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Climate risk report for the East Africa region

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Executive summary

This report highlights the headline risks to consider in climate resilient development planning for the East Africa region. Key climate-related risks for East Africa have been identified by considering how the current climate interacts with underlying socio-economic vulnerabilities, and how projected climate change for the 2050s may exacerbate these risks.

East Africa is considered in this report as including: Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, South Sudan, Tanzania and Uganda. The region has a diverse climate, ranging from hot, dry desert regions, to cooler, wetter highland regions, and large variability in seasonal rainfall. The current climate is around 1-1.5˚C warmer than pre-industrial times, and there is high confidence of further warming in the future. There is less confidence about how rainfall has changed in the past or may change in the future. However, future projections indicate an increase in mean rainfall across most of the region, with high confidence for an increase over the Ethiopian highlands. Interannual variability in seasonal rainfall amounts and timings is expected to increase, as is the frequency and intensity of heavy rainfall events.

Climate change is one of several risks to resources, livelihoods, assets and ecosystems. East Africa is a dynamic region, experiencing rapid population growth, urbanisation and economic transformation, and assessments of climate change risks can only ever provide a partial picture of the role climate change plays in shaping development outcomes. Seeing the 'bigger picture' of climate risks where multiple socio-economic risks compound, will remain important for those charged with designing, monitoring and evaluating development programmes. Most risks identified in this report are not new for the region, but the severity and distribution of those risks are changing as the climate changes. Our analysis identifies the following key risks as the most critical across the East Africa region, all such risks are interdependent therefore one might heighten the impact of another. This report is based on regional analysis, therefore risks at a national level may vary and would require a more detailed country level analysis.

Risks to agriculture and food security

Despite rapid economic growth and urbanisation over the last two decades, most of the region's poor live in rural areas and depend, directly or indirectly, on agriculture. The impacts of climate change in the region will be broadly negative in terms of agricultural production, though there will be significant variation of the scale of climate impacts across agro-ecological zones, farming systems and livelihoods. Impacts on food security, are more difficult to gauge. However, we would expect to see largely negative impacts on household purchasing power and supply chains (affecting access), as well as diminished nutrient absorption through an additional disease burden and malnutrition.

The most vulnerable to climate change particularly to changes in temperature and rainfall variability are those engaged in low intensity, low input rainfed farming, disconnected from markets and with few opportunities for building assets and breaking out of poverty. Pastoral and agro-pastoral livelihoods, significant across much of the hot, drier lowlands, may be impacted by forage and water shortages as well as heat stress, though threats to pastoralists' wellbeing will likely be driven mainly by policies of sedentarisation and resource appropriation/fragmentation. Rising temperatures will also have a negative impact on maize and wheat yields in hotter areas, and important cash crops such as tea, coffee and cocoa are also expected to be impacted as the ability to shift farming to higher (cooler) altitudes is limited. Land degradation and soil erosion, already major problems across the region, will likely be further exacerbated by more intense rainfall events, and rising temperatures may alter disease vectors and pest populations, with adverse effects on output variability and yields, as well as on the costs of control.

Irrigation development offers an opportunity to buffer rainfall variability and increase productivity, but also carries risks where competition for water is increasing in basin hot spots, particularly during the dry season and drier years when other water demands peak. Within rainfed systems, the array of land management practices that fall under the banner of climate smart agriculture hold promise in managing rainfall variability and addressing persistent water shortages, though approaches are context-specific. As it stands, there is no regionally-applicable evidence base to guide interventions across diverse agro-ecological zones.

Risks to water resources and water-dependent services

The impacts of climate change emerge largely through the water cycle, but predicting impacts remains tricky because of the complex causal chain linking rainfall and temperature with water resources and water-dependent services. Overall water availability compares favourably with other regions, though metrics conceal problems of temporal and spatial variability. Mobilising water for lives and livelihoods remains a key challenge, though 'hot spots' of intensive use and over-exploitation are emerging at the urban-rural interface, and in basins where irrigation and hydropower development coincide. Groundwater storage will provide a vital buffer against rainfall variability and recharge may benefit from more intensive rainfall events. Overall impacts on water availability will likely be modest compared with demand-side drivers, particularly population growth. The impacts of climate change on water quality will be broadly negative and transmitted through rising temperatures and high flow/flood-related sediment and pollution loads. Deteriorating water quality may emerge as a bigger threat to domestic users than water availability, with knock-on impacts on health and (mal)nutrition.

Water for domestic use is a small component of national water withdrawals, but access to safe drinking water is vital for human wellbeing and climate resilience. Extending and sustaining water access remain challenging, but most groundwater-dependent rural services are resilient if existing best-practices are followed, which is currently rare. Larger, longer-lived investments in hydropower to address energy gaps risk locking in inappropriate design based on historical climate conditions. The concentration of generating capacity in the inter-connected Nile basin, an area of similar rainfall variability, means that periods of low rainfall and river flow could affect multiple sites, with concurrent reductions in electricity generation.

Risks to health

Despite significant progress on health outcomes over the last three decades, a significant proportion of the region's population remain vulnerable to preventable deaths. By 2030, however, non-communicable (not transmittable) diseases are projected to overtake communicable (transmittable diseases), neonatal, and maternal mortality as the leading causes of death. Food insecurity, malnutrition and poverty remain overwhelmingly rural, though the pace of urbanisation and the growth of informal urban settlements may change the health landscape, with millions exposed to multiple 'urban' risks linked to poor housing, sanitary conditions and basic services.

Diarrheal diseases are the main causes of preventable deaths across 7 of the 11 countries in the region, particularly for young children. Rising temperatures, and the impact of heavy rainfall on sanitary conditions and water supplies will increase risks, especially given the numbers of people still lacking access to safe water and sanitation. Undernutrition is both a cause and a consequence of diarrhoea: malnutrition increases both the susceptibility to diarrhoea and the severity of episodes, with lasting impacts on growth and development. Changing rainfall patterns and rising temperatures will also affect the geographic range and incidence of vector-borne diseases such as malaria and Rift Valley Fever, especially along the margins of current distribution. Rising temperatures and temperature extremes will also lead to heat stress, particularly in cities, though in rural lowland areas temperatures are already reaching the upper limits of human habitability.

Risks to urban environments and infrastructure

East Africa faces major challenges in plugging its infrastructure gap in power, irrigation, water supply, sanitation, transport, communications, electricity and flood protection. New investments needed to unlock growth and poverty reduction risk locking in climate risk to both slow onset trends such as warming, changes in multi-annual variability, fluctuations in mean precipitation conditions and changes in the frequency and intensity of extremes such as droughts and floods. Risks to existing infrastructure are most obvious in established cities, but also the growing numbers of smaller towns and cities where planned infrastructure provision lags behind urban expansion. People and businesses in 'informal' settlements, especially, are exposed to multiple threats, including power and communication outages, damage to housing and the destruction of water, sanitation and drainage systems.

Disruption and damage to transport infrastructure, particularly from floods, is a critical yet under-reported issue in both urban and rural areas. In rural areas where road densities are low, loss of an individual road link or bridge can leave wide areas and large numbers of people without a connection to markets, supply chains and essential services. Flood-risk management, including early warning and response, will likely grow in importance, as will more integrated and 'greener' approaches to infrastructure development and urban planning. Nature-based solutions to manage flood risk and deliver a range of co-benefits are widely promoted in both rural and urban settings, and at the interface between them, but may do little to solve the problem of flooding after intense rainfall events unless combined with 'hard' infrastructure.

Risks to coastal areas and fisheries

East Africa has a long coastline, home to some of the region's most dynamic population centres, ports and tourism sites. A combination of rising sea levels, higher temperatures and more frequent and intense storm surges threaten livelihoods and local economies, with potential ripple effects throughout the region. This is because the ports of Djibouti, Berbera, Lamu, Mombasa, Zanzibar and Dar es Salaam serve the region's landlocked countries, with the low-lying coasts of Djibouti, Kenya and Tanzania most vulnerable to coastal risks. Coastal agriculture and drinking water supplies are also threatened by saline intrusion into coastal aquifers and flood damage, and coastal fisheries, coral reefs and marine ecosystems are threatened by both rising sea temperatures and marine heat waves.

East Africa also includes some of Africa's largest freshwater lakes supporting fisheries, agriculture, and tourism, as well as climate-sensitive ecosystems and biodiversity. A combination of rising temperatures and eutrophication already pose risks to fish stocks and ecosystem health, though changes are also being driven by over-fishing and the discharge of pollutants into river and lake systems. Periodic flooding around shorelines and back-flooding into tributary rivers already cause problems, displacing people and disrupting transportation, drinking water, sanitation, and power systems.

