VULNERABILITY, IMPACTS AND ADAPTATION ASSESSMENT IN THE EAST AFRICA REGION

CHAPTER 1:
CLIMATE BASELINE FOR EAST AFRICA

OCTOBER 2017

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DISCLAIMER

CONTENTS

ACRONYMS

DMI	Dipole Mode Index
EAC	East African Community
ENSO	El Niño Southern Oscillation
GDP	Gross domestic product
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
LVB	Lake Victoria Basin
QBO	Quasi-Biennial Oscillation
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
VIA	Vulnerability, Impacts and Adaptation Assessment
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

The impacts of climate variability and change are likely to have severe consequences for East Africa and the Lake Victoria Basin (LVB). Changes in temperature and rainfall affect many economic sectors in the region, particularly agriculture, including fisheries, livestock, and crop production, on which a large portion of the population depend for a livelihood. The region's economic dependence on these resources puts it at high risk of socioeconomic stress due to shifts in weather and increases in extreme events such as floods and drought.

The Fifth Assessment Report (AR5) of the United Nations Intergovernmental Panel on Climate Change (IPCC) found that warming of the climate system is unequivocal, and that many of the observed changes occurring around the world are unprecedented. Anthropogenic changes in climate result from greenhouse gas emissions that create conditions for warming the atmosphere, which effects weather systems. Among the major systems affected are the El Niño Southern Oscillation and the Indian Ocean Dipole, both of which influence the weather in East Africa. Changes in climate are exacerbated by the effects of land use changes in Africa and by the demands of rapidly increasing population.

This chapter summarizes the causes and effects of climate change and analyzes spatial and temporal variability and trends on rainfall and maximum and minimum surface temperatures in East Africa and the LVB. It establishes a baseline for current climatic conditions in the region that can be used in future assessments and in modeling possible future conditions. It highlights the impacts of climate variability and change on water and aquatic ecosystems, terrestrial ecosystems, agriculture, health, and energy and transport. Finally, the report describes the implications for international policy related to climate change, such as United Nations Framework Convention on Climate Change (UNFCCC) adopted in 1992, the Kyoto Protocol, and the Paris Agreement, which sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to an increase of well below 2°C over preindustrial levels.

1. INTRODUCTION

The Fifth Assessment Report (AR5) of the United Nations Intergovernmental Panel on Climate Change (IPCC) has indicated that warming of the global climate system is unequivocal. Since the 1950s the report finds, many of the observed changes occurring around the world are unprecedented over decades to millennia and that the atmosphere and ocean have warmed, amounts of snow and ice have diminished, sea level has risen, and concentrations of greenhouse gases have increased.

1.1 CAUSES OF CLIMATE CHANGE

The state of the global climate is determined by the amount of energy stored by the climate system, and in particular the balance between energy the Earth receives from the Sun and the energy the Earth releases back to space. Major causes of climate change include any process that can alter the global energy balance, and the energy flows within the climate system. Notable causes include changes in the Earth's orbit around the Sun, changes in the amount of energy coming from the Sun, changes in ocean circulation, or changes in the composition of the atmosphere. Such changes can be triggered by large volcanic eruptions, the atmospheric impacts of which can affect the global climate over decades, or by continental movements that alter ocean currents and weather systems that can affect the global climate over much longer time scales. Modern science has also demonstrated that human activities are altering the climate.

1.2 FACTORS IN ANTHROPOGENIC CLIMATE CHANGE

Among the human activities that effect the climate, the burning of carbon-based fuels, especially fossil fuels—coal, oil, natural gas—is a major cause of atmospheric modification. Burning releases gases to the atmosphere. These gases, including CO_2, water vapor, methane, and nitrous oxide, are collectively known as greenhouse gases for their effect on the Earth's atmosphere, which increases the retention of heat from the Sun's energy and restricts the rate at which the Earth's surface can radiate heat into space.

Since the industrial revolution, the concentrations of CO_2 and methane have steadily increased. Moreover, industrial development has released additional chemical pollutants into the Earth's atmosphere, such as chlorofluorocarbons (CFCs) that reduced the protective ozone layer in the atmosphere, exacerbating the effects of the greenhouse gases. Other anthropogenic chemicals, such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), add to the load of greenhouse gases in the atmosphere.

Changes in land use also contribute to climate change through a variety of effects. Deforestation contributes to changes in the atmosphere through burning, which increases particulate concentrations, through alterations in the evapotranspiration cycle, and through increasing CO_2 levels. In addition, urban and other settlement expansion increases impermeable surface area, which affects runoff and water exchange with the atmosphere, as well as the flow of pollutants into water bodies. Cities also store heat energy, creating imbalances with surrounding areas that can alter microclimates.

Agriculture, a significant economic activity in East Africa, affects climate not only through deforestation but also through other processes. Poor farming practices can lead to desertification and alterations in soils that can affect the water exchange between land and atmosphere.

1.3 GLOBAL PERSPECTIVES OF CLIMATE CHANGE

Climate change is a global phenomenon the effects of which are different on continental, national, local scales. Those differences, particularly with regard to temperature, indicate that the effects of climate change are already evident and are rapidly increasing across most of the globe. Figure 1 shows the observed temperatures for the period 1910–2010 in the different continents of the world.

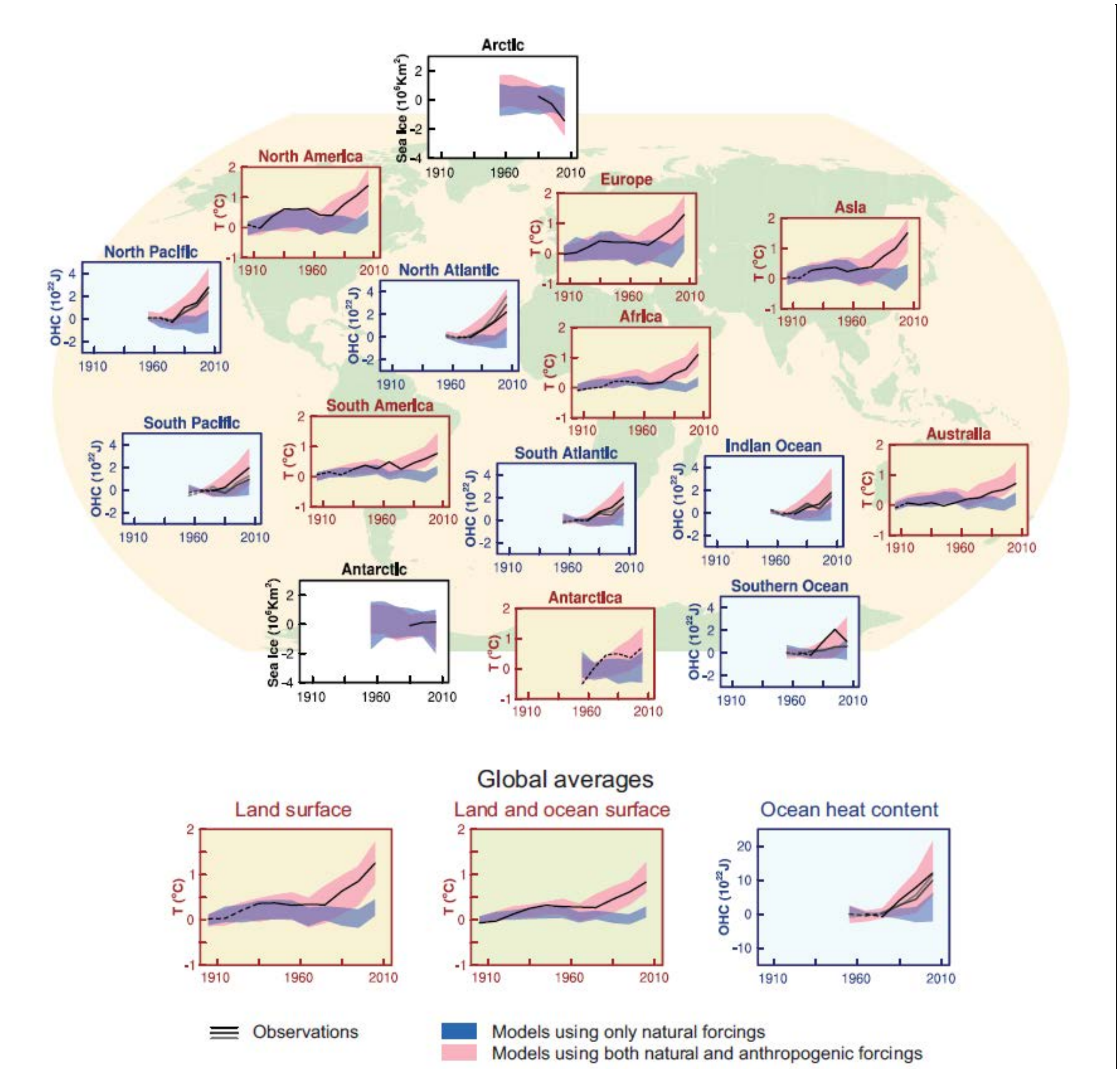


Figure 1: Observed global temperature changes (IPCC 2014)

Climate models suggest a global warming of about 3°C and a sea level rise of about 68 centimeters by the year 2100 due to the CO_2 emission projected under the business-as-usual scenario (Figure 2).

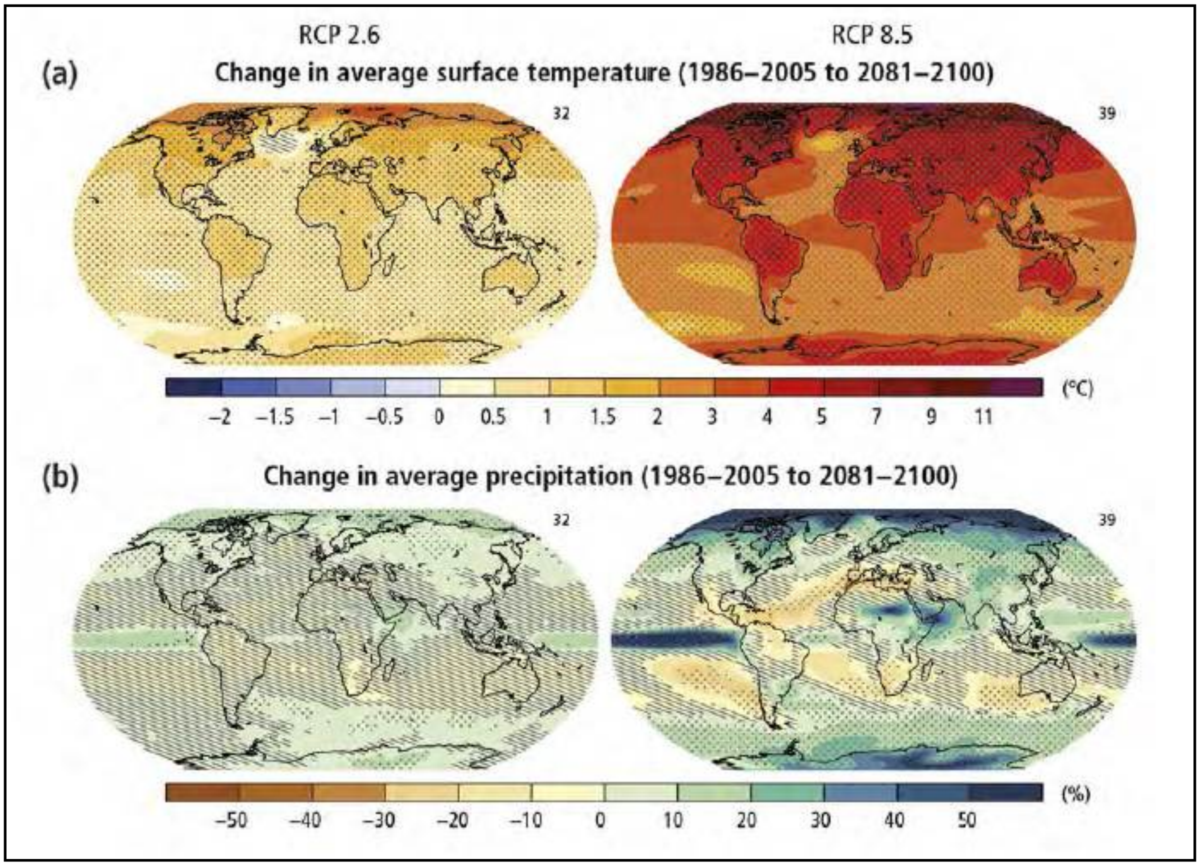


Figure 2: Change in average surface temperature (a) and change in average precipitation (b) based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios.

