa.

Mavuti, K.M., 1989: "An account of some important freshwater wetlands of Kenya" in S.A. Crafter, S.G. Njuguna, and G.W. Howard (eds), *IUCN Conference Proceedings on Wetlands of Kenya*, pp. 23–35.

Mfugale, D., 2007: "Usangu Game Reserve to become part of Ruaha National Park," *The Guardian*, 11 July.

Milly, P., K. Dunne, and A. Vecchia, 2005: "Global pattern of trends in streamflow and water availability in a changing climate." *Nature* 438, 347–350.

MININFRA, 2010: National Policy and strategy for water supply and sanitation. Kigali. Rwanda.

Mjemah IC, Mtoni Y, Elisante E, Tungaraza CT, Mtakwa PW, Walraevens K (2012) Sources of salinity in the Quaternary sand aquifer of Dar-es-Salaam, Tanzania. In: da Silva GC Jr, and Montenegro SMGL (eds).

Mote, P.W., and G. Kasser, 2007: "The shrinking glaciers of Kilimanjaro: can global warming be blamed?" *American Scientist* 95, 4, 6.

Mtoni, Y., I.C. Mjemah, C. Bakundukize, M. Van Camp, K. Martens, and K. Walraevens, 2013: "Saltwater intrusion and nitrate pollution in the coastal aquifer of Dar es Salaam, Tanzania." *Environ Earth Sci* 70:1091–1111.

Muli, J.R., and K.M. Mavuti, 2001: "The benthic macrofauna community of Kenyan waters of Lake Victoria." *Hydrobiologia* 458: 83–90.

Mulwa, J.K., S.J. Gaciri, J.O. Barongo, N. Opiyo-Akech, and G. K. Kianji, 2005: "Geological and Structural influence on groundwater distribution and flow in Ngong Area, Kenya." *African Journal of Science and Technology* 6. 105–115.

Mumma, A., M. Lane, E. Kairu, A. Tuinhof, and R. Hirji, 2011: Kenya: Groundwater Governance Case Study. Water Papers: Water Partnership Programme.

Mutabazi, A., 2011: Rwanda Country Situational Analysis.

Mutie, S.M., B. Mati, P. Home, H. Gadain, and J. Gathenya, 2006: Evaluating land use change effects on river flow using USGS geospatial stream flow model in Mara River Basin, Kenya. Center for Remote Sensing of Land Surfaces, Bonn, 28-30.

Mwanja Waiswa W., Signa D. & Eshete D. (2011). Fisheries and Aquaculture in Eastern Africa. FAO SFE Technical Document Series – Addis Ababa

Mwendera, E., 2010: Situation Analysis for Water and Wetlands Sector in Eastern and Southern Africa, International Union for Conservation of Nature (IUCN), Eastern and Southern Africa Regional Office, Nairobi, Kenya.

Mwiturubani, D.A., and J.A. van Wyk, 2010: Climate change and access to water resources in the Lake Victoria Basin, Institute for Security Studies.

Nampinga, R., 2008: Gender Perspectives on Climate Change.

NEMA, 2015: facts/status of water resources in Kenya. http://www.nema.go.ke. accessed 25th June 2015.

Nepworth, N., 2010: Climate Change Vulnerability and Adaptation Preparedness in Tanzania, LTS Africa pp. 29–34.

Ngongondo, C.S., 2006: "An analysis of long-term rainfall variability, trends and groundwater availability in the Mulunguzi river catchment area, Zomba mountain, Southern Malawi." *Quaternary International* 148(1): 45–50.

Ngupula, G.W., and R. Kayanda, 2010: "Benthic macrofauna community composition, abundance and distribution in the Tanzanian and Ugandan inshore and offshore waters of Lake Victoria." *African Journal of Aquatic Science* 35(2): 185–192.

Nhapi, I., Wali, U.G., Uwonkunda, B. K., Nsengimana, H., Banadda N. and Kimwaga, R. 2011.Assessment of water pollution levels in the Nyabugogo Catchment, Rwanda, The Open Environmental Engineering Journal, 2011, 4, p40-53.

Nicholson, S., 1998: "Fluctuations of Rift Valley Lakes Malawi and Chilwa during historical time: a synthesis of geological, archaeological and historical information," in *Environmental change and response in East African lakes,* J.T. Lehman, (ed.), 207–231, Kluwer Academic Punblishers, Dordrecht.

Nile Basin Initiative, 2012: The State of the Basin. Myriad Editions, Brighton, UK. Printed by Graphic Systems, Kampala, Uganda.