Headline climate statements for East Africa	
Temperature	• The East Africa region is predominantly hot throughout the year with some cooler areas in the higher elevation parts of the East Africa Rift Valley. • The current climate in East Africa is around 1-1.5˚C above pre-industrial levels (1850-1900), at a rate comparable to that of most other continents • Climate model projections for East Africa show high confidence for an increase in average annual temperatures of 1-2˚C in the 2050s across the region, depending on future greenhouse gas emissions. • The intensity and frequency of hot extremes, such as the number of days above 35˚C, is also projected to increase, whereas the intensity and frequency of cold extremes is projected to decrease.
Precipitation	• Precipitation is unevenly distributed across the East Africa region and throughout the year: eastern and southern parts experience two rainy seasons, northern and western parts experience one rainy season, and some areas in the far north receive very little rain at all. The region also experiences some of the largest interannual rainfall variations in the world. • There is large uncertainty in how precipitation across most of East Africa is projected to change by the 2050s. However, there is high confidence for an increase in seasonal rainfall over the Ethiopian highlands. • Year-to-year variability in seasonal rainfall amounts and timings will continue to be a feature of the future climate. This variability is projected to increase resulting in more frequent wetter and drier years and a higher risk of flood and drought events. • The frequency and intensity of heavy rainfall events is also projected to increase.
Oceans	• Sea levels have been rising and are projected to rise by around 0.3m by the 2050s. • As the climate warms, sea surface temperatures are also projected to increase by 1-2˚C on average by the 2050s, as is the frequency and intensity of marine heatwaves.

Headline risk statements for East Africa	
Agriculture and food security	• Agricultural production in East Africa will be severely impacted by climate change. Many livelihoods across the region are heavily dependent on agriculture and as such food security will be negatively affected, especialy for marginal rainfed farming and fragile pastoral livelihoods which are particularly vulnerable. • Higher temperatures will increase water and heat stress for crops and livestock, lowering the productivity of pastoral livelihoods and negatively impacting the production of important crops such as maize, wheat, cotton, and coffee. • Increased temperatures and heavy precipitation will result in the growth of pest populations, such as desert locusts which can devastate crops affecting both agricultural livelihoods and food availability across the region. • Land degradation and soil erosion will be exacerbated by more intense rainfall events, posing risks to the natural resource base, agricultural productivity and subsequently food security, particularly in already degraded areas.
Water resources and water dependent services	• Mobilising and manging water for lives and livelihoods remains a key challenge in East Africa and will likely become more difficult as rainfall variability increases. • The impacts of climate change on freshwater availability will likely be modest compared with demand-side pressures; localised 'hot spots' of over-exploitation are likely to grow in number, particularly in and around fast-growing urban centres. • Greater rainfall variability may challenge hydropower generation across East Africa, with periods of low rainfall and river flow potentially affecting multiple sites across the region with concurrent reductions in electricity production. • The impacts of climate change on water quality will be broadly negative and transmitted through rising temperatures and high flow/flood-related sediment and pollution loads, posing threats to health across both urban and rural areas.
Health	• Changing rainfall patterns and rising temperatures will affect the geographic range and incidence of vector-borne diseases, increasing incidence of malaria in highland areas that are currently not suitable for transmission, and increased Rift Valley Fever. • Increasing temperature extremes will result in more days of the year exceeding critical heat-health thresholds; temperatures above 31°C are related to increased mortality and risks of non-communicable diseases which disproportionately affect children, the elderly, migrant workers, and those working outdoors. • Higher temperatures are known to impact the nutritional value of crops which is associated with lower nutritional status for children, increasing the disease burden as the under-18 population is projected to increase considerably. • More flood events that contaminate water sources and longer stretches of higher temperatures that facilitate bacterial growth increase the likely incidence of diarrheal and other water-related diseases.

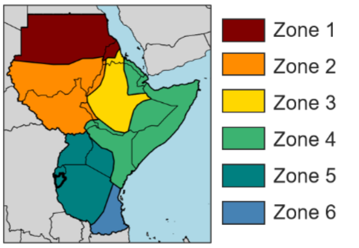
Urban environments and infrastructure	• More intense rainfall events will increase flood risk in both rural and urban areas, with densely populated, low-lying urban areas particularly vulnerable. • People and businesses in 'informal' settlements and fast-growing towns with poor infrastructure are exposed to multiple threats, including damage to housing, power, communications and water and sanitation systems. • More intense flooding events and extreme heat can also damage roads and bridges, potentially leaving wide areas and large numbers of people without a connection to markets, supply chains and essential services. • New infrastructure investments needed to unlock growth and reduce poverty that don't account for the changing climate potentially lock-in climate risk, particularly for long-lived investments designed for historical and/or average climate conditions.
Coastal areas and fisheries	• Rising sea levels, higher temperatures and more frequent and intense storm surges threaten coastal livelihoods and local economies. • Rising temperatures and eutrophication pose risks to fish stocks and ecosystem health, compounded further by overfishing. • Periodic flooding around shorelines and back-flooding into tributary rivers already cause problems, displacing people and disrupting transportation, drinking water, sanitation, and power systems • In freshwater fisheries, rises in surface water temperature are reducing deep water nutrient upswelling and increasing thermal stratification, diminishing the productivity of pelagic fisheries.

Country summaries

Analysis is conducted at the regional level using six newly identified zones. These country summaries are intended to help direct reading towards the relevant sections within the report by country; they are not a complete assessment of the full range of risks at a country level.

Burundi country profile

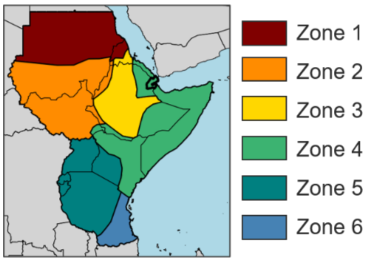
Burundi is located in the west of the East Africa region in the Great Rift Valley and is included in Zone 5 in this report.



Summary of analysis relevant to Burundi	**Report section**
Burundi (Zone 5) experiences a tropical climate. Over 86% of the population is considered rural, and most people live in the north of the country (World Bank, 2020b). The predominant livelihood in Burundi is highland perennial farming, though some households practice root and tuber crop farming. There are also fish-based livelihoods along Lake Tanganyika. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 35˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in annual rainfall. Variability in seasonal rainfall amounts and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events.	3.3.5
Regional risks relevant to Burundi	**Report section**
Flooding around Lake Tanganyika	4.5.3
Food security	4.1.3
Health risks, particularly around shifting patterns of vector borne diseases	4.3.3

Djibouti country profile

Djibouti is located in the Horn of Africa on the coast of the Gulf of Aden and is included in Zone 4 in this report.

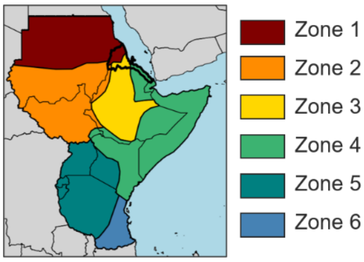


Summary of analysis relevant to Djibouti	**Report section**
Djibouti (Zone 4) experiences a hot desert climate. The population is concentrated along coastal regions and in the capital city of Djibouti. The majority of Djibouti is urban (nearly 80% of the population), though in rural areas there are some pockets of pastoral livelihoods as well as oasis farming (World Bank, 2020c). Along the coasts, there are fish-based livelihoods. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in October – December seasonal rainfall. Variability in seasonal rainfall and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events. Sea levels will continue to rise and the frequency and intensity of marine heatwaves will also increase.	3.3.4

Regional risks relevant to Djibouti	**Report section**
Sea-level rise and salt-water intrusion	4.5.3
Water availability	4.2.3
High temperatures, particularly in Djibouti City	4.4.3
Health risks, particularly related to higher temperatures	4.3.3

Eritrea country profile

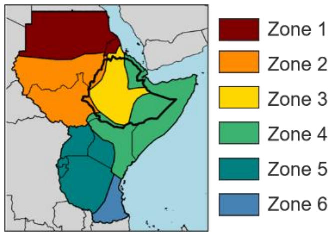
Eritrea is located in the northeast of the East Africa region on the coast of the Red Sea and is divided between three zones in this report: Zone 1, Zone 3 and Zone 4.