The dots in Figure 2 indicate regions where the projected change is large compared to natural internal variability while the hatching (diagonal lines) indicates regions where the projected change is less than one standard deviation of the natural internal variability (IPCC 2014).

1.4 Regional Perspectives of Climate Change (Africa and East Africa)

Africa is at higher risk to the effects of climate change than other continents given its geographical location (IPCC 2001, 2007), as well as limitations in its capacity to adapt (AMCEN). In its 4th Assessment Report (AR4), the IPCC said of Africa: "Among the risks the continent faces are reductions in food security and agricultural productivity, particularly regarding subsistence agriculture, increased water stress and, as a result of these and the potential for increased exposure to disease and other health risks, increased risks to human health." Africa's human populations and development are under threat from the adverse impacts of climate change—its population, ecosystems, and unique biodiversity are all potential victims. The ability to adapt to changes in climate will be limited by underdeveloped human capital, constraints on technical options, lack of information, and poor market integration nationally, regionally, and internationally.

IPCC projections indicate that by 2050 average temperatures in Africa are expected to increase by 1.5°– 3°C, and they will continue to rise into the future (Figure 3). In East Africa, the observed change in temperature is about 0.3°C per decade as calculated between 1980 and 2011 (Figure 3). The temperature increase between now and 2050 is 2°– 4°C.

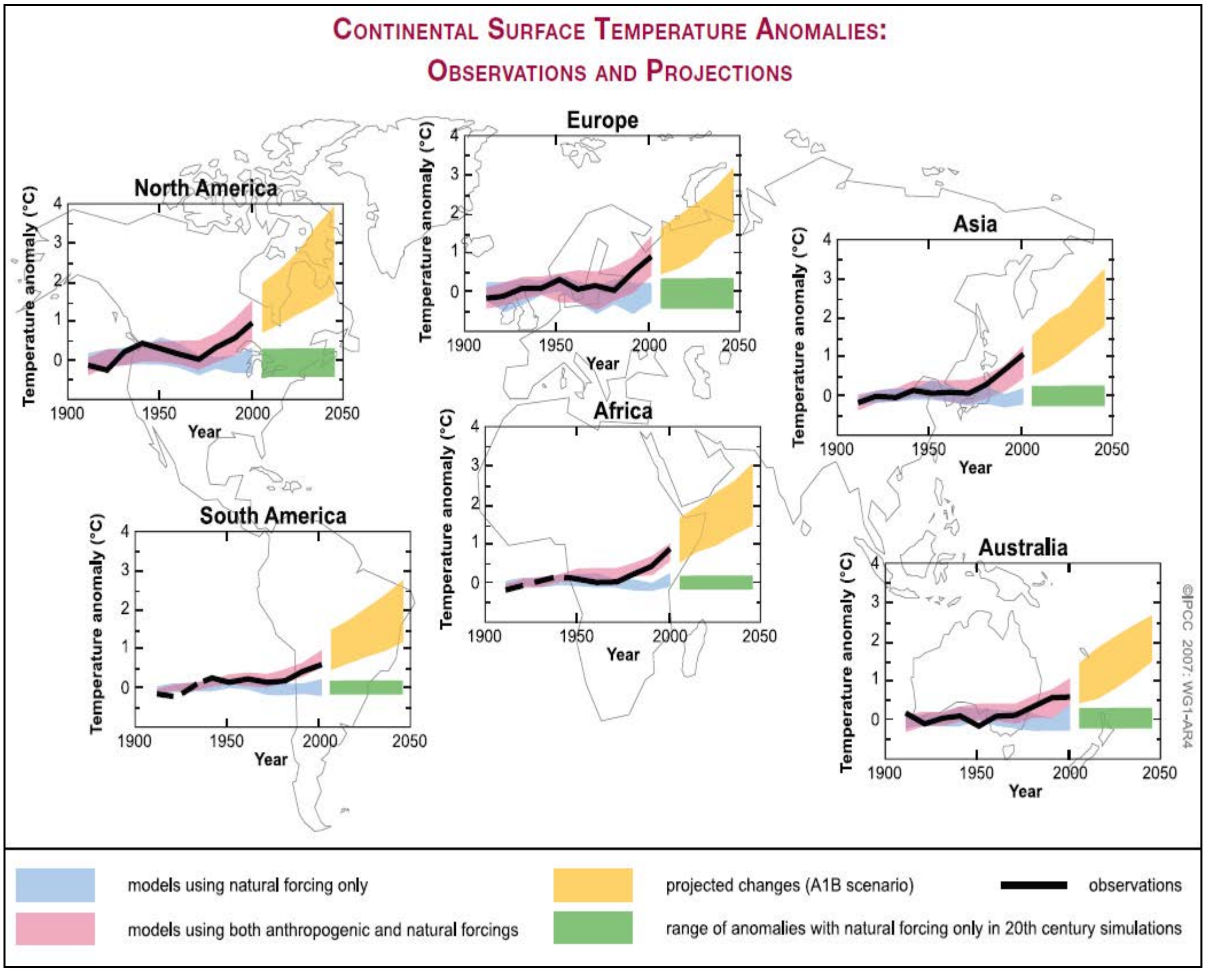


Figure 3: Continental surface temperature anomalies—observations and projections (IPCC 2007)

The projections for Africa indicate that by 2080 arid and semi-arid land will increase by 5 to 8 percent and droughts will become more common, especially in the tropics and subtropics. Human health could be negatively affected by climate change and climate variability, for example, malaria could increase in southern Africa and the East African highlands (IPCC 2007). Projections for agriculture indicate that in some countries yields from rain-fed cultivation could be reduced by up to 50 percent by 2020. Agricultural production will be severely affected, with yield reductions of up to 50 percent in some countries by 2020. This will have consequences for food and nutrition security as well as for incomes and human well-being, as farm revenues decline, particularly among smallholders.

Rising sea levels could affect coastal populations. The continent has about 320 coastal cities with populations of at least 10,000 people, and an estimated population of 56 million (2005) living at low elevations. These people will be at increased flooding risk as well as weather-related disasters such as heavy rainfall and high temperatures.

The impact of climate change on ecosystems in Africa will be severe. The continent's ecosystems will be disrupted, with consequences for biodiversity and human health. Between 25 and 40 percent of mammal species in national parks in Sub-Saharan Africa will become endangered (IPCC 2007, AMCEN report) and there is evidence that climate is modifying natural mountain ecosystems via complex interactions and feedback.

Table 1 summarizes the impacts observed on vulnerability or climate change in Sub-Saharan Africa indicating severe impacts of heat extremes, drought, aridity, and sea level rise in the region with extreme impacts on terrestrial ecosystems. Aridity is projected to spread due to changes in temperature and precipitation. In a world that is 4°C warmer, total hyper-arid and arid areas are projected to expand by 10 percent compared to 1986–2005 (World Bank 2013).

Table 1: Summary of Climate Impacts and Risks in Sub-Saharan Africa

Risk/impact		Observed vulnerability or change	Around 1.5°C (=2030s)	Around 2°C (=2040s)	Around 3°C (=2060s)	Around 4°C (=2080s)
Heat extreme (in the Southern Hemisphere summer)	Unusual heat extremes	Virtually absent	20–25 percent of land	45 percent of land	70 percent of land	>85 percent of land
	Unprecedented heat extremes	Absent	<5 percent of land	14 percent of land	35 percent of land	>55 percent of land
Drought		Increasing drought trends observed since 1950	Increasing drought risk in southern, central, and West Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of severe drought in southern and central Africa, increased risk in West Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of extreme drought in southern Africa and severe drought in central Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of extreme drought in southern Africa and severe drought in central Africa, decrease in East Africa, but West and East African projections are uncertain
Aridity		Increased drying	Little change expected	Area of hyper-arid and arid regions grows by 3 percent		Area of hyper-arid and arid regions grows by 10 percent. Total arid and semi-arid area increases by 5 percent
Sea level rise above present (1985–2005)		About 21cm to 2009	30cm in 2040s 50cm in 2070 70cm by 2080–2100	30cm in 2040s 50cm in 2070 70cm by 2080–2100	30cm in 2040s 50cm in 2070 90cm by 2080–2100	30cm in 2040s 50cm in 2070 105cm by 2080–2100

Source: World Bank 2013

2. FACTORS AFFECTING CLIMATE VARIABILITY AND CHANGE IN AFRICA AND EAST AFRICA

The rainfall pattern of the tropical regions is characterized by strong seasonality, with dry and short rainy seasons for half of the year, and wet and long rainy seasons for the other half. This seasonal cycle results from differential variation in solar radiation and the meridional and zonal migration of weather-producing systems. The position and intensity of the meteorological systems affect the amount and distribution of climatic elements such as rainfall, temperature, humidity, and wind.

Seasonal rainfall patterns over East Africa are very complex due to complex topography (Figure 4), such as the Rift Valley system, mountains, plateaus, and large inland water bodies (Asnani and Kinuthia 1979, Asnani 1993). Temporal variations in rainfall occur on various time scales, including diurnal (Asnani and Kinuthida 1979, Asnani 1993, Barring 1987), quasi-biweekly (Okoola 1989), intraseasonal or monthly (Tomsett 1969, Omeny 2008), seasonal (Ogallo 1983), and annual and decadal (Shreck and Semazzi 2004, Omondi et al. 2012a and 2012b, Omondi et al. 2013). Quasi-periodic fluctuations of time scales greater than a year have also been observed (Rodhe and Virji 1976, Nyenzi 1992, Ogallo 1988).

East Africa has two major rainfall seasons, locally referred to as the "long rains" (March–May) and the "short rains" (October–December). The long season is concentrated in March to May while the short season occurs from late September to November or early December. The southern parts of the region, extending from central to southern Tanzania, have a unimodal rainfall regime between September and April (Nyenzi 1992). The equatorial sector (north of about 5°S latitude)—covering northern Tanzania, most of Uganda, and Kenya—generally exhibits a bimodal rainfall regime, with peaks during March–May and October–December. During Northern Hemisphere summer, some areas receive substantial rainfall outside of the long and short rainfall seasons. The regions that commonly experience this trimodal regime include the East African coast, western Kenya, and most of Uganda. These areas receive incursions of shallow, westerly, moist airmass from the Atlantic Ocean and the Congo Basin (Anyamba 1984). Some areas around Lake Victoria and the coast receive substantial rainfall throughout the year as they are close to large water bodies.

In East Africa, both large and local-scale drivers of the climate system greatly influence rainfall variability, with much of the variability occurring during the short rainy season. This variability is linked to large-scale climate systems such as the El Niño Southern Oscillation (ENSO) (Mutai and Ward 2000, Indeje et al. 2000) and the Indian Ocean Dipole (IOD) (Behera et al. 2005, Owiti et al. 2005, Cai et al. 2014). The next section discusses some of the systems that influence weather patterns in the study region.

2.1 Inter-Tropical Convergence Zone

The Inter-Tropical Convergence Zone (ITCZ) is the main synoptic-scale system that controls the intensity and migration of seasonal rainfall over East Africa. It is a boundary defined by a confluence of hemispheric winds near the surface that result from inter-hemispheric monsoon wind systems over the region. The ITCZ sweeps across the region twice a year and has significant influence on rainfall patterns. It is linked to the two major rainfall seasons experienced over the equatorial segment (north of about 5°S latitude).

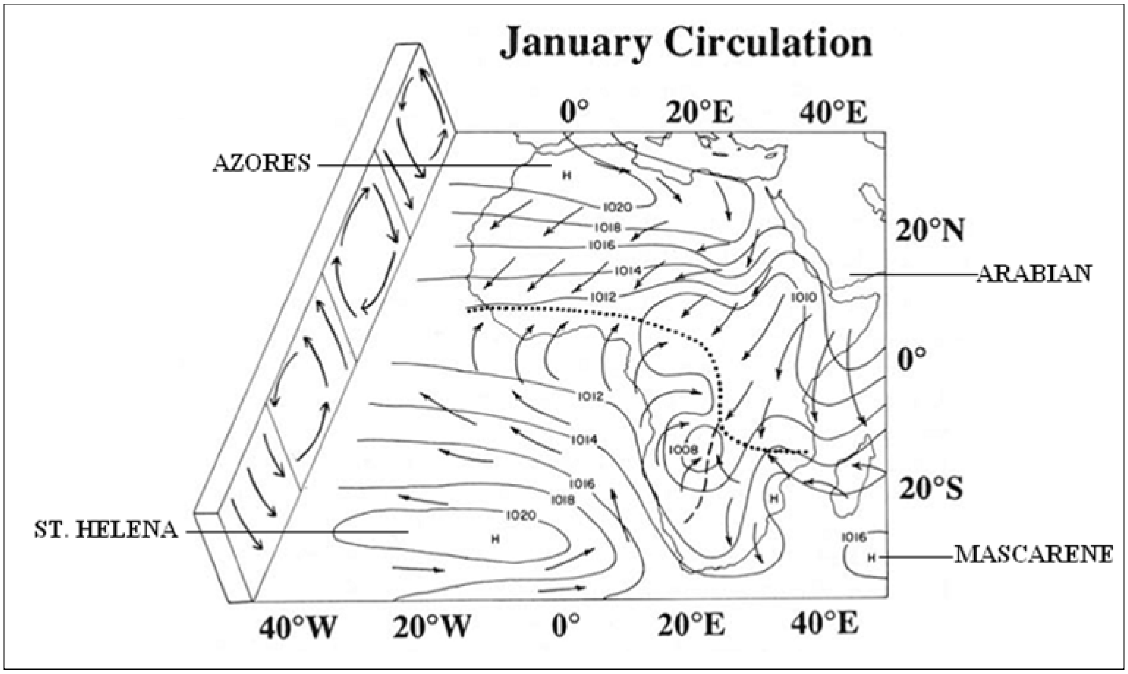


Figure 5a: Schematic of the general patterns of winds, pressure, and convergence over Africa during January (adapted from Nicholson et al. 1988). Dotted lines indicate the ITCZ, dashed lines indicate other convergence zones.