Norbert, J., J. Ndayizeye, and S. Mkhandi, 2011: "Regional Flow Duration Curve Estimation and its application in assessing Low Flow Characteristics for Ungauged Catchment: a case Study of Rwegura Catchment, Burundi." *Nile Basin Water Science & Engineering Journal* 4(1):14–23.

Nsengimana, H., F. Masengesho, and D. Kalisa Nyirimbibi, 2012: Some physico-chemical characteristics of groundwater in Rwanda.

Nsubuga, F.N.W., E.N. Namutebi, and M. Nsubuga-Ssenfuma, 2014: "Water Resources of Uganda: An Assessment and Review." *J. of Water Resource and Protection* 6, 1297–1315. http://dx.doi.org/10.4236/jwarp.2014.614120.

Nyingi, D.W., and J.F. Agneses, 2012: Phylogeography of the Nile Tilapia in Africa. Lambert Academic Publishers.

Nyingi, D.W., 2013: Guide to the common freshwater fishes of Kenya. Moran Publishers, Nairobi, Kenya.

O'Reilly, C.M., 2007: "The impact of recent global climate change on the East Africa Rift Valley lakes." *Earth-Sci. Rev.,* submitted.

O'Reilly, C.M., S.R. Alin, P.D. Plisnier, A.S. Cohen, and B.A. McKee, 2003: "Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa." *Nature* 424, 766–768.

Odada, E.O., D.O. Olago, K. Kulindwa, M. Ntiba, and S. Wandiga, 2004: "Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy options analyses," *Ambio* 33(1–2).

OECD (Organization for Economic Co-operation and Development), Development Assistance Committee (DAC), 2005: Water and violent conflict, Issues Brief, mainstreaming conflict prevention Available at http://www.oecd.org 2005.

Ogutu-Ohwayo, R., K.N. Odongkara, and W. Okello, 2011: Impact of climate variability and change on riparian and aquatic ecosystems, fisheries and livelihoods. National Fisheries Resources Research Institute, Jinja, Uganda.

Olago, D., A. Opere, and J. Barongo, 2009: "Holocene palaeohydrology, groundwater and climate change in the lake basins of the Central Kenya Rift." *Hydrol. Sci. J.* 54(4), 765–780.

Onyancha, C., E. Mathu, S. Mwea S., and W. Ngecu, 2014: "Effects of drilling deep tube wells in the urban areas of Nairobi city, Kenya" *ARPN Journal of Earth Sciences* 1: 17–24.

Opiyo, S.V., 1991: Feeding ecology of *Oreochromisesculentus* (Graham) (Pisces: Cichlidae) in Lake Kanyaboli, Kenya, M.Sc. Thesis, University of Nairobi, 147 pp.

Parry, M., C. Rosenzweig, A. Iglesias, F. Günther, and M. Livermore, 1999: "Climate change and world food security: a new assessment." *Global Environmental Change*, 9 S51–S67.

Phoon, S.Y., A.Y. Shamseldin, and K. Vairavamoorthy, 2004: Assessing impacts of climate change on Lake Victoria Basin, Africa. People-Centered Approaches to Water and Environmental Sanitation. 30th WEDC International Conference, Vientiane, Lao PDR.

Pinter, N., 2010: Fluvial geomorphology and flood hydrology. Southern Illinois University Carbondale.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg, 1997: "The natural flow regime: a paradigm for river conservation and restoration." *BioScience* 47:769–784.

Poff, N.L., M.M. Brinson, and J.W. Day Jr., 2002: Aquatic ecosystems and global climate change. Technical Report, Pew Center on Global Climate Change, Arlington, Virginia, USA.

Poole, J.H., 1989: "Announcing intent: the aggressive state of musth in African elephants." *Animal Behavior*. 37: 140–152.

Porter, J.R., Xie, L., Challinor, A.J., Cochrane, K., Howden, S.M., Iqbal, M.M., Lobell, D.B. & Travasso, M.I. 2014. Food security and food production systems.

PREPARED, 2014: Planning for Resilience in East Africa through Policy, Adaptation, Research, and Economic Development. Lake Victoria Basin Ecosystem Profile Report.

Reaka-Kudla, M.L., 1997: "The global biodiversity of coral reefs: A comparison with rain forests," in M.L. Reaka-Kudla, D.E. Wilson, and E.O. Wilson (eds), *Biodiversity II: Understanding and protecting our biological resources*. Joseph Henry Press, Washington, D.C., 83–108.

Republic of Kenya, 2013: National Water Master Plan 2030. Ministry of Environment, Water and Natural Resources.