Summary of analysis relevant to Eritrea	**Report section**
The north-western part of Eritrea is included in Zone 1 and experiences a hot desert climate. In this sparsely populated area, the most common livelihoods are pastoral and arid pastoral and oasis farming. Along the coast, there are fish-based livelihoods. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year, with larger increases during the hottest summer months, resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests a small increase in June-September seasonal rainfall.	3.3.1
The highland regions of Eritrea are included in Zone 3 and experience a semi-arid climate. The most common livelihood system is highland mixed, a continuity from highlands in neighbouring regions of Ethiopia. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 30˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in June-September seasonal rainfall.	3.3.3
The eastern part of Eritrea is included in Zone 4 and experiences a hot desert climate. As with Zone 1, the most common livelihoods in this part of Eritrea are pastoral and arid pastoral and oasis farming. Along the coast, there are fish-based livelihoods. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in October – December seasonal rainfall.	3.3.4
Across the country, variability in seasonal rainfall amounts and timings is expected to increase, as is the frequency and intensity of heavy rainfall events. Sea levels will continue to rise and the frequency and intensity of marine heatwaves will also increase in all zones along the Eritrean coast.	3.3.1, 3.3.3, 3.3.4
Regional risks relevant to Eritrea	**Report section**
Food security for pastoralists and highland farmers	4.1.3
Sea-level rise and salt water intrusion along the coastline	4.5.3
Rural water security	4.3.2
Health risks, particularly related to high temperatures	4.3.3

Ethiopia country profile

Ethiopia is located in the Horn of Africa and is divided between three zones in this report: Zone 2, Zone 3 and Zone 4.

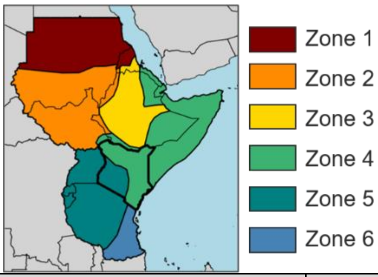


Summary of analysis relevant to Ethiopia	**Report section**
The western borders of Ethiopia are included in Zone 2 and experience a tropical savannah climate. In this area of Ethiopia, people engage in maize-mixed livelihoods. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in annual rainfall, with the largest increases during the June-September season.	3.3.2
The highland regions of Ethiopia are included in Zone 3 and experience a wet temperate climate due to the high elevation. Most people live in this part of Ethiopia and are concentrated in major cities such as Addis Ababa. In the highlands, there are a variety of livelihood systems. In the northern parts of the zone, people practice agropastoral or highland mixed livelihoods. In the centre of the zone, people practice maize mixed, highland perennial, and highland mixed livelihoods. Towards the southern end of the zone, agropastoral and highland perennial livelihoods are more common. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 30˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in June-September seasonal rainfall.	3.3.3
The eastern lowland regions of Ethiopia are covered by Zone 4 and experience an arid and semi-arid climate. In the lowlands of Ethiopia, pastoral livelihoods dominate. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in October – December seasonal rainfall.	3.3.4
Across the country, variability in seasonal rainfall and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events.	3.3.2, 3.3.3, 3.3.4

Regional risks relevant to Ethiopia	**Report section**
Household water security	4.2.3
Food security for pastoralist and highland perennial and highland mixed farmers	4.1.3
Heavy rainfall and soil erosion which threatens food security	4.4.3
Health risks, particularly related to shifting patterns of vector-borne diseases, diarrheal disease, and malnutrition	4.3.3
Health risks related to high temperatures	4.3.3

Kenya country profile

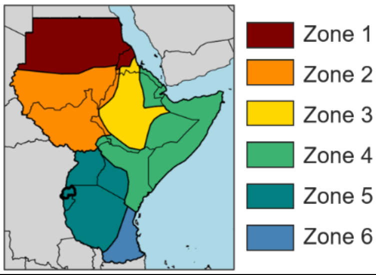
Kenya is located on the Indian Ocean coastline and is divided between two zones in this report: Zone 4 and Zone 5.



Summary of analysis relevant to Kenya	**Report section**
The northern and eastern parts of Kenya are included in Zone 4 and experience an arid and semi-arid climate. In these areas, pastoral livelihoods are most common, though fish-based livelihoods are common along Lake Turkana. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in October – December seasonal rainfall.	3.3.4
The western and southern parts of Kenya are included in Zone 5 and experience a cooler and more temperate climate. Most people live in this part of Kenya, with concentrated populations in major cities such as Nairobi and near to Lake Victoria in the west. The primary livelihoods are highland perennial, maize mixed, and agropastoral. Near Lake Victoria, fish-based livelihoods are practiced. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 30˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in annual rainfall.	3.3.5
Across the country, variability in seasonal rainfall amounts and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events. Sea levels will continue to rise and the frequency and intensity of marine heatwaves will also increase in all zones along the Kenyan coast.	3.3.4, 3.3.5
Regional risks relevant to Kenya	**Report section**
Household water security	4.2.3
Food security for agropastoralist and pastoral livelihoods in arid and semi-arid lands	4.1.3
Risks of high temperatures and floods in cities	4.4.3
Health risks as disease transmission moves to higher altitudes, higher temperatures increase non-communicable disease and malnutrition	4.3.3
Risks of flooding along Lake Turkana, Lake Victoria, and sea-level rise along coasts	4.5.3
Rising surface water temperatures in freshwater fisheries diminish productivity	4.5.3
Food security for maize-based livelihoods	4.1.3

Rwanda country profile

Rwanda is located in the western part of the East Africa region in the Great Rift Valley and is included in Zone 5 of this report.

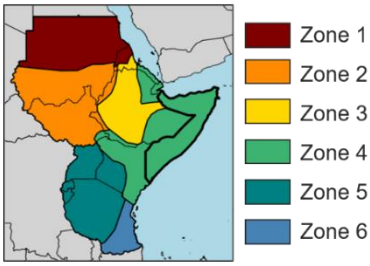


Summary of analysis relevant to Rwanda	**Report section**
Rwanda (Zone 5) experiences a tropical climate. Rwanda is densely populated, though 80 per cent of the population is rural (World Bank, 2020a). In Rwanda, highland perennial livelihood systems dominate. Around Lake Kivu, there are some fish-based livelihoods. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 30˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in annual rainfall. Variability in seasonal rainfall amounts and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events.	3.3.5

Regional risks relevant to Rwanda	**Report section**
Flood risks in urban areas and infrastructure	4.4.3
Heavy rainfall and soil erosion which threatens food security	4.1.3
Household water security in the eastern, drier part of the country	4.2.3
Health risks related to changing patterns of vector borne disease transmission and higher temperatures	4.3.3

Somalia country profile

Somalia is located in the Horn of Africa on the coast of the Gulf of Aden and Indian Ocean and is included in Zone 4 of this report.

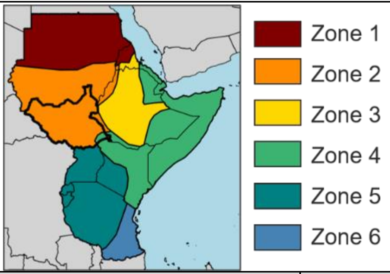


Summary of analysis relevant to Somalia	Report section
Somalia (Zone 4) experiences a hot desert in the north of the country and a semi-arid climate in the south. Most people live in major cities such as Mogadishu on the coast. Somalia is dominated by pastoral and agro-pastoral livelihoods, though there is some large-scale irrigated agriculture in riverine areas in the south of the country. Along the southern coast of the country, fish-based livelihoods are practiced. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in October – December seasonal rainfall. Variability in seasonal rainfall and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events. Sea levels will continue to rise and the frequency and intensity of marine heatwaves will also increase.	3.3.4

Regional risks relevant to Somalia	Report section
Food security for pastoral and agro-pastoral livelihoods, especially as desert locust invasions become more common	4.1.3
Household water security	4.2.3
Health risks linked to water-borne diseases and malnutrition	4.3.3
Health risks related to high temperatures	4.3.3
Salt water intrusion and sea level rise along coasts	4.5.3

South Sudan country profile

South Sudan is located in the western part of the East Africa region and is divided between two zones in this report: Zone 2 and Zone 4.

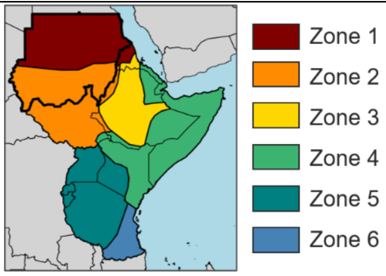


Summary of analysis relevant to South Sudan	Report section
The majority of South Sudan is included in Zone 2 and experiences a tropical savannah climate. Most people live in major cities such as Juba. The country encapsulates a range of livelihoods; from agropastoral in the north, cereal-root crop mixed in the centre, and maize mixed and root and tuber crop-based livelihoods in the south of the country. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in annual rainfall, with the largest increases during the June-September season.	3.3.3
A small region in the southeast of South Sudan is included in Zone 4 and experiences a semi-arid climate. Within this region, pastoral and maize mixed livelihoods are practiced. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in October – December seasonal rainfall.	3.3.4
Across the country, variability in seasonal rainfall amounts and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events.	3.3.3, 3.3.4

Regional risks relevant to South Sudan	Report section
Health risks as vector-borne disease transmission patterns shift	4.3.3
Health risks associated with higher temperatures	4.3.3
Food security in pastoral and maize mixed livelihoods	4.1.3
Flooding in the Sudd wetlands and along major rivers	4.5.1

Sudan country profile

Sudan is located in the northern part of the East Africa region and is divided between two zones in this report: Zone 1 and Zone 2.