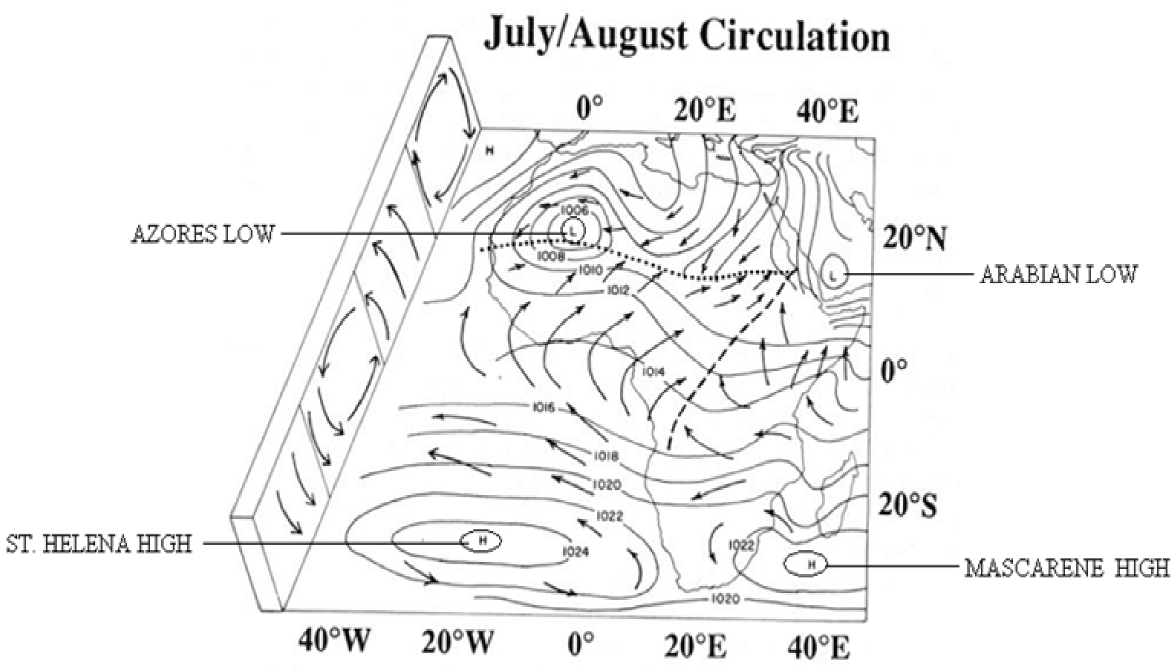


Figure 5b: Schematic of the general patterns of winds, pressure, and convergence over Africa during July/August (adapted from Nicholson et al. 1988). Dotted lines indicate the ITCZ, dashed lines indicate other convergence zones.

Over East Africa, and during the Southern Hemisphere summer (November–March), the ITCZ has two unique components—the normal east-west orientation called the zonal component and a north-south orientation (Figure 5) referred to as the meridional component. The meridional component is formed by the convergence of easterly winds from the Indian Ocean and moist westerlies from the Atlantic Ocean and the Congo Basin. This component oscillates roughly between longitudes 25°E and 36°E. Sometimes it couples with the quasi-permanent Lake Victoria Trough to create active weather over much of western Kenya throughout the year (Asnani 1993).

The meridional branch of the ITCZ (Figure 6) is shifted furthest east during June and July, which causes large parts of the region to be under a moist westerly monsoonal current from Atlantic Ocean and the moist Congo Basin. This eastward displacement of the meridional arm of ITCZ is often associated with the influx of the moist westerly airmass, which is locally known as the "Congo airmass." Anomaly in the meridional arm has been closely associated with anomalous rainfall over the region as observed in some years (Asnani 1993, Anyamba 1984).

2.2 El Niño and La Niña

El Niño and La Niña are normal phenomena related to changes that occur in and over the Pacific Ocean. In a neutral state, the Trade Winds carry cool waters from the eastern Pacific toward warmer waters in the western Pacific (Figure 6). When the waters to the east are warmer than normal, an El Niño event results in drier than normal conditions over Southeast Asia and Australia and wetter than normal conditions over the eastern Pacific (Figure 7). When the waters in the eastern Pacific are cooler than normal, a La Niña event results in wetter conditions over Southeast Asia and Australia and drier conditions over the eastern Pacific (Figure 8).

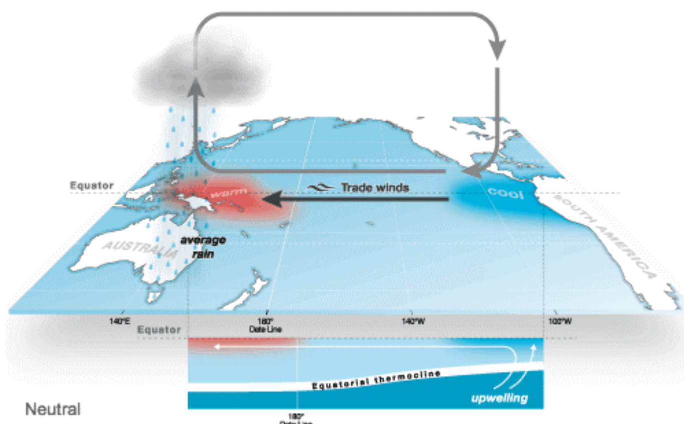


Figure 6: Sea surface under neutral conditions (source: www.bom.gov.au)

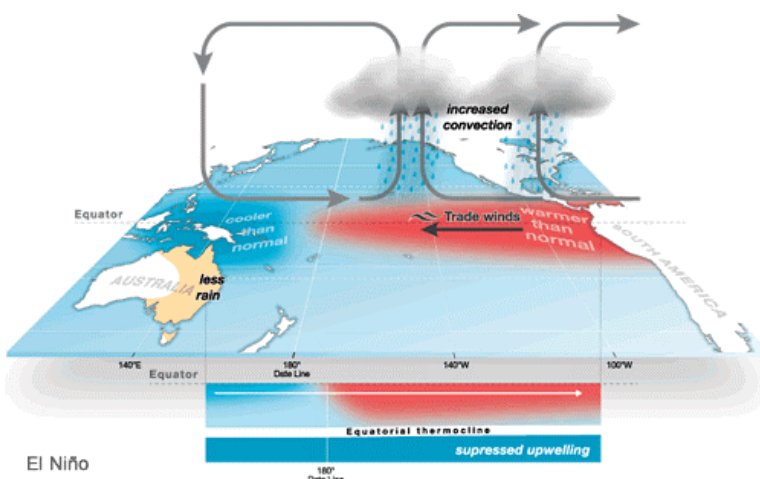


Figure 7: Sea surface under El Niño conditions (source: www.bom.gov.au)

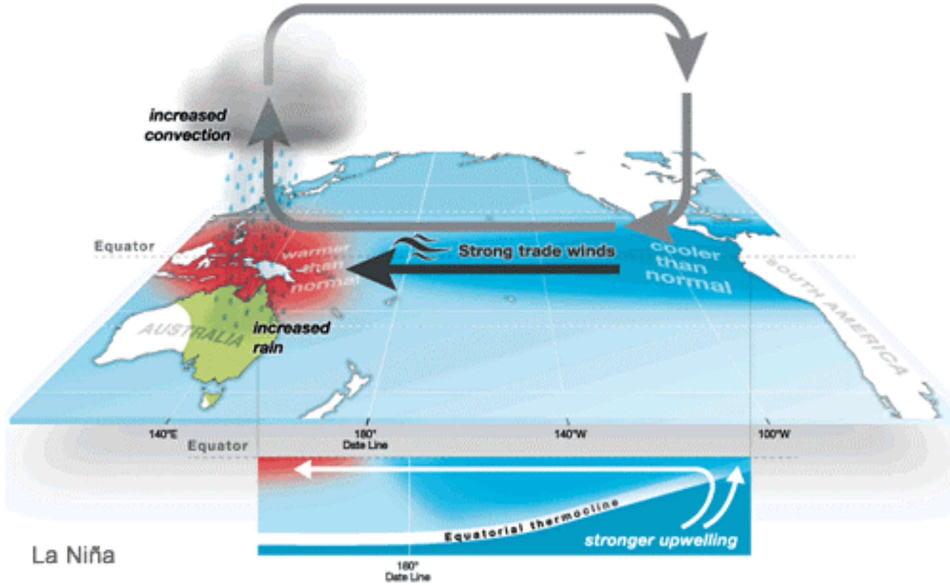


Figure 8: Sea surface under La Niña conditions (source: www.bom.gov.au)

The El Niño phenomenon is associated with inter-annual variability of precipitation in East Africa. The warm ENSO phase, together with a positive IOD are associated with anomalously high rainfall in East Africa, while the cold and the negative phases are associated with drought (Ogallo et al. 1988, Owiti 2005).

The warm western and cool eastern Indian Ocean is associated with enhanced October–December seasonal rainfall over East Africa (Behera et al. 2005, Black et al. 2003, Black 2004, Clark et al. 2003, Owiti 2005). Anomalous latent heat flux and vertical heat convergence associated with the modified Walker circulation contribute to the alteration of moist western anomalies toward Eastern Africa.

Major ENSO episodes lead to massive displacements of the tropical rainfall regions, bringing drought to vast areas and torrential rains to other regions, as shown in Figure 9.

The known impacts of El Niño in the greater Horn of Africa are as follows:

- Drought north of the equator with a poor June–August rainfall season. For example, if the rains were to fail in June–August 2015, there would be no rains until June–August 2016.
- Drought south of the equator with the December–February rainfall season. For example, if rains were to fail in December–February 2015, there would be no rains until December–February 2016.
- Floods in the equatorial zone with the October–December rainfall season. The driest season of January–February often gets very wet.