Republic of Rwanda, 2011: Water Resources Management Sub-sector Strategic Plan (2011-2015), Ministry of Natural Resources

Ricciardi, A., and J.B. Rasmussen, 1999: "Extinction rates of North American freshwater fauna." *Conservation Biology* 13, 220–222.

Roessig, J.M., C.M. Woodley, J.J. Cech, Jr., and L.J. Hansen, 2004: "Effects of global climate change on marine and estuarine fishes and fisheries." *Reviews in Fish Biology and Fisheries* 14: 251–275.

Rwanda Environmental Management Authority (REMA), 2009: Rwanda State of Environment and outlook report. Chapter VII water and wetland resources.

Sekadende, B.C., T.J. Lyimo, and R. Kurmayer, 2005: "Microcystin production by cyanobacteria in the Mwanza Gulf (Lake Victoria, Tanzania)." *Hydrobiologia* 543: 299–304.

Shah, T., J. Burke, and K. Villholth, 2007: "Groundwater: a global assessment of scale and significance," in *Water for Food, Water for Life* (D. Molden, ed.), 395–423. Earthscan, www.earthscan.co.uk.

Siebert, S., J. Burke, J.M. Faures, K. Frenken, J. Hoogeveen, P. Döll, and F.T. Portmann, 2010: Groundwater use for irrigation—a global inventory. *Hydrology and Earth System Sciences* 14, 1863–1880.

Sokoine University of Agriculture (SUA), 2008: Proposal for a programme on climate change impacts, adaptation and mitigation in Tanzania, Sokoine University, Morogoro, Tanzania, 2008.

Stockholm Environment Institute, 2008: Climate change and adaptation in African agriculture.

Sutcliffe, J.V., and Y.P. Parks, 1999: The Hydrology of the Nile. IAHS Special Publication. GIBB Water, Reading, UK.

Sutcliffe, J.P., 2013: "Ecosystem profile assessment – Lake Victoria Basin," *Hydrology*, LTS Africa.

Swallow, B.M., J.K. Sang, M. Nyabenge, D.K. Bundotich, A.K. Duraiappah, and T.B. Yatich, 2009: "Tradeoffs, synergies and traps among ecosystem services in the Lake Victoria Basin of East Africa." *Environ. Sci. Policy* 12, 504–519.

Sweeney, B.W., 1992: "Streamside Forests and Physical, Chemical and Trophic Characteristics of Predmont Streams in Eastern North America." *Water Sciences and Technology*. 26:2653–2673.

Talling, J.F., 1957: "Some observations on the stratification of Lake Victoria." *Limnol. Oceanogr.* 2:213–221.

Tate, E., J. Sutcliffe, D. Conway, and F. Farquharson, 2004: "Water balance of Lake Victoria: update to 2000 and climate change modeling to 2100." *Hydrological Sciences–Journal–des Sciences Hydrologiques* 49(4) August 2004.

Taylor, R., and C. Tindimugaya, 2012: "The Impacts of Climate Change and Rapid Development on Weathered Crystalline Rock Aquifer Systems in the Humid Tropics of sub-Saharan Africa: Evidence from South-Western Uganda," in H. Treidel, J.L. Martin-Bordes, and J.J. Gurdak (eds).

Taylor, R.G, B. Scanlon, P. Döll, M. Rodell, R. van Beek, Y. Wada, L. Longuevergne, M. Leblanc, J.S. Famiglietti, M. Edmunds, L. Konikow, R.T. Green, J. Chen, M. Taniguchi, M.F.P. Bierkens, A. MacDonald, Y. Fan, R.M. Maxwell, Y. Yechieli, J. Jason, J.J. Gurdak, D. Allen, M. Shamsudduha, K. Hiscock, P. J.-F. Yeh, I. Holman, and H. Treidel, 2012: "Ground water and climate change." *Nature Climate Change*. 1744. 3: 322–330.

The United Republic of Tanzania, Ministry of Water and Irrigation, 2008: National Water Sector Development Strategy. Dares Salaam, Tanzania.

Thirgood, S., A. Mosser, S. Tham, G. Hopcraft, E. Mwangomo, T. Mlengeya, M. Kilewo, J. Fryxell, A.R.E. Sinclair, and M. Borner, 2004: "Can parks protect migratory ungulates? The case of the Serengeti wildebeest." *Animal Conservation* 7: 113–120.

Thole, B., 2013: Groundwater Contamination with Fluoride and potential Fluoride removal.

Tolo, C.U., E.A Majule, and J. Perfect, 2012: Changing Trends of Natural Resources Degradation in Kagera Basin: Case Study of Kagera Sub-Basin, Uganda. *Natural Resources*, 2012, 3, 95-106.