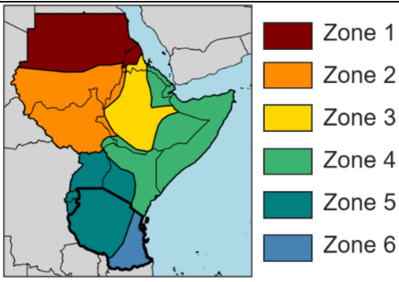


Summary of analysis relevant to Sudan	**Report section**
The northern part of Sudan is included in Zone 1 and experience a hot desert climate. Most people live in the capital city of Khartoum and along the River Nile, whereas the rest of this region is sparsely populated. Zone 1 has large-scale irrigation along the Nile, but is otherwise predominately arid pastoral and oasis farming livelihoods. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year, with larger increases during the hottest summer months, resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests a small increase in June-September seasonal rainfall. Sea levels will continue to rise and the frequency and intensity of marine heatwaves will also increase.	3.3.1
The southern part of Sudan is included in Zone 2 and experiences a mix of hot desert and semi-arid climate with seasonal rainfall. Within Zone 2 of Sudan, there is large-scale irrigation practiced south of Khartoum. There are also pastoral livelihoods around this zone, and agropastoral livelihoods south of it, along the border with South Sudan. In the southeast corner of Sudan, bordering Ethiopia, people practice cereal-root crop mixed livelihoods. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in annual rainfall, with the largest increases during the June-September season.	3.3.2
Across the country, variability in seasonal rainfall amounts and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events.	3.3.1, 3.3.2

Regional risks relevant to Sudan	**Report section**
High temperatures, floods, and desert storms in Khartoum and urban areas	4.4.3
Household water security (see 4.2.3).	4.2.3
Health risks related to high temperatures (heat stroke, noncommunicable diseases) and diarrheal disease related to flood events	4.3.3

Tanzania country profile

Tanzania is located in the south of the East Africa region on the Indian Ocean coastline and is divided between two zones in this report: Zone 5 and Zone 6.

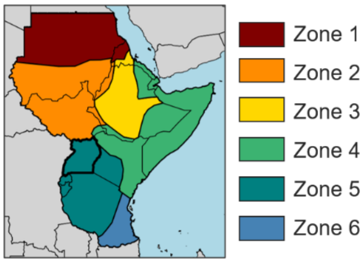


Summary of analysis relevant to Tanzania	Report section
The highland regions of Tanzania are included in Zone 5 and mostly experience a tropical savannah climate. This region is cooler than in Zone 6 due to the higher elevation, with the mountainous regions experiencing a more temperate climate. Most people live in the north of this region near to Lake Victoria. Near Lake Victoria, people practice fish-based livelihoods. Bordering the lake, root and tuber crop livelihoods are common in the southwest corner of the lake. Along the southeast corner, agropastoral livelihoods dominate. Near the border with Kenya, people practice maize-mixed livelihoods and agropastoral livelihoods. Maize mixed livelihoods and highland perennial livelihoods are practiced in the southern parts of Zone 5 in Tanzania. Along Lake Tanganyika, fish-based livelihoods are common. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 30˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in annual rainfall.	3.3.5
The coastal regions of Tanzania are included in Zone 6 and experience a tropical savannah climate. Most people live along the coast and in major cities such as Dar es Salaam. Inland, maize mixed livelihoods are most commonly practiced. Along the coast, most people practice fish-based livelihoods. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year. There is uncertainty as to whether annual rainfall will increase or decrease resulting in more frequent days above 35˚C. Sea levels will continue to rise and the frequency and intensity of marine heatwaves will also increase.	3.3.6
Across the country, variability in seasonal rainfall amounts and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events.	3.3.5, 3.3.6

Regional risks relevant to Tanzania	Report section
Salt water intrusion in coastal aquifers and sea level rise	4.5.3
Food security especially for agropastoralist and maize-based livelihoods	4.1.3
Risks of flooding and high temperatures in urban areas	4.4.3
Health risks as patterns of vector-borne disease transmission shift to higher altitudes	4.3.3
Health risks of increased diarrheal disease and malnutrition due to more intense flooding and higher temperatures	4.3.3
Rising surface water temperatures in freshwater fisheries diminish productivity	4.5.3

Uganda country profile

Uganda is located in the Great Rift Valley and is included in Zone 5 of this report.



Summary of analysis relevant to Uganda	Report section
Uganda (Zone 5) experiences a tropical climate. Most people live near to Lake Victoria, and in major cities such as Kampala and Entebbe. In Uganda, there are a range of livelihoods practiced. In the northeast, pastoral livelihoods are present. The northwest of the country is largely maize-mixed livelihoods. In the southern parts of the country, highland perennial livelihoods are most common. Along Lake Victoria, there is a pocket of agropastoral livelihoods. Near Uganda's lakes, fish-based livelihoods are common. This region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be warmer than the current climate throughout the year resulting in more frequent days above 40˚C. Although there is less confidence in rainfall projections, our analysis suggests an increase in annual rainfall. Variability in seasonal rainfall amounts and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events.	3.3.5

Regional risks relevant to Uganda	Report section
Flooding and food security along Lake Victoria	4.1.3, 4.5.3
Food security for pastoralist, agropastoral, and maize mixed livelihoods	4.1.3
Risks of urban flooding and high temperatures	4.4.3
Changing patterns of disease transmission, particularly at higher altitudes	4.3.3
Health risks of increased diarrheal disease and malnutrition due to more intense flooding and higher temperatures	4.3.3
Rising surface water temperatures in freshwater fisheries diminish productivity	4.5.4

Glossary

Acronyms

AR5	IPCC 5th Assessment Report
AR6	IPCC 6th Assessment Report
CMIP5	Coupled Model Intercomparison Project Phase 5
CMIP6	Coupled Model Intercomparison Project Phase 6
CORDEX	CoOrdinated Regional climate modelling Downscaling EXperiment
EAPP	East African Power Pool
ENSO	El Niño Southern Oscillation
FCDO	Foreign, Commonwealth & Development Office (UK Government)
GCM	Global Climate Model
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GMST	Global Mean Surface Temperature
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
MHW	Marine Heat Waves
MJO	Madden-Julian Oscillation
NAO	North Atlantic Oscillation
NBS	Nature-Based Solutions
NCD	Non-Communicable Diseases
ODI	Overseas Development Institute
QBO	Quasi-Biennial Oscillation
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RVF	Rift Valley Fever
SES	Semi-Enclosed Seas
SLR	Sea Level Rise
SST	Sea Surface Temperature
SSA	sub-Saharan Africa
SWI	Saltwater Intrusion
UHI	Urban Heat Island
UNFCCC	United Nations Framework Convention on Climate Change
WASH	Water, Sanitation and Hygiene
WCRP	World Climate Research Project

Technical terms

These definitions have been taken from the IPCC reports from 2001, 2013, 2014, 2018, 2019, and 2021; the Met Office website (www.metoffice.gov.uk/weather/learn-about; https://www.metoffice.gov.uk/hadobs/monitoring/climate_modes.html); Wikipedia, the World Atlas (https://www.worldatlas.com); Dixon et al (2020)'s "Africa through the farming system lens: Context and Approach" (see Appendix C for more details); and the Cambridge dictionary (https://dictionary.cambridge.org/).

Term	Definition
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.
Aerosols	A suspension of airborne solid or liquid particles, with a typical size between a few nanometres and 10 μm that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in several ways: through both interactions that scatter and/or absorb radiation and through interactions with cloud microphysics and other cloud properties, or upon deposition on snow- or ice-covered surfaces thereby altering their albedo and contributing to climate feedback.
Agropastoral [livelihood]	Mixed crop-livestock farming found in semi-arid (medium rainfall) areas of Africa, typically with low access to services. It includes the dryland mixed farming system of North Africa, often depending on wheat, barley and sheep. In SSA the main food crops are sorghum and millet, and livestock are cattle, sheep and goats. In both cases, livelihoods include pulses, sesame, poultry and off-farm work.
Anomaly	The deviation of a variable from its value averaged over a reference period.
Anthropogenic	Resulting from or produced by human activities.
Atmosphere	The gaseous envelope surrounding the earth, divided into five layers – the *troposphere* which contains half of the Earth's atmosphere, the *stratosphere*, the mesosphere, the thermosphere, and the exosphere, which is the outer limit of the atmosphere.
Arid pastoral and oasis [livelihood]	Extensive pastoralism and scattered oasis farming associated with sparsely settled arid zones across Africa, generally with very poor access to

services. Livelihoods include date palms, cattle, small ruminants and off-farm work, irrigated crops and vegetables.