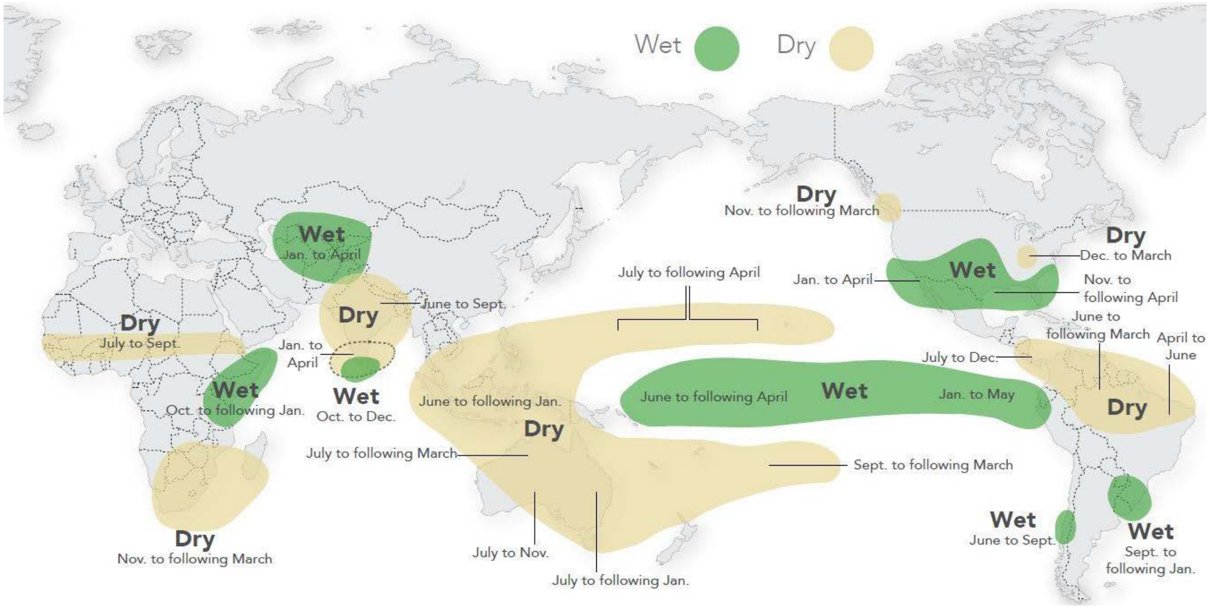


Figure 9: El Niño precipitation and temperature effects globally (ESU601)

2.3 Quasi-Biennial Oscillation

The Quasi-Biennial Oscillation (QBO), with a periodicity of 26–30 months, features an alternation in phase of the zonal winds in the lower stratosphere. The phases of the zonal winds feature vertical propagation that leads to changes in vertical wind shear and associated stability. The QBO has been found to affect a variety of atmospheric parameters around the world. Some of the atmospheric variables that have exhibited QBO include temperature (Rasmusson et al. 1981), ozone (Funk and Garnham 1962, Hasebe 1980), Indian monsoon (Mukherjee et al. 1979) and African rainfall (Rodhe and Virji 1976, Ogallo 1983, Nicholson and Entekhabi 1986, Indeje and Semazzi 2000).

Studies have demonstrated that the QBO plays an important role in linking the different layers of the atmosphere by descent from the middle stratosphere after a few months affecting several tropospheric and surface parameters, such as rainfall (Njau 2006). This suggests that global wind circulation in the lower stratosphere can, after a few months, have some effects on major weather events that occur over the globe. The lower stratospheric QBO plays a role in modulating rainfall over southern Africa (Mason and Tyson 1992) and East Africa (Jury et al. 1994, Kabanda and Jury 1999, and Indeje et al. 2000).

Indeje et al. (2000) found the strongest statistical association between rainfall over East Africa and QBO during the boreal summer season (June–August) and the weakest association in boreal winter (December–February). The strongest correlations were found over western parts of East Africa. Their results further indicated a significant relationship between QBO and the Indian Ocean Dipole Mode Index (DMI). Ogallo et al. (1994) applied spectral analysis to examine the effect of QBO over tropical East Africa using data for the period 1966–1987. They found a common period of 28 months in the oscillation, as well as a significant association (at 5 percent level) between rainfall and QBO based on the oscillation in zonal winds.

Distinct QBO spectral peaks in East Africa have been reported in several studies (Rodhe and Virji 1976, Ogallo 1983, Nicholson and Entekhabi 1986). Nicholson and Entekhabi (1986) presented evidence of several quasi-periodicities common to African rainfall, especially over southern and equatorial regions of the continent. In the low latitudes, spectral peaks in the ranges of 2.2–2.4 years and 5.0–6.3 years are common. Recurrence of the QBO mode has been reported by several authors, including Indeje and Semazzi (2000) and Claud and Terry (2007), among others.

2.4 Tropical Cyclones

The World Meteorological Organization (WMO) defines a tropical storm as a low-pressure system whose sustained wind speeds are 34–63 knots. Such storms become tropical cyclones when the sustained wind speed is equal to or greater than 64 knots (Reiter 1961). Tropical cyclones are cyclonic circulations whose origins are in the low latitudes between 50° and 20° north or south of the equator. The tropical cyclones that influence weather over East Africa originate in the western Indian Ocean, north of 20°S latitude. North of the equator, they form in northern spring and late fall and move northward into the Arabian Sea.

Tropical cyclones usually reach their maximum frequency in August–September in the Northern Hemisphere and January–February in the Southern Hemisphere. They cause severe weather that is destructive of both life and property (Asnani 1993). These systems rarely reach the East African coast; however, on a few occasions, as in October 1972 and 1984, they did reach the coast and caused increased rainfall as far north as Somalia and northern Kenya. They can cause one to two days of heavy precipitation and their effects can extent to within a 200-kilometer radius of the coast. Tropical cyclones can either enhance or reduce rainfall depending on their characteristics.

2.5 Indian Ocean Dipole

The Indian Ocean Dipole (IOD) is a sustained shift in surface temperatures of the Indian Ocean. Like the La Niña event, the positive phase of the IOD arises when the surface water temperatures along the coast of Africa are warmer than normal, which results in increased precipitation in the western Indian Ocean.

The negative phase of the IOD, like the El Niño, features warmer water and higher precipitation in the eastern Indian Ocean, while the west experiences cooler and drier conditions (Figure 10).

The heavy rains of 1961, which covered the entire region, were associated with the strong positive phase of IOD (Anyamba 1984).

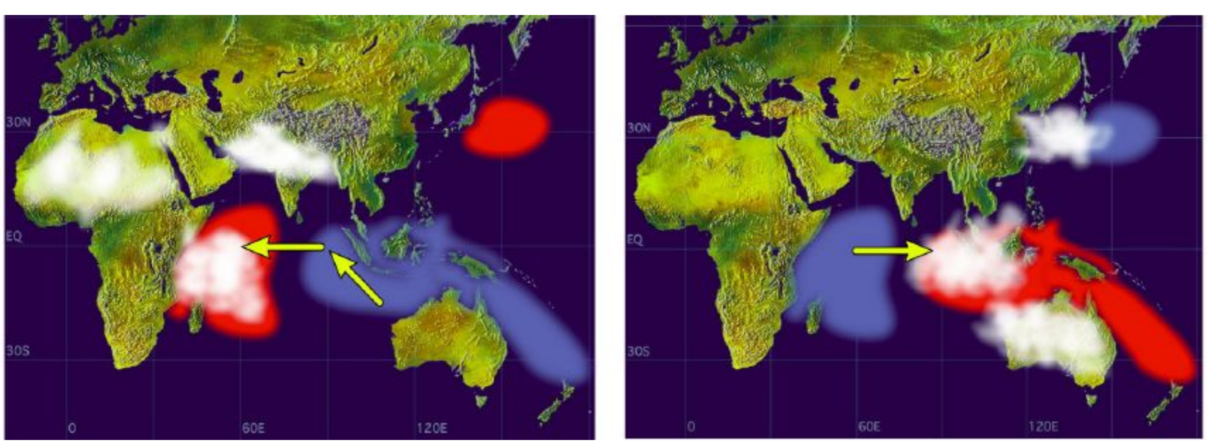


Figure 10: (a) Positive and (b) negative Indian Ocean Dipole

3. CLIMATE EXTREMES IN EAST AFRICA AND THE LAKE VICTORIA BASIN

Climate extremes manifest themselves in floods and droughts that have severely affected livelihoods and the economic development of East African countries. Such events have increased in frequency and severity over the past 30 years. The recurrent patterns of some of the droughts and floods have been associated with the ENSO and IOD, as well as anomalies in many other systems that drive the climate of various parts of Africa.

The climate extremes often wipe out years of national development investment and infrastructure and force many African nations to redirect scarce national development resources to disaster response and recovery, including relief programs. Climate change leading to changes in the space-time patterns could add new threats to the region's development efforts. Figure 11 presents some of the climate extreme impacts associated with the ENSO and the IOD.

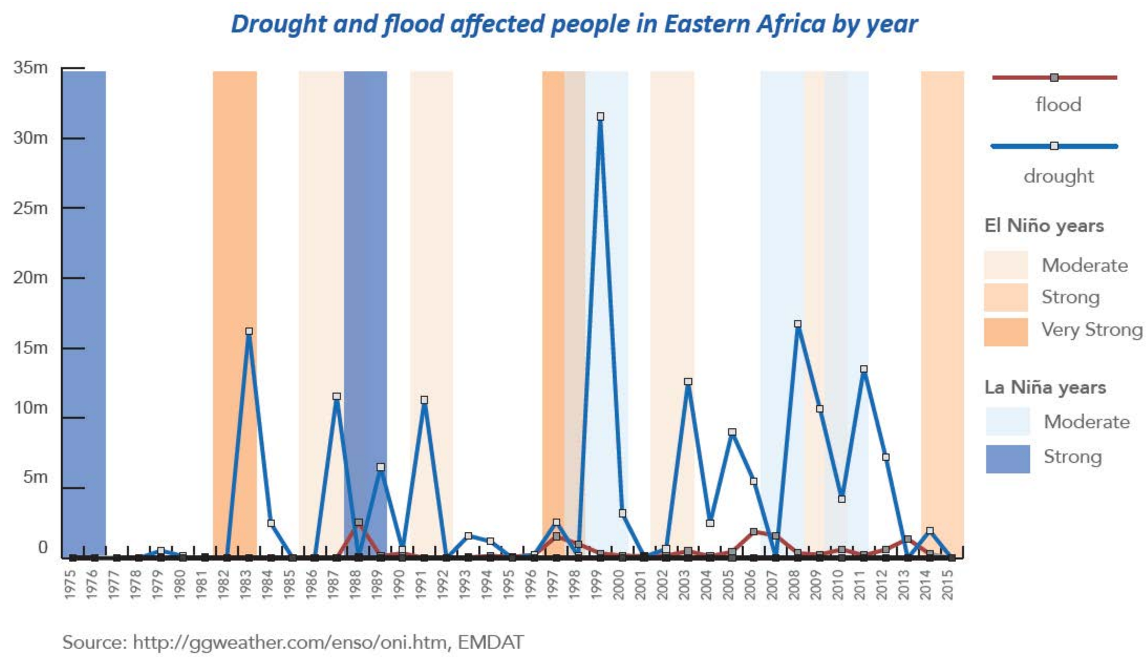
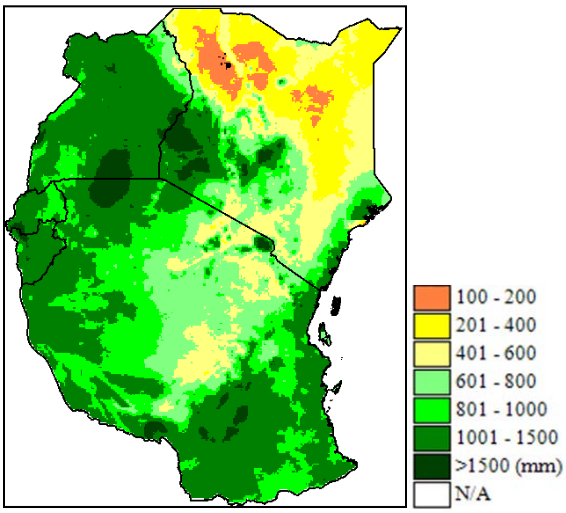


Figure 11: (a) Positive and (b) negative Indian Ocean Dipole

3.1 Rainfall Variability and Trends in East Africa and Lake Victoria Basin

This section presents the results of analyses of temporal trends in rainfall and maximum and minimum temperatures covering the East African Community (EAC) Partner States and the Lake Victoria Basin (LVB) from 1900 to 2014. The analyses were completed by blending satellite data from the Climate Hazards Infra—red Precipitation with stations (CHIRPs) database with regional available observation station data sets and analyzed using the GeoCLIM tool[1]. For each of the three climatic variables, the statistical methods used for analysis and the main results are summarized.

East Africa has a diverse climate profile to match its highly diverse geography. The seasonal cycle of rainfall is complex, and varies widely across the region. As noted earlier, the annual cycle of rainfall is bimodal. The long rains (March–May) account for more than 70 percent of the annual rainfall and the short rains for less than 20 percent (WWF 2006). Much of the inter-annual variability comes from the short rains (coefficient of variability is 74 percent compared with 35 percent for the long rains) (WWF 2006; see Figures 12a, 12b, 12c, and 12d).