Twagiramungu, F., 2006: Environmental Profile of Rwanda. Report for the National Authorizing Officer of FED and the European Commission, Kigali, Rwanda.

Uganda National Water Development Report—2005 2nd UN World Water Development Report.

UN-Water Country Brief United Republic of Tanzania. http://www.unwater.org/activities/multi-agency-featured-projects/country-briefs/en/.

UNECA (United Nations Economic Commission for Africa), 1999: *Global Environment Outlook 2000 (GEO)*, London; Earthscan, 1999.

——————, 2009: Kenya: Atlas of our changing Environment: The People, the Land and Natural Resources. UNEP.

UNEP (United Nations Environment Programme), 2009: Lake Victoria Basin Environment Outlook, www.unep.org/dewa/africa.

——————, 2010: Africa Water Atlas. http://www.unep.org/pdf/africa_water_atlas.pdf accessed 25th June2015.

——————, 2013: "Adaptation to Climate change" Induced Water Stress in the Nile Basin: A Vulnerability Assessment Report. Division of Early Warning and Assessment. UNEP. Nairobi, Kenya.

UNESCO (United Nations Educational, Scientific and Cultural Organization), 2008: International Hydrological Programme of the UNESCO. GRAPHIC framework document. [Online] Available from: http://unesdoc.unesco.org/images/0016/001631/163172e.pdf.

UNGA (United Nations General Assembly), 2001: *Road map towards the implementation of the United Nations Millennium Declaration*. Report of the Secretary General. Fifty-sixth session. 6 September 2001. New York, UN.

United Republic of Tanzania, 2007: National Adaptation Programme of Action (NAPA), Vice President's Office, Dar es Salaam, Division of Environment.

UN-Water, 2014: The United Nations World Water Development Report, WWDR4, Volume 1. Water and Energy. World Water Assessment Programme, www.unesco.org/water/wwap.

Vanacker, V., M. Linderman, F. Lupo, S. Flasse, and E. Lambin, 2005: "Impact of short-term rainfall fluctuation on interannual land cover change in sub-Saharan Africa." *Global Ecology and Biogeography* 14: 123–135.

Verschuren, D., T.C. Johnson, H.J. Kling, D.N. Edgington, P.R Leavitt, E.T. Brown, D.M.R. Talbot, and R.E. Hecky, 2002: "History and timing of human impact on Lake Victoria, East Africa." *Proc. R. Soc. Lond. B* (2002) 269, 289–294.

Waititu, A., 2009: Global Warming and Conflicts over Water Resources in Eastern Africa. Conference on Water—Sources of Conflict. Berne. Switzerland.

White, I., T. Falkland, T. Metutera, E. Metai, M. Overmars, P. Perez, and A. Dray, 2007: "Climatic and human influences on groundwater in low atolls." *Vadose Zone Journal,* 6(3): 581–590.

WHO and UNICEF (World Health Organization/United Nations Children's Fund), 2014: *Progress on drinking water and sanitation: 2014 Update.* New York, WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation. http://www.wssinfo.org/fileadmin/user_upload/resources/JMP_report_2014_webEng.pdf.

World Bank, 2005: The Role of Groundwater in the Water Supply of Greater Nairobi, Kenya. Sustainable groundwater management lessons from practice. Case profile collection. Number 13.

—————, 2009. World Development Indicators. 2009. Washington, DC

—————, 2014: Turn down the heat: Confronting the new climate normal. International Bank for Reconstruction and Development.

WWAP (United Nations World Water Assessment Programme), 2006: National Water Development Report: Uganda Case study: Prepared for the 2nd UN World Water Development Report. UN-Water.

—————, 2009: The United Nations World Water Development Report 3: Water in a Changing World, World Water Assessment Programme. Paris, UNESCO Publishing.

—————, 2015: *The United Nations World Water Development Report 2015: Water for a Sustainable World.* Paris, UNESCO.

WWF (World Wide Fund for Nature), 2006: Climate Change Impacts on East Africa: A *review of the scientific literature*, Gland Switzerland, World Wide Fund for Nature.

Xenopoulos, M.A., D.M. Lodge, A. Alcano, M. Marker, K. Shulze, and D.P. Van vuuren, 2005: "Scenarios of freshwater fish extinction from climate change and water withdrawal." *Global Change Biology* 11, in press.

Yin, X., and S.E. Nicholson, 1998: "The water balance of Lake Victoria," *Journal of Hydrological Sciences* 5(43), 789–811.

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