Baseline	The state against which change is measured. It might be a 'current baseline,' in which case it represents observable, present-day conditions. It might also be a 'future baseline,' which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.
Biodiversity	The variability among living organisms from terrestrial, marine, and other ecosystems. Biodiversity includes variability at the genetic, species, and ecosystem levels.
Carbon Dioxide (CO2)	A naturally occurring gas, CO2 is also a by-product of burning fossil fuels (such as oil, gas and coal), of burning biomass, of land-use changes (LUC) and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas (GHG) that affects the Earth's radiative balance.
Catchment	An area that collects and drains precipitation.
Cereal-root crop mixed [livelihood]	Mixed farming with medium-high access to services dominated by at least two starchy staples (typically maize and sorghum) alongside roots and tubers (typically cassava) found in the subhumid savannah zone in West and Central Africa. Other livelihood sources include legumes, cattle and off-farm work.
Climate	In a narrow sense, climate is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization.
Climate Change	A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.
Climate Feedback	An interaction in which a perturbation in one climate quantity causes a change in a second and the change in the second quantity ultimately leads to an additional change in the first. A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced.

Climate Information	Information about the past, current state, or future of the climate system that is relevant for mitigation, adaptation and risk management. It may be tailored or "co-produced" for specific contexts, taking into account users' needs and values.
Climate Impacts	Impacts describe the consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability.
Climate Indicator	Measures of the climate system including large-scale variables and climate proxies.
Climate Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Climate Model	A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties.
Climate Projection	The simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHG) and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.
Climate Risk	The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.
Climate System	The highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere and the interactions between them.

Climate Variability	Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events.
Communicable Disease	Refers to an illness caused by an infectious agent or its toxins that occurs through the direct or indirect transmission of the infectious agent or its products from an infected individual or via an animal, vector or the inanimate environment to a susceptible animal or human host (CDC, 2012).
Confidence	The robustness of a finding based on the type, amount, quality and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement across multiple lines of evidence.
Crop Water Deficit	A water deficit occurs whenever water loss exceeds absorption. The use of total water potential as the best single indicator of plant water status has its limitations while attempting to understand the effect of water deficits on the various physiological processes involved in plant growth. Water deficits reduce photosynthesis by closing stomata, decreasing the efficiency of the carbon fixation process, suppressing leaf formation and expansion, and inducing shedding of leaves.
Disaster	A 'serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts' (UNGA, 2016).
Deltaic	Of or pertaining to a river delta.
Downscaling	A method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses.
El Niño Southern Oscillation (ENSO)	The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere–ocean phenomenon, with preferred time scales of two to about seven years, is known as the El Niño-Southern Oscillation (ENSO). The cold phase of ENSO is called La Niña.
Emissions Scenario	A plausible representation of the future development of emissions of substances that are radiatively active (e.g., greenhouse gases (GHGs), aerosols) based on a coherent and internally consistent set of assumptions

	about driving forces (such as demographic and socio-economic development, technological change, energy and land use) and their key relationships.
Enhanced Greenhouse Effect	The process in which human activities have added additional greenhouse gases into the atmosphere, this has resulted in a 'stronger' greenhouse gas effect as there are more gases available to trap outgoing radiation.
Evaporation	The physical process by which a liquid (e.g., water) becomes a gas (e.g., water vapour).
Evapotranspiration	The process in which water moves from the earth to the air from evaporation (= water changing to a gas) and from transpiration (= water lost from plants).
Exposure	Exposure describes the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.
Extreme/heavy precipitation event	An extreme/heavy precipitation event is an event that is of very high magnitude with a very rare occurrence at a particular place. Types of extreme precipitation may vary depending on its duration, hourly, daily or multi-days (e.g., 5 days), though all of them qualitatively represent high magnitude. The intensity of such events may be defined with block maxima approach such as annual maxima or with peak over threshold approach, such as rainfall above 95th or 99th percentile at a particular space.
Fifth Assessment Report (AR5)	A series of IPCC reports published in 2013-2014, reports are divided into publications by three working groups.
Fish-based [livelihood]	Found along coasts, lakes and rivers across Africa with medium-high access to services, with fish a major livelihood. Other livelihood sources include coconuts, cashew, banana, yams, fruit, goats, poultry and off-farm work.
Fossil Fuels	Carbon-based fuels from fossil hydrocarbon deposits, including coal, oil, and natural gas.
Global Breadbasket	The term "breadbasket" is used to refer to an area with highly arable land. The breadbaskets of the world are the regions in the world that produce food, particularly grains to feed their people as well as for export to other places.

Global Warming	The estimated increase in global mean surface temperature (GMST) averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue.
Greenhouse Effect	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect.
Greenhouse Gas (GHG) Concentrations	Lead to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect.
Greenhouse Gases (GHGs)	The gaseous constituents of the atmosphere. both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapour (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and ozone (O3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO2, N2O and CH4, the Kyoto Protocol deals with the GHGs sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). [IPCC, 2018].
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.
Heat Stress	A range of conditions in, e.g., terrestrial or aquatic organisms when the body absorbs heat during overexposure to high air or water temperatures or thermal radiation. In aquatic water breathing animals, hypoxia and acidification can exacerbate vulnerability to heat. Heat stress in mammals (including humans) and birds, both in air, is exacerbated by a detrimental combination of ambient heat, high humidity and low wind-speeds, causing regulation of body temperature to fail.

Heatwave	A period of abnormally hot weather often defined with reference to a relative temperature threshold, lasting from two days to months. Heatwaves and warm spells have various and, in some cases, overlapping definitions.
Highland mixed [livelihood]	Highland mixed farming above 1700 m dominated by wheat and barley, found predominantly in subhumid north-east Africa with pockets in Southern, West and North Africa. Other livelihood sources include teff, peas, lentils, broad beans, rape, potatoes, sheep, goats, cattle, poultry and off-farm work.
Highland perennial [livelihood]	Highland perennial farming is characterized by a dominant perennial crop (banana, plantains, enset or coffee) and good market access, and is found in humid East African highlands. Other livelihoods derive from diversified cropping including maize, cassava, sweet potato, beans, cereals, livestock and poultry augmented by off-farm work.
Ice sheet	An ice body originating on land that covers an area of continental size, generally defined as covering >50,000km^2, and that has formed over thousands of years through accumulation and compaction of snow. [IPCC, 2019].
Impacts	Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system.
Indian Ocean Dipole	The Indian Ocean Dipole (IOD), is an irregular oscillation of sea surface temperatures in which the western Indian Ocean becomes alternately warmer (positive phase) and then colder (negative phase) than the eastern part of the ocean.
Intergovernmental Panel on Climate Change (IPCC)	The leading international body for the assessment of climate change. Scientists come together approximately every six years, to assess peer-reviewed research in working groups to generate three reports including the Physical Science Basis, impact adaptation and vulnerability, and Mitigation of Climate Change.
Intertropical Convergence Zone (ITCZ)	The Intertropical Convergence Zone (ITCZ) is a band of low pressure around the Earth which generally lies near to the equator. The trade winds of the northern and southern hemispheres come together here, which leads to the development of frequent thunderstorms and heavy rain.
Irrigated [livelihood]	Large-scale irrigation schemes associated with large rivers across Africa, e.g. Nile. Often located in semi-arid and arid areas but with medium-high access to services. Includes the associated surrounding rainfed lands.

	Diversified cropping includes irrigated rice, cotton, wheat, faba, vegetables and berseem augmented by cattle, fish and poultry.
Madden-Julian Oscillation (MJO)	The Madden-Julian Oscillation (MJO) is characterised by an eastward spread of large regions of enhanced and suppressed tropical rainfall, mainly observed over the Indian and Pacific Ocean.
Maize mixed [livelihood]	Mixed farming dominated by maize with medium access to services in subhumid areas of East, Central and Southern Africa. Other livelihood sources include legumes, cassava, tobacco, cotton, cattle, goats, poultry and off-farm work.
Marine heatwave	A period during which water temperature is abnormally warm for the time of the year relative to historical temperatures with that extreme warmth persisting for days to months. The phenomenon can manifest in any place in the ocean and at scales of up to thousands of kilometres.
Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Nature-Based Solutions (NBS)	Nature-based solutions (NBS) refers to the sustainable management and use of nature for tackling socio-environmental challenges. The challenges include issues such as climate change, water security, water pollution, food security, human health, biodiversity loss and disaster risk management.
North Atlantic Oscillation (NAO)	The North Atlantic Oscillation (NAO) is a large-scale atmospheric process that governs local weather patterns as it influences the intensity and location of the North Atlantic jet stream. It is defined as the pressure difference between the Azores islands and Iceland: a positive (negative) NAO is associated with higher (lower) than average pressure difference.
Ocean acidification	A reduction in the pH of the ocean, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO2) from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity.
Overharvested	Refers to harvesting a renewable resource to the point of diminishing returns.