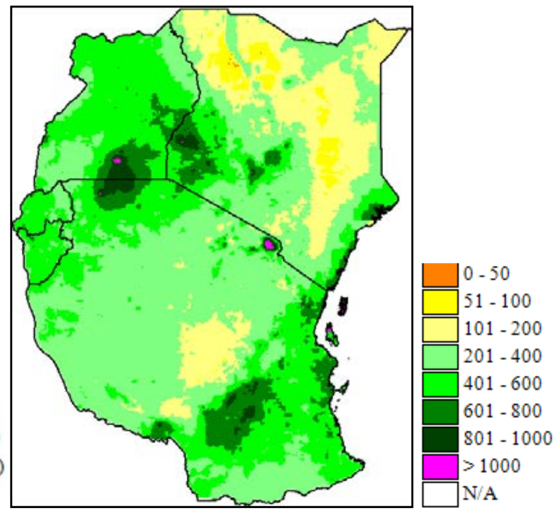
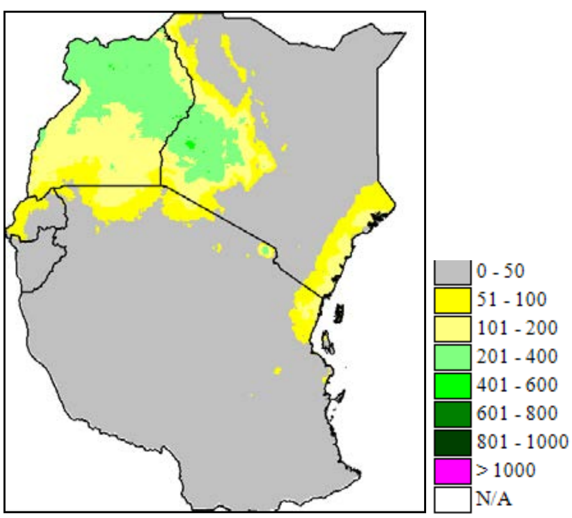


Figure 12a: Annual average rainfall (mm) Figure 12b: March–June seasonal rainfall (mm)



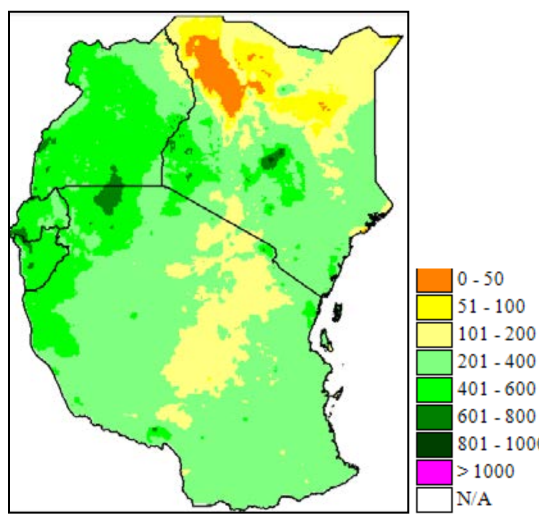


Figure 12c: June–August seasonal rainfall (mm) Figure 12d: September–December seasonal rainfall (mm)

[1] CHIRPs and GeoCLIM were developed by the University of California – Santa Barbara Climate Hazards Group in collaboration with the Famine Early Warning Systems Network (FEWSNET) and the United States Geological Survey (USGS).

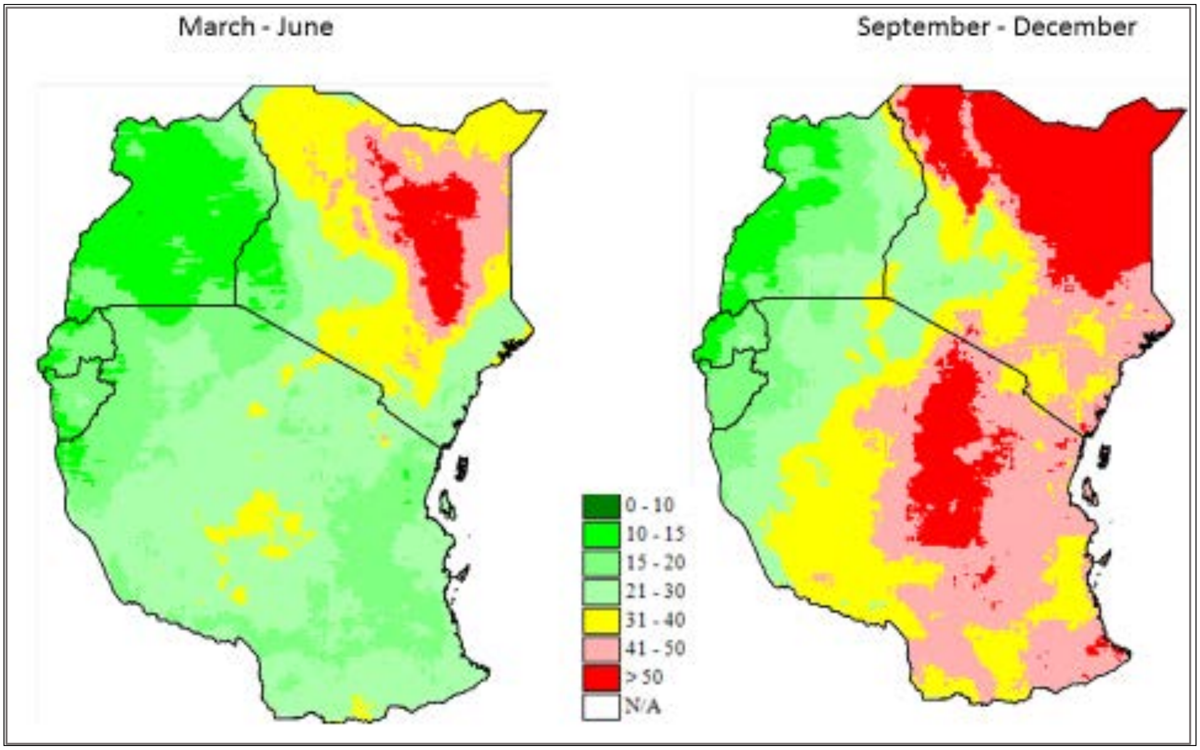


Figure 13: Seasonal rainfall variability (%)

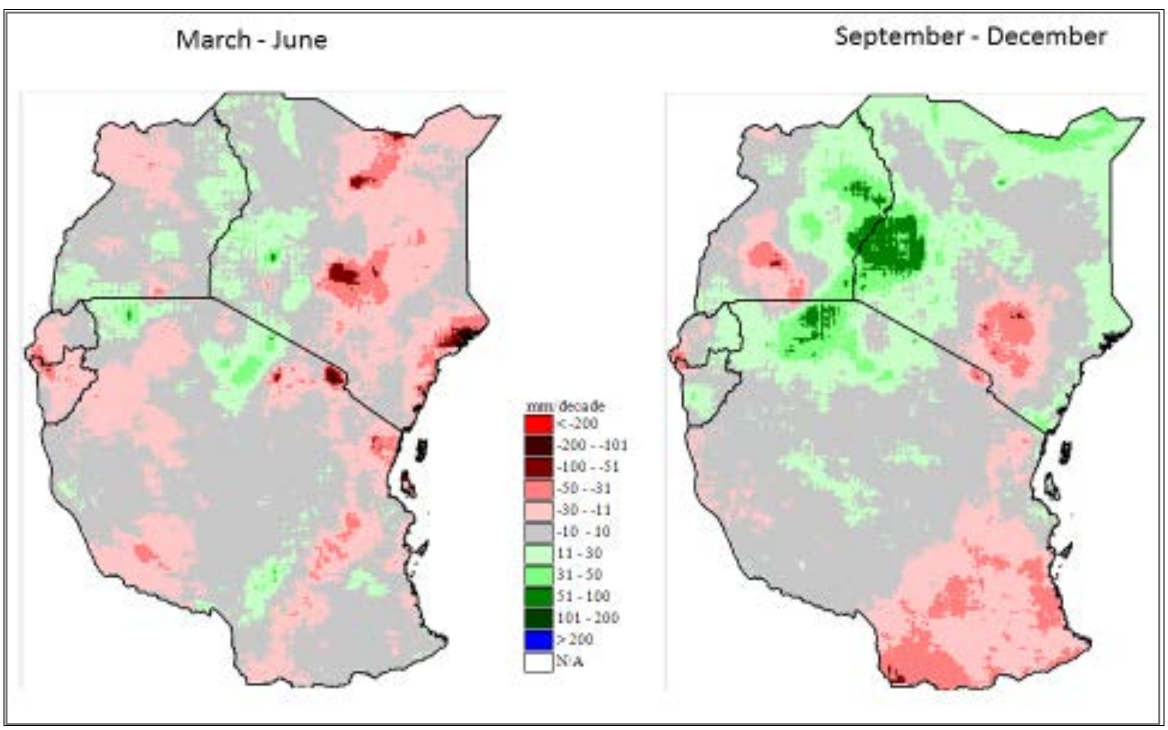


Figure 14: Seasonal rainfall trends (mm/decade)

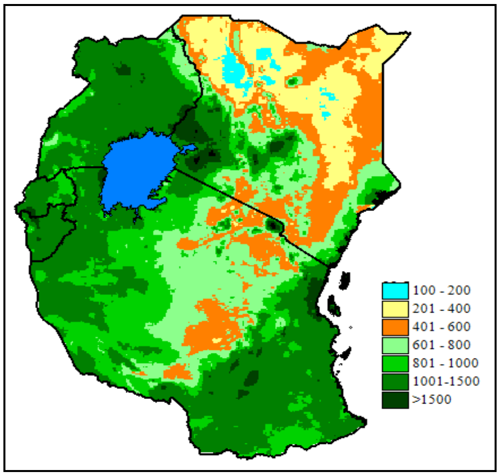


Figure 15a: Average annual rainfall (mm) (1981–2014) for the EAC

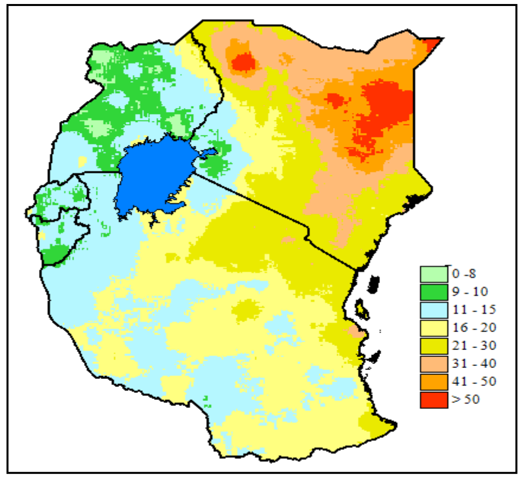


Figure 15b: Rainfall coefficient of variation (%) for the EAC

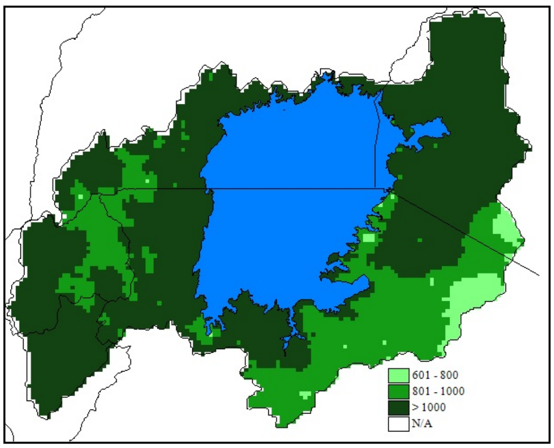


Figure 16a: Average annual rainfall (mm) (1981–2014) for the LVB

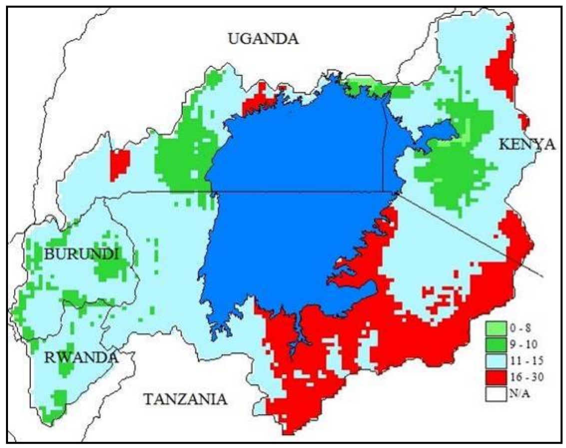


Figure 16b: Coefficient of variation (%) for annual rainfall (1981–2014) for the LVB

The maps show that most parts of LVB receive more than 1,000 millimeters of annual rainfall. However, the southeastern part of LVB receives less than 800 millimeters and has high inter-annual variability.

The temporal trends in monthly (January–December) rainfall were modeled simultaneously, considering the rainfall records for all 12 months in each year as a multivariate random vector. The trends were effectively linear, so a linear approximation was used to test for the significance of the temporal trends in rainfall. The tests sought to establish whether rainfall has been increasing or decreasing in particular months and whether the patterns of increase or decrease differ significantly among regions (LVB, Burundi, Kenya, Rwanda, Tanzania, and Uganda) or in nine hotspots.