Paris Agreement	The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted on December 2015 in Paris, France, at the 21st session of the Conference of the Parties (COP) to the UNFCCC. The agreement, adopted by 196 Parties to the UNFCCC, entered into force on 4 November 2016 and as of May 2018 had 195 Signatories and was ratified by 177 Parties. One of the goals of the Paris Agreement is 'Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels', recognising that this would significantly reduce the risks and impacts of climate change. Additionally, the Agreement aims to strengthen the ability of countries to deal with the impacts of climate change.
Pastoral [livelihood]	Extensive pastoralism (dominated by cattle), found in dry semiarid (low rainfall) areas with poor access to services. Other livestock include camels, sheep and goats alongside limited cereal cropping, augmented by off-farm work.
Pelagic Fish	Pelagic fish live in the pelagic zone of ocean or lake waters – being neither close to the bottom nor near the shore.
Projection/projected	A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised.
Quasi-Biennial Oscillation (QBO)	A near-periodic oscillation of the equatorial zonal wind between easterlies and westerlies in the tropical stratosphere with a mean period of around months. The alternating wind maxima descend from the base of the mesosphere down to the tropopause, and are driven by wave energy that propagates up from the troposphere.
Radiative Forcing	The change in the net, downward minus upward, radiative flux (expressed in W m-2) at the tropopause or top of atmosphere due to a change in a driver of climate change, such as a change in the concentration of carbon dioxide (CO2) or the output of the sun.
Reanalysis	Atmospheric and oceanic analyses of temperature, wind, current and other meteorological and oceanographic quantities, created by processing past meteorological and oceanographic data using fixed state-of-the-art weather forecasting models and data assimilation techniques.

Representative Concentration Pathways (RCPs)	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover.
Resilience	The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.
Resolution	In climate models, this term refers to the physical distance (metres or degrees) between each point on the grid used to compute the equations. Temporal resolution refers to the time step or time elapsed between each model computation of the equations.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure and hazard.
Root and tuber crop [livelihood]	Lowland farming dominated by roots and tubers (yams, cassava) found in humid areas of West and Central Africa. Other livelihood sources include legumes, cereals and off-farm work.
Runoff	The flow of water over the surface or through the subsurface, which typically originates from the part of liquid precipitation and/or snow/ice melt that does not evaporate or refreeze and is not transpired.
Scenario	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g. rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions.
Signal	Climate signals are long-term trends and projections that carry the fingerprint of climate change.
Sixth Assessment Report (AR6)	The latest series of IPCC reports published in 2021-2022, reports are divided into publications by three working groups. At the time of writing this report only the Working Group I contribution to the Sixth Assessment Report published in 2021 was available to use.

Soil moisture	Water stored in the soil in liquid or frozen form. Root-zone soil moisture is of most relevance for plant activity.
Special Report on Emissions Scenarios (SRES)	A report by the Intergovernmental Panel on Climate Change (IPCC) that was published in 2000. The SRES scenarios, as they are often called, were used in the IPCC Third Assessment Report (TAR), published in 2001, and in the IPCC Fourth Assessment Report (AR4), published in 2007.
Storm surge	The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. [IPCC, 2019].
Stream Flow	Water flow within a river channel, for example, expressed in m^3s^{-1}. A synonym for river discharge.
Teleconnection	Association between climate variables at widely separated, geographically fixed locations related to each other through physical processes and oceanic and/or atmospheric dynamical pathways. Teleconnections can be caused by several climate phenomena, such as Rossby wave-trains, mid-latitude jet and storm track displacements, fluctuations of the Atlantic Meridional Overturning Circulation, fluctuations of the Walker circulation, etc. They can be initiated by modes of climate variability thus providing the development of remote climate anomalies at various temporal lags.
Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. In climate change analysis, it may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes, or uncertain projections of human behaviour.
United Nations Framework Convention on Climate Change (UNFCCC)	The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in May 1992 and opened for signature at the 1992 Earth Summit in Rio de Janeiro. It entered into force in March 1994 and as of May 2018 had 197 Parties (196 States and the European Union). The Convention's ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.' The provisions of the Convention are pursued and implemented by two treaties: the *Kyoto Protocol* and the *Paris Agreement*. [IPCC, 2018].
Urban Heat Island	The relative warmth of a city compared with surrounding rural areas, associated with changes in runoff, effects on heat retention, and changes in surface albedo.

Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm, and lack of capacity to cope and adapt.
Weather	The conditions in the air above the earth such as wind, rain, or temperature, especially at a particular time over a particular area.

Image location: Somalia

1 Introduction

1.1 Purpose of this report

This report provides an evidence base on the East Africa region's current climate and its variability and looks at how this is expected to change by the 2050s. It also identifies how these changes could impact socio-economic development within individual countries. The aim is to inform and support development programming and policy dialogue for East Africa.

This report is part of a series of climate risk reports commissioned by the UK Government's Foreign, Commonwealth & Development Office (FCDO). In this series we are standardising how we process and interpret climate information to support FCDO offices and climate risk informed development planning in different regions. This provides consistency both within the specified region and across regions. It also ensures we are consistent with other climate information such as briefing notes and monthly outlooks that the Met Office, the UK's meteorological service, provides to FCDO country offices.

This report takes a methodological approach for translating and communicating climate information, applying it to socio-economic contexts that development planners need to consider.[1] It combines the Met Office's climate science expertise with socio-economic analysis of the East Africa region provided by Overseas Development Institute (ODI). FCDO regional representatives have also provided input to ensure it is both usable and relevant. Collaborating in this way has allowed us to tailor and frame future climate projections so that they are easier to include in development planning. Appendix A includes more information on the approach.

The geographic scope of the report includes the following countries in the East Africa region (as shown in Figure 1, left panel): Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, South Sudan, Sudan, Tanzania, and Uganda. Key aspects of the region also included in the analysis, such as the geography of the region and population densities, are also shown in Figure 1 (middle and right panels).

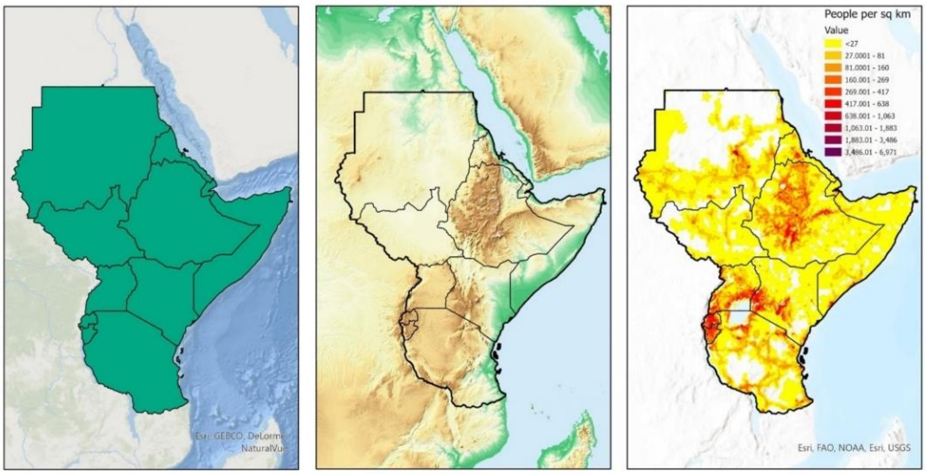


Figure 1: The East Africa region considered in this report. Left panel: countries included in the analysis, middle panel: geography of the region, right panel: population density.

[1] A report documenting the Met Office Climate in Context methodology is in preparation and due to be published in 2022.

1.2 Methodological approach

1.2.1 Data and methods

1.2.1.1 Socio-economic data and methods

The socio-economic contributions to this report draw on a review of the relevant literature and key informant interviews with experts working on both climate and climate-sensitive sectors, such as agriculture and water. Outputs from these analyses informed the identification of appropriate livelihood groupings and key socio-economic variables, as well as suitable climate indicators to support the climate data analysis.

1.2.1.2 Climate data and methods

This report makes use of bespoke climate data analysis in the selected spatial analysis zones (see Section 3.2) and relevant scientific literature. The bespoke data analysis involved processing gridded reanalysis[2] data to characterise the current climate over the 1981-2010 baseline period, and climate model projections to assess the projected trends in average temperature and precipitation for the 2050s (using the 2041-2070 future time period compared to the baseline period). The baseline period of 1981-2010 represents an observed increase of around 1°C in global average temperature compared to pre-industrial levels.

To characterise the baseline climate, we processed temperature from ERA5[3] (Hersbach et al., 2020) and precipitation data from WFDE5 (Cucchi et al., 2020) over the 1981-2010 baseline period. Using this dataset and time period keeps this report consistent with FCDO climatology briefing notes provided to FCDO offices for many of the countries in the East Africa region.

For the future climate projections we used global and regional climate model simulations to assess the projected change in temperature and precipitation for the 2050s under different scenarios of future greenhouse gas emissions. The results presented in this report show projected changes for the 2050s under the RCP8.5[4,5] scenario (van Vurren et al., 2011). This future time period and scenario combination represents an increase in global average temperature of around 2.5˚C compared to pre-industrial levels. This is higher than the target of limiting warming to well below 2˚C set by the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement. The baseline period of 1981-2010 considered

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[2] A gridded dataset that blends climate observations and model data to present the current climate for use as a baseline in future climate assessments.

[3] All observational and reanalysis datasets have associated uncertainties and limitations. For example, reanalysis datasets may underestimate observed extremes, and cannot fully represent localised features such as intense precipitation caused by complex topography, partly due to their limited resolution in space and time. Additionally, ERA5 precipitation fields are derived from 'forecast' output and are therefore more affected by imperfections within the underlying model. The benefit, however, of using reanalyses is that they provide a systematic approach to producing gridded, dynamically consistent datasets for climate monitoring, particularly over data-scarce regions. However, the use of these data to characterise climatological means for the purpose of this analysis is largely uninfluenced by these biases, and the benefits of using a dataset that is globally consistent and consistent with other climate information products outweighs this.

[4] The RCP8.5 Representative Concentration Pathway represents a future pathway of on-going and substantial increases in future global emissions of greenhouse gases. Other pathways represent stabilisation or reduction of future emissions, however there is little difference in the projected climate change between these pathways in the 2050s time period. Analysis of the RCP4.5 scenario was also conducted and results were broadly consistent with those presented here for RCP8.5.

[5] The SSP5-8.5 scenario was used for the CMIP6 generation of climate models.

in this report represents an observed increase of around 1°C in global average temperature compared to pre-industrial levels.

We used the following model simulations in this analysis (more details on specific models included are available in Appendix B):

- Thirty Global Climate Model (GCM) simulations from the World Climate Research Project (WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2012), used to inform the Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR5; IPCC, 2013). The horizontal resolution of these models varies by model, ranging from 100-300 km.
- Twenty GCM simulations from the WCRP CMIP Phase 6 (CMIP6; Erying et al., 2016) used to inform the most recent IPCC Assessment Report (AR6; IPCC, 2021). Similarly to CMIP5, the horizontal resolution of the CMIP6 models varies by model. The range is large; many models are higher resolution compared to those in CMIP5, whereas some are unchanged.
- Twenty Regional Climate Model (RCM) simulations from the WCRP CoOrdinated Regional climate modelling Downscaling EXperiment (CORDEX; Giorgi & Gutowski, 2015). These are downscaled CMIP5 simulations over the CORDEX Africa domain (AFR-44) at a resolution of 50km.

The climate data analysis focuses on quantifying projected changes in annual, seasonal and monthly means in the spatial analysis zones. We drew information on the projected changes in other relevant climate variables and indicators – such as Sea Surface Temperatures (SSTs), Sea Level Rise (SLR) and relevant climate extremes – from appropriate scientific literature and from the IPCC Interactive Atlas (2021).

1.3 How to use this report

This report presents the outcomes of a collaborative and integrated analysis of climate risk in the East Africa region, combining climate information with social and economic analysis to frame key threats to production systems, resources, economies, services and livelihoods. The report aims to guide development planners to focus areas that may need attention and, within those, to key risks and uncertainties. The report provides a detailed overview of those risks and uncertainties, bringing prominent regional risks to the fore, rather than a comprehensive analysis of country-specific threats.

The climate analysis and subsequent discussion endeavours to outline the expected changes in climate between the present day and the 2050s. Country summaries have been provided in the Executive Summary above to outline prominent climate risks for that location within the regional context. However, such summaries do not provide a national level analysis and therefore there will be additional climate risks that are pertinent at a national scale that should also be considered in a national or subnational development plan. . For individual programmes supported by FCDO and others, where relevant risks are identified, or where national or sub-national scale risk information is required, additional climate and socio-economic analysis is recommended.

Section 2 sets the scene by providing an overview of the current vulnerability and climate resilience in the East Africa region. The current climate already includes significant changes in climate which some aspects of human and ecological systems are not well adapted to. This section justifies the need for an intersectional approach when it comes to interpreting compound risks associated with, or exacerbated by, climate change.

Section 3 focuses on the current and future climate projections for the East Africa region and sub-regions defined by their main climate characteristics. In each zone the baseline climate is presented in the context of prevailing socio-economic conditions. Future projections and their relevance are then summarised. A look-up table that relates countries to zones is provided (see Table 1).

Section 4 interprets the climate projections in terms of risks across five key themes: agriculture and food security, water resources and water-dependent services, human health, urban environments and infrastructure, and fisheries and coasts. For each theme, an overview of key socio-economic trends and a summary of the relevant climate projections from Section 3 are provided. This is followed by discussion on the implications and potential compound risks arising from the threats identified.

Image location: Tanzania

2 Vulnerability and climate resilience in East Africa: an intersectional approach

East Africa has witnessed the most robust economic growth of any region in Africa, with growth rates of over 6% in the five years prior to the COVID-19 pandemic (UNDESA, 2021). Yet the benefits of growth have not been equally shared. Some countries, like South Sudan, Burundi, and Somalia, have far lower growth rates, inhibited by lack of peace and security (WFP, 2020). Even within economically dynamic countries like Ethiopia and Rwanda, poverty remains stubbornly high. Limited economic diversification has restricted the movement of people out of low productivity and increasingly volatile agricultural livelihoods. There remain relatively low levels of industrialisation, and there is limited economic diversification. All East African countries' export mostly primary commodities rather than manufactured goods (Kassegn & Endris, 2021; AfDB, 2020).

East Africa is characterised by its varied topography, from highly mountainous areas to savannah plains, arid deserts and extensive wetlands. These diverse conditions host pastoral, agro-pastoral, and agricultural livelihoods, nearly all of which are dependent on the bimodal or single rainy seasons that help shape its agro-ecological zones. As the climate changes, these livelihoods will be increasingly forced to grapple with continuing variability in rainy seasons and extreme rainfall, with seasonal shifts in precipitation and increased incidence of droughts and floods already observed (McSweeney et al., 2010). The consequences of exposure to climate variability can be severe, as household food security is tightly linked to rain and temperature-dependent production systems (Gebre & Rahut, 2021). Prior to the COVID-19 pandemic, nearly a third of the population of East Africa suffered from undernourishment (FAO, 2019). Accentuated by climate change, East Africa suffers from sharp fluctuations in agricultural production, which still accounts for around 25% of regional GDP.

Agricultural systems in East Africa have always had to respond to climate variability. For example, regular flooding of the Nile has provided a source of water for agricultural lands over centuries, yet one out of every five Nile floods was considered poor, endangering harvests and dry season pastureland (Serels, 2021). The consequences of East Africa's cyclical droughts have intensified in recent decades (Haile et al., 2019). Against a backdrop of rapid population growth, changing land use patterns and political fragility, drought has fueled some of the world's worst humanitarian crises in recent memory. The most notorious of these was the 1984-1985 drought in Ethiopia and Sudan, which resulted in 450,000 deaths and helped spawn the international NGO system that remains prominent in East Africa today (Gill, 2010). Other major droughts have been associated with El Niño or La Niña weather cycles, which respectively bring rainfall deficits and rainfall excess to the region (Vashisht et al, 2021). In 2010-2011, over 250,000 Somalians died after two consecutive rainy seasons failed (Carty, 2017). In 2015-2016, a drought led to poor harvests and a major spike in food insecurity in Kenya, Ethiopia, and Somalia, leaving over 12 million people dependent on humanitarian aid (Funk, 2020). At the time of drafting this report, the Eastern Horn of Africa has been reeling under the effects of another major drought, the consequence of three consecutive poor rainy seasons from 2020 to 2022 (Multi-Agency East Africa Drought Alert, 2021; see also Focus Box 4)

Population growth in the region is over double the world average at 2.5% per year, despite fertility rates dropping steadily since the 1960s (OECD, 2017). Combined with increases in life expectancy, population growth will increase demands on basic services and generate pressure for job creation in rural non-farm and urban economies, particularly for younger adults (ibid). For those struggling to meet basic needs, some East African governments administer major social safety net programmes, such as Ethiopia's Productive Safety Net Programme, the Tanzanian Social Action Fund and Kenya's Hunger Safety Net Programme, amongst others. Social protection programmes have been a key policy instrument in mitigating some of the worst impacts of climate stresses, as the programmes are designed to support household incomes during the lean season, scale up during disasters, and invest in local public works (e.g. watershed rehabilitation) that can help adapt to the impacts of climate change (see Focus Box 5). The coverage of these programmes remains patchy in both geographic and demographic terms, however. Adaptive capacity to deal with climate change remains low, especially for the one-third of the population that lives below the poverty line (AfDB, 2020).