3.2 Temporal Trends in Rainfall in the Lake Victoria Basin

Temporal trends in total monthly rainfall for January–December differed significantly in the LVB (Figure 17a) and in each section of the LVB within the five countries, as indicated by the significant month-by-year interaction term for each region. Temporal variations in rainfall also differed over the 12 months in the LVB and in each section (Figure 17b).

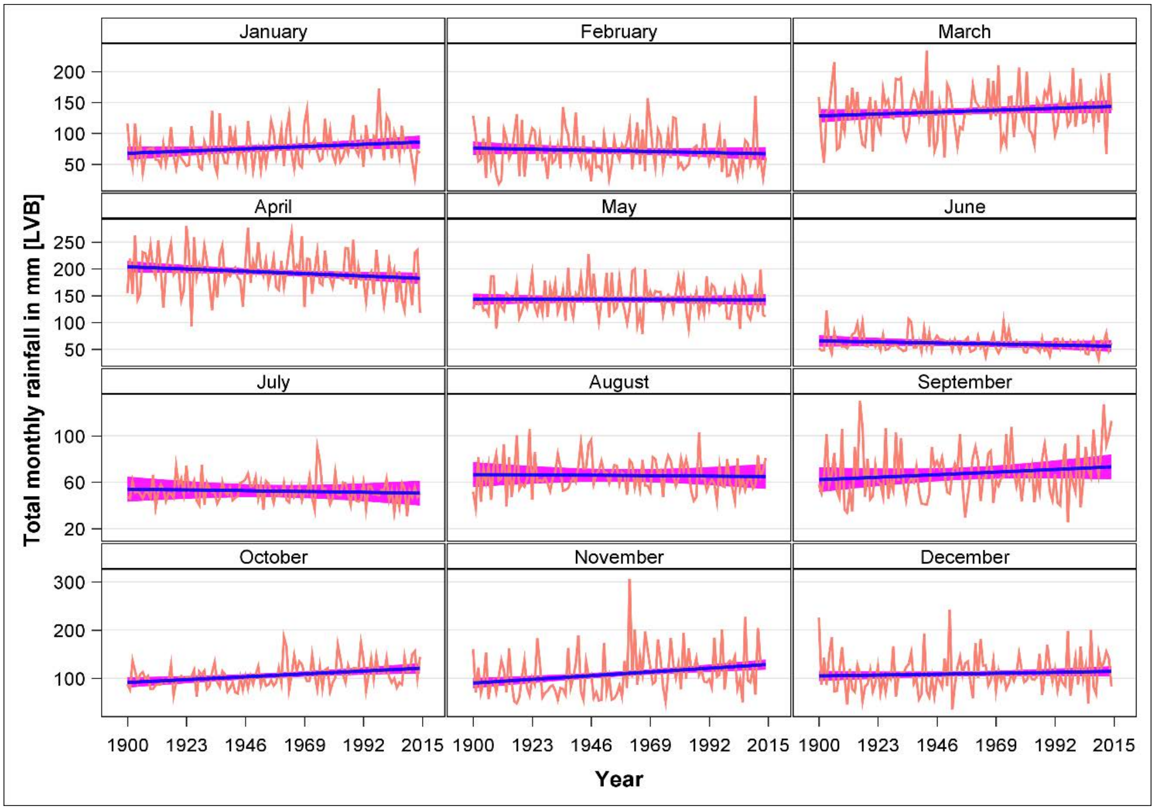


Figure 17a: Temporal trends in the total monthly rainfall in the LVB between 1900 and 2014. The solid lines are the fitted trend lines, the shaded bands are the 95 percent pointwise confidence bands whereas the plotted series are the total monthly rainfall averaged over all 10 kilometer × 10 kilometer grid cells in the LVB.

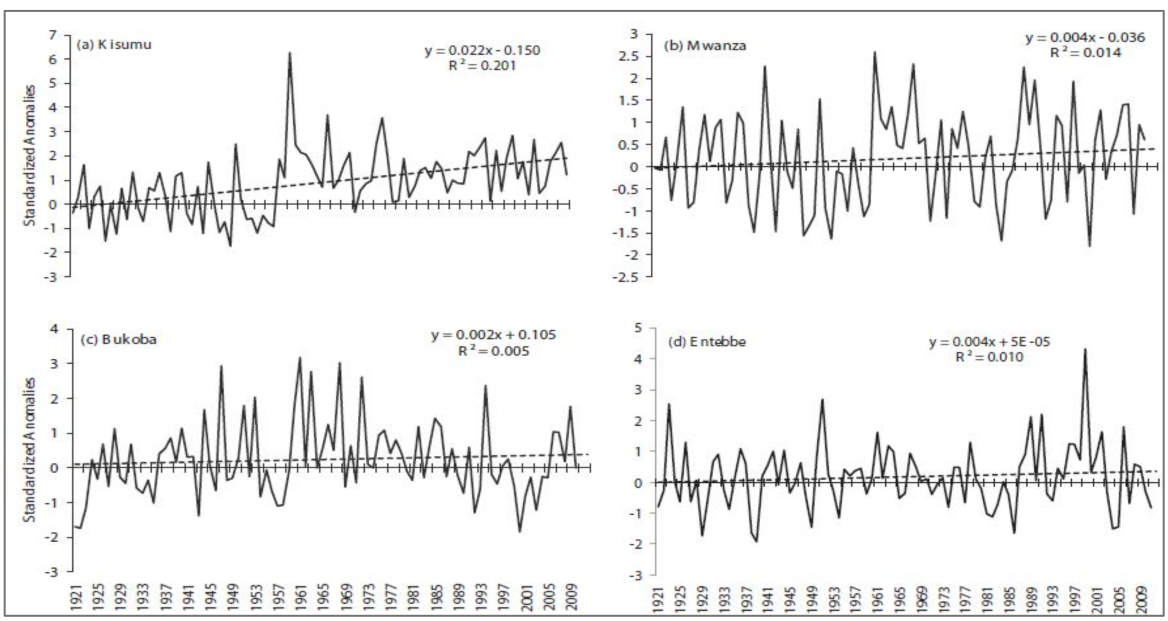


Figure 17b: Temporal variation of rainfall over some selected stations in the LVB between 1921 and 2009 (Omondi et al. 2012a)

In the LVB, and in each country section, total monthly rainfall for October and November increased significantly between 1900 and 2014. The modeled trends suggest that this increasing trend is likely to continue. Concurrent with this increase in the October–November rainfall is a significant decrease in rainfall in April, particularly in LVB, Burundi, Rwanda, and Tanzania, and marginally in Uganda but, surprisingly, not in Kenya. In aggregate, the temporal patterns in monthly rainfall suggest that the short rains are increasing, and the long rains are decreasing in the LVB over most of the past century.

Plate 1: Lake Victoria is Africa's largest lake and the largest tropical lake in the world (Photo: www.journeysbydesign.com)

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 all five country sections (Figure 18). It is also apparent from Figure 18 that Kenya and Uganda receive higher annual rainfall than Burundi, Rwanda, and Tanzania in the LVB.

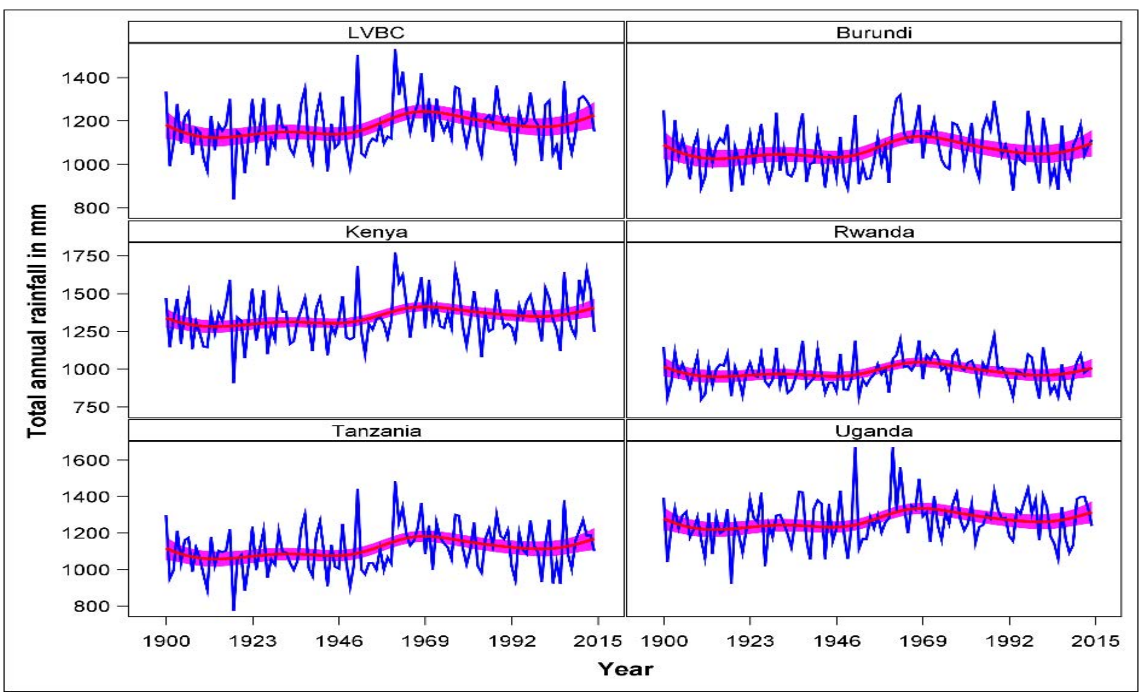


Figure 18: Temporal trends in the total annual rainfall (January–December) in the five country sections of the LVB between 1900 and 2014. The solid lines are the fitted trend lines, the shaded regions are the 95 percent pointwise confidence bands; the plotted series are the total annual rainfall averaged over all 10 kilometers × 10 kilometers grid cells in the section of the LVB in each country.

3.3 DECADAL TRENDS (SEASONAL AND ANNUAL)

Spectral density analysis provided clear evidence of quasi-periodic (quasi-cyclic or approximately periodic) oscillations in the annual rainfall component, with an approximate cycle of 5 years for the LVB and the five country sections of the LVB. The spectral densities are largest when the estimated cycle period is 5 years, meaning that the oscillation with the 5-year period is the most dominant cyclical oscillation in the annual rainfall series. This result is consistent with wet phases of approximately 5 years followed by dry phases of about 5 years in the LVB.

3.4 DECADAL VARIATION IN RAINFALL SEASONALITY IN THE LAKE VICTORIA BASIN

Rainfall showed strong seasonality in the LVB, which varied little across decades over 1900–2014. However, the short rains, spanning October–December, showed far greater variability over time than did the rains received during the January–September period. Also noteworthy is that Kenya receives more rainfall during the dry season months than any of the other countries in the LVB (Figure 19).

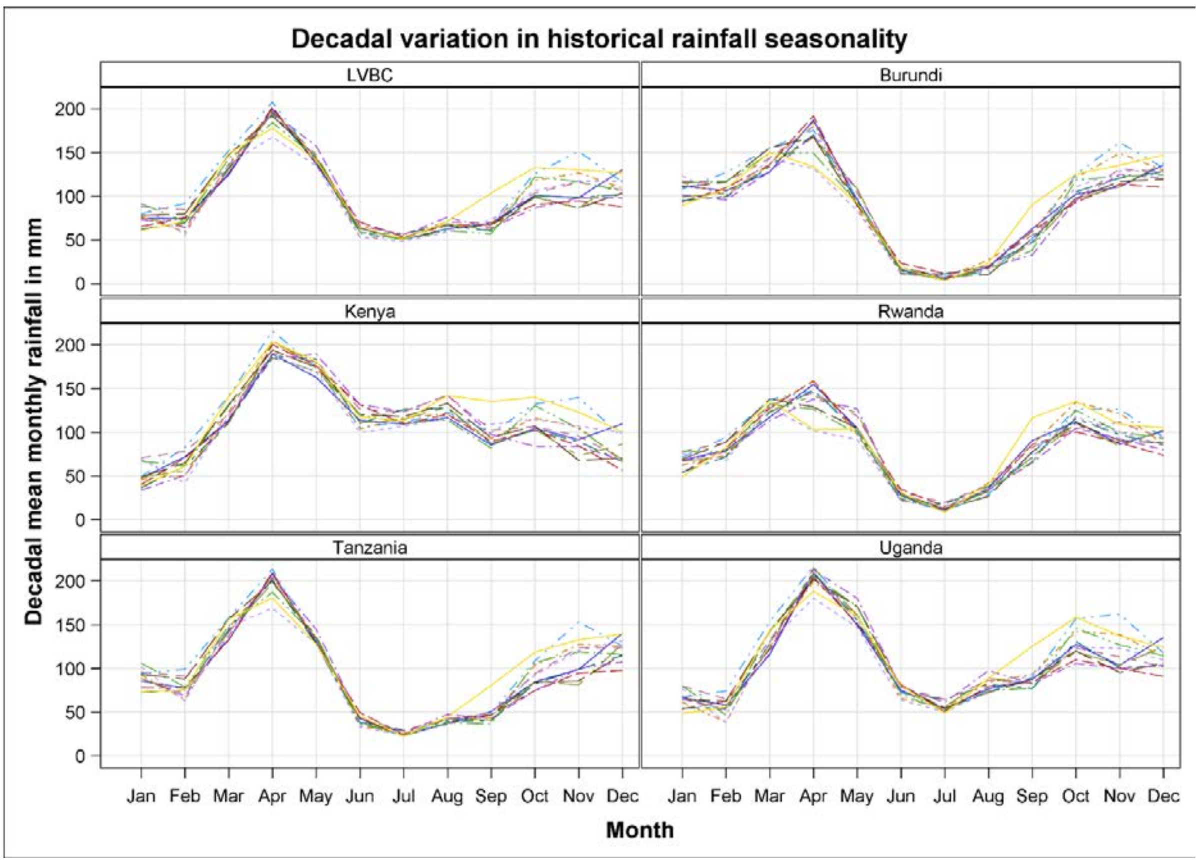


Figure 19: Mean annual rainfall cycle over LVB and the five country sections.

3.5 Temperature Trends in the Lake Victoria Basin

Figures 20 and 21 give concise interpretations of the results of the trends in maximum and minimum temperatures. The maximums and minimums increased in LVB, Burundi, Kenya, Rwanda, Tanzania, and Uganda between 1920 and 2013 but at rates that differed significantly among months within each region. The 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.

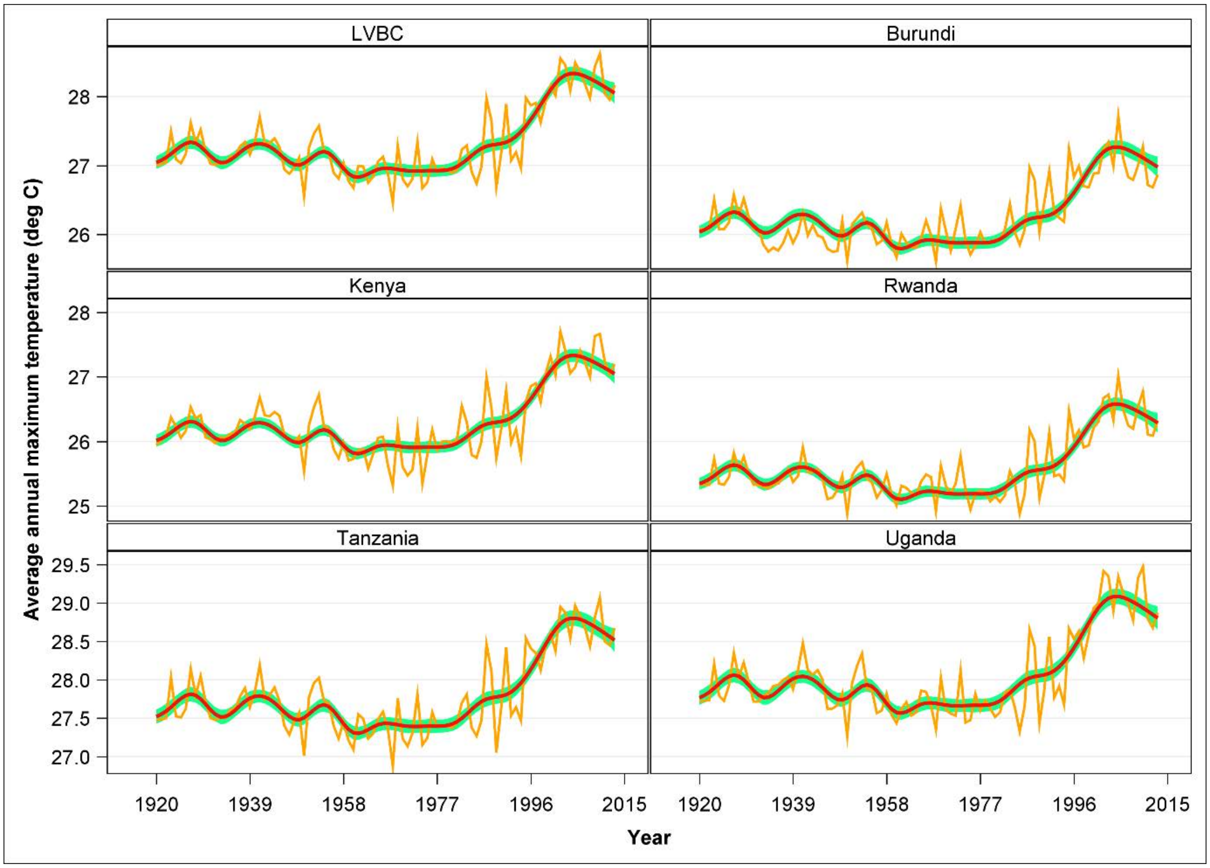


Figure 20: Temporal trends in the average maximum temperature (solid lines) in the LVB between 1900 and 2013. The shaded regions are the 95 percent pointwise confidence bands; the series plots represent the average annual maximum temperature.

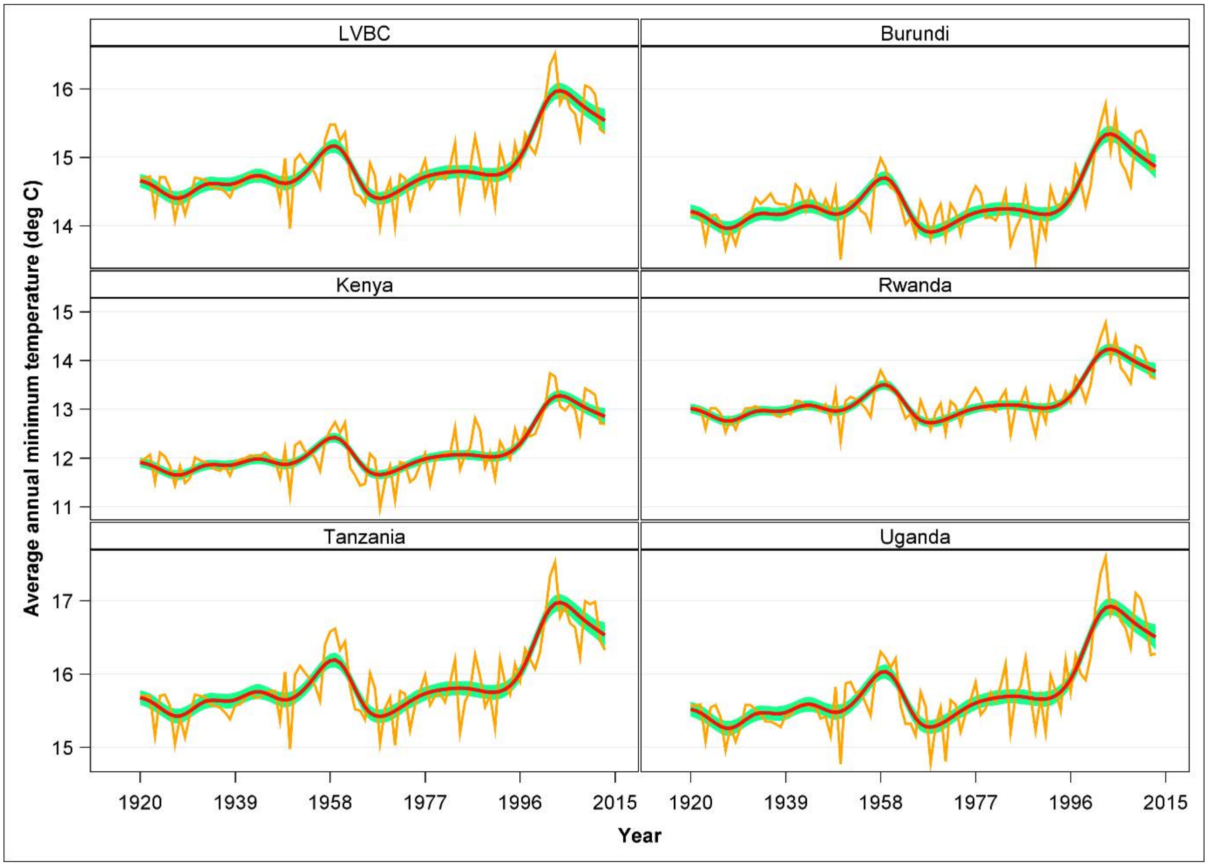


Figure 21: Temporal trends in the average minimum temperature (solid lines) in the LVB between 1900 and 2013. The shaded regions are the 95 percent pointwise confidence bands; the series plots represent the average annual minimum temperature.

Both the minimum and maximum temperature components averaged across all 12 months of the year increased significantly between 1920 and 2013. For the maximum component the magnitude of increase ranged between 0.7°C and 1.2°C.

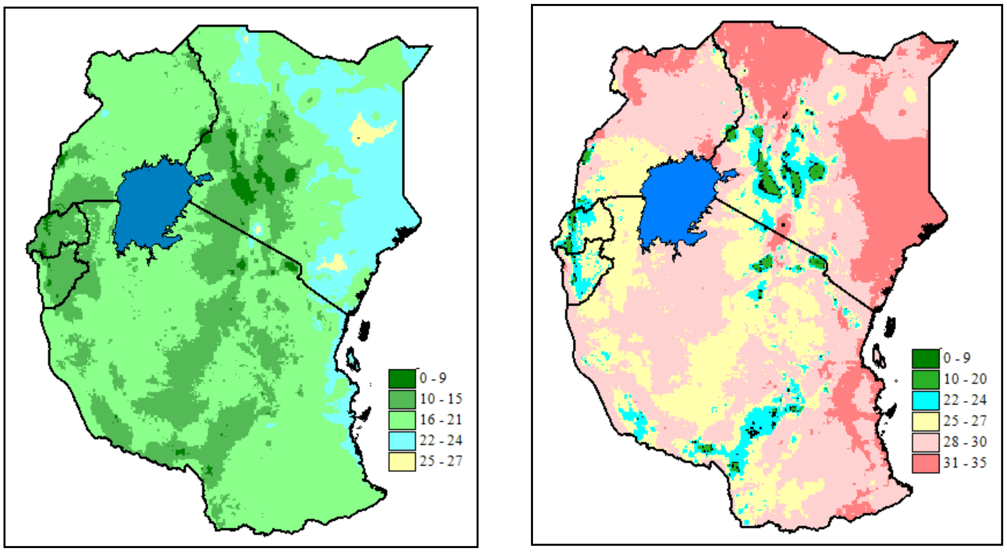


Figure 22: Average minimum and maximum temperatures (°C) (1981–2014) for the EAC.

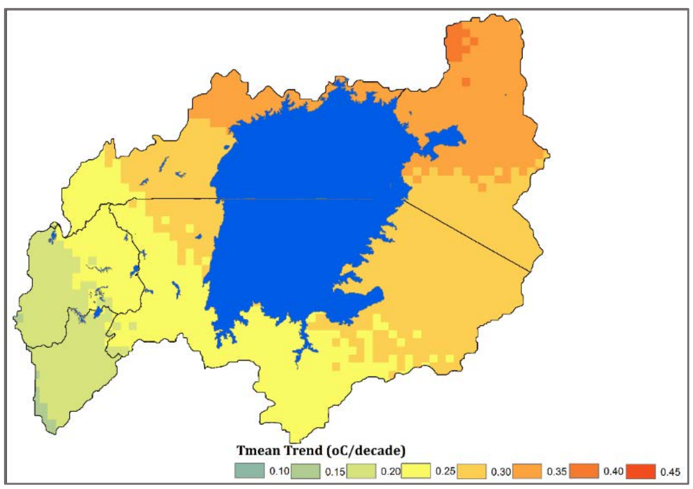


Figure 23: Average mean maximum temperatures over the LVB

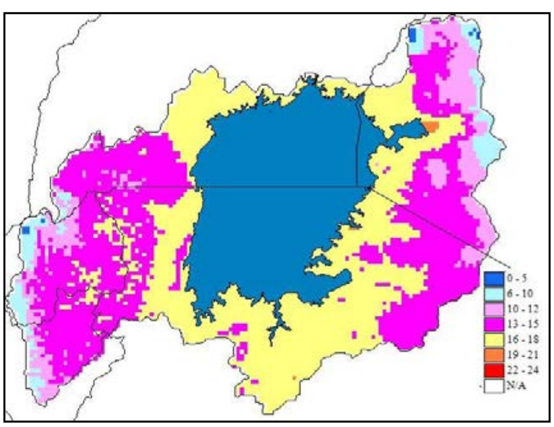


Figure 24a: Average minimum temperature (°C) (1981–2014) for the LVB

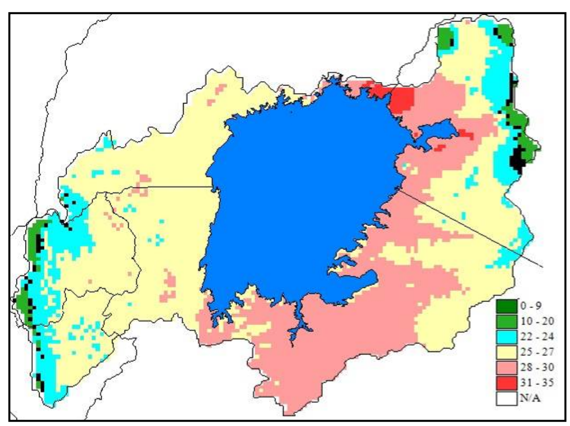


Figure 24b: Average maximum temperature (°C) (1981–2014) for the LVB

4. SECTORAL IMPACTS OF CLIMATE VARIABILITY AND CHANGE IN EAST AFRICA AND LAKE VICTORIA BASIN

4.1 Impacts on Water Resources

- Warmer temperatures accelerate the hydrologic cycle, which will alter precipitation amounts, magnitude, and timing of runoff, as well as intensity and frequency of floods and droughts.
- Climate change will also modify groundwater discharge, storage, saltwater intrusion in coastal areas, and biogeochemical reactions. The most noticeable impact of climate change is on groundwater quality and quantity.
- Climate variability and change influences groundwater systems both directly through replenishment by recharge and indirectly through changes in groundwater use due to drought and non-availability of surface water.
- Water quality is vulnerable to climate change in the EAC. This is because the quality of water in rivers, lakes, and wetlands is influenced by both temperature and flow regime, hence the wide temporal variation. Increased river and lake water temperatures could arise from climate change.
- Surface water resources are more vulnerable to climate change, as lower flows will imply less volume for dilution and higher concentrations of nutrients and other pollutants downstream of discharge points.
- Water supply infrastructure, including water treatment plants, pipelines, and dams for irrigation will be affected by extreme events such as floods, sedimentation due to excessive runoff, as well as other climate hazards, and lead to financial losses.
- Water-related hazards account for 90 percent of natural hazards and their frequency and intensity are generally rising, with serious consequences for economic development.
- Increasing water temperature due to warming air temperatures will alter stream flow patterns, and increase rainfall events in ways that will have severe consequences for aquatic ecosystems.
- In addition to affecting aquatic biodiversity, these changes are expected to have profound effects on functioning and productivity of aquatic ecosystems. Decrease in water levels in aquatic ecosystems will negatively affect these services, leading to lack of food, building materials, and energy shortages.
- The impact of climate change and climate variability may be both negative and positive on water resources and the water sector. Changes in rainfall patterns leading to heavy rainfall events, flooding, or droughts affect water supply, water quality, and availability, as well as freshwater ecosystems and their functions.
- Climate change and climate variability will affect aquatic ecosystems and biodiversity at different scales of biological organization (genes, populations, species, communities, and ecosystems) and spatial scales (habitat, local, national, and regional).

4.2 Impacts on Terrestrial Ecosystems

- Essential ecological processes are governed, maintained, or heavily moderated by terrestrial ecosystems and are essential to food production, health, and other aspects of survival and sustainable development. For this reason, terrestrial ecosystems, including forests, wildlife, and the tourism sector are highly prioritized in the EAC and the LVB. Like other ecosystems, the terrestrial sector is severely affected by climate change.

Vegetation, forest, and wildlife populations are being depleted with irreversible consequences for wildlife-based tourism, biodiversity, and other resources.

- The sector is vulnerable to impacts of climate change. As defined in AR4, "vulnerability is 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 2004). This study used a Vulnerability Impact Assessment framework, based upon IPCC guidelines. Using this framework, four key components have been recognized as determinants of whether, and to what extent, the terrestrial ecosystem is susceptible to climate change. These four components are exposure, sensitivity, potential impact, and adaptive capacity.
- Climate change vulnerability assessment based on the four components identifies the Serengeti-Mara Ecosystem (Kenya-Tanzania) and Nyungwe-Kibira Ecosystem (Rwanda-Burundi) as hotspots for the terrestrial sector within the LVB.
- Increased rainfall variability affects vegetation growth and consequently affects habitat for wild animals and pasture for livestock. Analysis of rainfall trends between 1984 and 2014 shows that rainfall on the southeastern side of the LVB, which includes the Serengeti-Mara ecosystem, is more variable compared to other parts of the basin. This could have negative effects on the terrestrial sector because rainfall is crucial to the growing cycle and to changes in vegetation cover. As a result, habitat for wild animals and pasture for livestock will be affected, leading to increased competition between species (Ogutu et al. 2014).
- Increased warming is projected to bring shifts in ecosystems, fundamentally altering species composition and even leading to the extinction of some species. Ecosystem composition will be affected, as will individual organisms and populations, species distribution are also likely to be altered by climate change.
- Land use is a major threat to terrestrial ecosystems. This change is driven by socioeconomic processes such as human population growth that have demanded more land for settlement and farming, economic development, and trade resulting in the blockage of migratory corridors and deforestation. Climate change will add impacts to already stressed, threatened, and overexploited ecosystems due to land use changes and population pressure.
- Most of East Africa's wildlife is in reserved areas. However, vegetation in those areas will be unable to respond quickly to a changing and variable climate. Under such conditions, wildlife that would normally adapt through migration to more suitable areas will be unable to do so. This is because no corridors connect the various reserves, and most are near human settlements. These pressures are likely to increase human-wildlife conflicts. The most likely result is a decline in wildlife populations. For example, a 30-year trend of wildlife in Kenya indicated a decline of 67 percent between 1977 and 2013.

4.3 Impacts on Agriculture

- Some of the effects of climate change will have far-reaching consequences for the poor and marginalized groups, the majority of whom depend on rain-fed agriculture for their livelihood (Nicholson 2015). Agriculture accounts for more than 40 percent of gross domestic product (GDP) across East Africa. Furthermore, the region's countries have among the highest population growth rates in the world with endemic poverty affecting more than 50 percent of the region's 360 million people (Thorn et al. 2015). While urbanization and industrial development are growing across the region, agriculture will continue to dominate the region's economies. Therefore, climate change will complicate the existing challenges of socioeconomic development.

- Rainfall and temperature regimes are perhaps the most important factors in determining the productivity of various agricultural enterprises either directly or indirectly. Their direct effects determine the suitability, rate of growth, and potential yield of crops while the indirect effects influence the supply of nutrients and water through changes in nutrient and hydrological cycles. The extent to which climate change affects crop production at a given location depends in part on current climatic conditions at that location, type of crops grown, level of management, and status of soil and other resources.
- Precipitation is critical for livestock survival, reproduction, and productivity. This is because water affects pasture germination, growth, and regeneration. The main source of water for animal production systems is rainfall. It is paramount then to understand and monitor their amount, frequency, variability, minimum, maximum, onset, and delays of rainfall in livestock farming areas.
- Temperature also affects all classes of livestock. Average, minimum, maximum, and seasonal variations are crucial to the growth, regeneration, and survival of livestock. Very high temperatures, beyond 30°C, affect pasture quality as well as optimal animal physiology and regulate climate-related parasites and diseases like East Coast Fever and Rift Valley Fever.
- Climate change is already affecting fisheries and aquaculture. Shifts in temperature and rainfall are altering the seasonality of some biological processes and marine and freshwater food chains. The consequences for fish production, will be declining catches, though with increased aquaculture production, as well as increased risks of species invasions and vector-borne diseases.

4.4 Impacts on Health

- Climate change will profoundly affect the social and environmental determinants of health, including clean air, safe drinking water, and sufficient food and secure shelter.
- The biology and ecology of disease vectors and intermediate hosts will be altered by climate change and variability. This will have implications for disease transmission and disease patterns.
- The combination of higher temperatures, prolonged droughts, and extreme weather characterized by floods—coupled with scarce water resources and poor sanitation—make the EAC vulnerable to outbreaks of cholera and other waterborne diarrheal diseases.
- Respiratory infections follow seasonal patterns and in tropical areas, childhood pneumonia, and death associated with pneumonia, mainly occur during the rainy season when the temperature is low.
- Climate change could affect the size and characteristics of rural and urban human settlements in Africa because the scale and type of rural-urban migration are partially driven by climate change.
- Climate-related hazards that affect urban areas include floods, flash floods, tropical cyclones, drought, fires, and heat waves. These are expected to increase in frequency and/or intensity with climate change and sea level rise.

4.5 Impacts on Energy, Transport, and Related Infrastructure

- Climate change will affect the energy sector, particularly the renewable energy component, posing significant risks, challenges, and opportunities. Beyond the challenge of variability in climate, other factors include changes in seasonality, changing patterns of demand, and the changing risk profile of extreme weather and climate events.

- The climate variables critical for performance of the energy sector include precipitation (frequency and intensity) and temperature (intensity). Frequencies and intensities of rainfall and temperature determine reliability of hydropower and quantity of hydropower generated (Kiiza et al. 2010).
- Hydroelectric power plants are sensitive to the volume and timing of river flows. Decrease in precipitation negatively affects the production levels of hydropower plants. Sustaining stream flows to supply dams during reduced inflows presents potential for conflicts over water access, especially for users in lower riparian areas.
- On the other hand, heavy rainfall leading to floods has a significant impact on electricity generation and transmission infrastructure (UNEP 2009).
- Increased rains increase runoff and consequent siltation, thus increasing the costs of maintenance of dams. Above-normal rains also lead to downstream flooding due to overflow from dams. Temperature affects the hydrological cycle, which affects water quantity (for hydropower) through regulation of evaporation and evapotranspiration. Temperatures also contribute to fluctuation of wind intensity and frequency (UNEP 2009).
- Climate change is a major cause of loss of vegetation and wood biomass, affecting energy access for local communities.
- Forests are the main sources of biomass and often serve as "water towers" for the drainage basins, but they are vulnerable to climate variability and climate change.
- Rainfall enhances vegetation growth and biomass supply, but decrease in rainfall coupled with increased temperature and wind may trigger forest fires, adversely affecting natural forests, water catchments, and their ecosystem (Kiiza et al. 2010). Furthermore, increased temperature and wind may trigger forest fires and lead to biomass scarcity.
- The effects of climate variability and change will vary in scale, intensity, duration, and space for different forms of transportation and transport infrastructure.
- Impacts of climate change on the transport sector have negative effects on other sectors of the economy. East Africa has a well-structured road network, but the condition of most rural roads makes it difficult to travel or move goods, particularly during the wet season.

5. CLIMATE CHANGE POLICY IMPLICATIONS

Climate change is a natural phenomenon. Anthropogenic climate change has been accelerated by the emission of greenhouse gases, primarily from industrialization, deforestation, and increased use of fossil fuels for transport. Scientific evidence, as cited by the IPCC, clearly indicates the wide scale of climate change. The IPCC Fourth Assessment Report (AR4) clearly indicates that anthropogenic activities have accelerated the process of global climate change. Increasing greenhouse gas emissions has contributed to increase in the atmospheric temperature, resulting in location-specific impacts. Climate change has also brought changes in rainfall patterns (high, low, and intensive rainfall) and seasons. These changes have direct and indirect effects on water resources, agriculture, forests and biodiversity, health, infrastructure development, tourism, and livelihoods. Recognizing this, the international community is actively engaged in minimizing the current effects.

In a move intended to address climate change, the United Nations General Assembly adopted a resolution to develop an international legal instrument for the purpose. The resolution resulted in several meetings of the Intergovernmental Negotiation Committee and, ultimately, the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in May 1992. The framework was introduced at the 1992 United Nations Conference on Environment and

Development in Rio de Janeiro. The UNFCCC is now the main international treaty for addressing climate change. Its objective is to prevent dangerous human interference with the global climate system.

The Kyoto Protocol, established in 1997, commits its signatories to setting binding targets for emissions reductions. It was designed to have a greater effect on the most developed countries than on those that are less developed.

The Paris Agreement was adopted in 2015 to go into effect in 2020. Its major initiative is to limit global warming to below 2°C and thereby avoid further damage to the climate.

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