Focus box 1: Exposure, vulnerability and development

A climate or disaster hazard does not in itself create risk. Risk is a function of both an individual's or community's exposure and vulnerability to a hazard (Figure 2, IPCC, 2014). Exposure and vulnerability are separate, yet both emerge from socio-economic contexts and are exacerbated by uneven development dynamics such as: rapid urbanisation and demographic change, environmental degradation, weak governance, and lack of economic opportunity (Figure 2, IPCC, 2014; UNDRR, 2015). Climate vulnerability and poverty are often mutually reinforcing; a growing body of evidence highlights the role of climate risk in persistent poverty and poverty traps (Hansen et al, 2019; Sachs et al., 2004). This is a challenge exacerbated by the political marginalisation of many poor and climate vulnerable people (Wisner et al., 2003).

Climate change is interwoven with development challenges and across the Sustainable Development Goals. As factors such as economic inequality, education, gender, nutrition, and health, shape the risk profile of individuals and communities, supporting sustainable development indirectly supports their capacity for managing climate risk (Wisner et al., 2003; Schipper and Pelling, 2006).

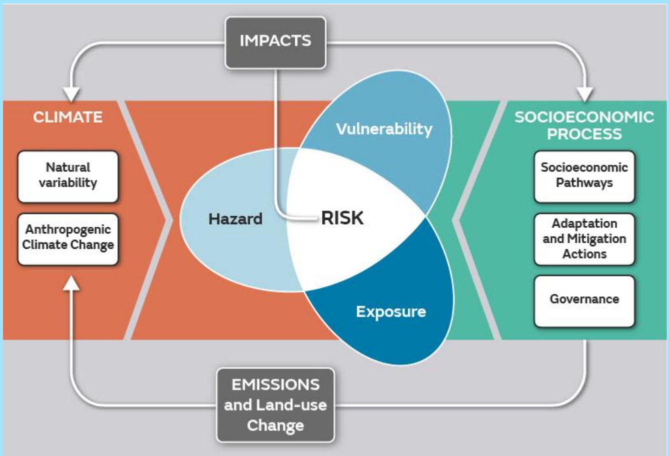

Figure 2: Climate risk is the product of the hazard, vulnerability to the hazard and exposure to the hazard. Image adapted from IPCC (2014).

2.1 Key risk factors in the report

The interpretation of climate projections in this report is informed by six factors that run through our analysis of themes:

- Economic growth and infrastructure
- Capacity and human capital
- Population and demography
- Livelihood systems and key crops
- Disaster risks
- Conflict and migration

Hence our analysis of risks to urban environments and infrastructure in Section 4, for example, considers demographic change and urban growth, disaster risks with a focus on flooding, and ways in which infrastructure planning might inadvertently build in climate risk if conducted on the basis of historical climate conditions.

The factors above help guide the analysis but are not exhaustive, or definitive. Other (similar) framings can be used, including the 'risk informed development' approach outlined in Focus Box 2.

Focus box 2: Risk-informed development

There is increasing recognition that development is exposed to multiple, intersecting threats (Opitz-Stapleton et al., 2019). However, identifying risks to development programming is often the result of single threat analysis, meaning that it fails to be risk-informed (Opitz-Stapleton et al., 2019). In order to be risk-informed, programme decision making must undertake multi-threat analysis that considers how different threats merge with existing and changing socioeconomic contexts to create complex risk (Opitz-Stapleton et al., 2019). In practice, this means that climate-resilient development must not only consider threats to programme outcomes from climate and environmental degradation, but also political, economic and financial instability, cyber and technology, transboundary crime and terrorism, geopolitical volatility, conflict and global health pandemics (Opitz-Stapleton et al., 2019).

Risk-informed development requires us not only to think about risks to development but also risks from development (Opitz-Stapleton et al., 2019). Development outcomes are uneven, creating opportunities for some and risks for others. Risk-informed development must account for trade-offs inherent in development choices, including climate adaptation and mitigation (Opitz-Stapleton et al., 2019). Such decisions are inherently political, involving the redistribution of resources and navigating unequal power structures (Eriksen et al., 2015).

2.2 Climate risk rankings and comparisons

Figure 3 provides a snapshot of climate risk across the region using widely used ND-GAIN[6] country rankings for 2019 – the most recent year for which data are available. The ND-GAIN country index uses a range of metrics to assess both a country's vulnerability to climate change and other global challenges (36 indicators covering exposure, sensitivity and adaptive capacity – see Focus Box 1), and its readiness to build resilience (nine indicators covering economic, governance and social capacity).

The multi-indicator metric does not provide a complete picture of climate risk since climate hazards are excluded (see Focus Box 1). Keen observers will also note that the 'vulnerability' framing includes 'exposure', in contrast to the IPCC (2014) definitions used in Figure 2. Nonetheless the ND-GAIN index provides a useful and quick way of gauging a country's position and progress[7] in addressing climate risk.

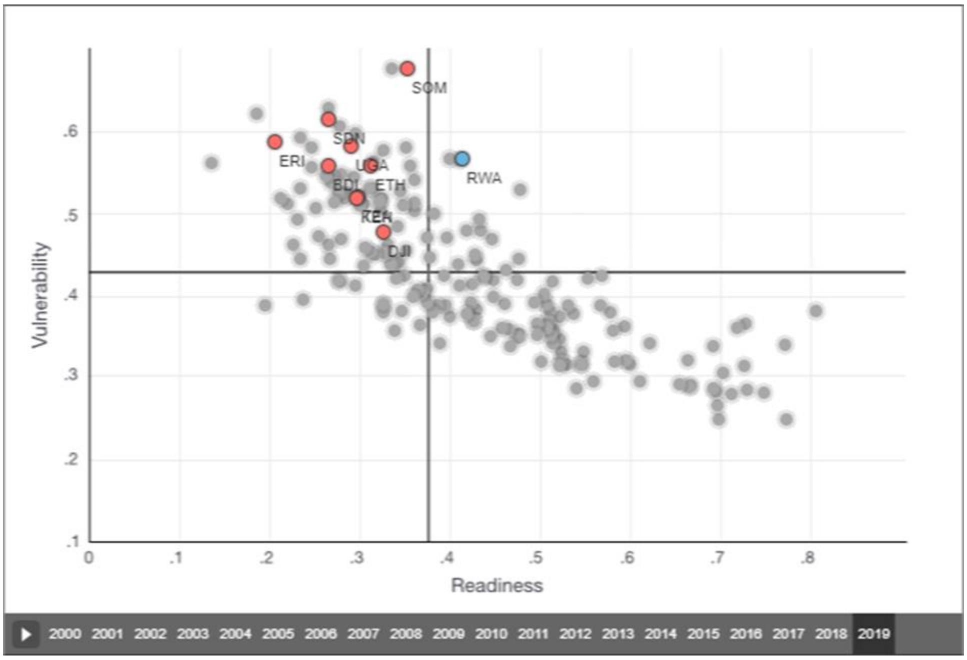

Figure 3: ND-GAIN country scores for the East Africa region. Note: Tanzania (TAN) and Kenya (KEN) have the same score so overlap. Separate scores are not available for South Sudan and Sudan. Source: https://gain.nd.edu/

All of the East African countries considered in this report occupy the top left quadrant with the exception of Rwanda (top right quadrant). Countries in the top left quadrant combine high vulnerability with low levels of readiness, indicating an urgent need for adaptation action. Within the 'high risk' quadrant country positions vary somewhat, with Djibouti, Tanzania and Kenya (for example) faring better than Eritrea and Sudan. Rwanda, the outlier here, appears in the top right quadrant because of its higher 'readiness' score. This derives largely from its more positive governance and economic conditions.

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[6] Notre Dame Global Adaptation Initiative: https://gain.nd.edu/ ND-GAIN country scores and rankings are used by, amongst others, the World Bank in their climate risk country profiles – see https://climateknowledgeportal.worldbank.org/. Scores are available for a total of 182 countries based on data for 2019.

[7] Time series data are available on the open access platform, albeit for a limited number of years.

Image location: Kenya

3 Climate in Context: Current and future climate in the East Africa region

3.1 Climate overview for the East Africa region

The East Africa region has a diverse climate which is strongly influenced by areas of high elevation along the East African Rift Valley, and long coastlines with the Red Sea, Gulf of Aden and Indian Ocean. Elevation is a key factor in temperature and precipitation variation across the region with highland regions experiencing cooler and wetter climates compared to the hotter, more arid lowlands (Figure 4). Annual average precipitation amounts, and annual average minimum, mean and maximum temperatures are shown in Figure 4. These maps represent the average annual values over the 30-year baseline climate period (1981-2010).

The seasonal cycle of rainfall across East Africa is characterised by northern and western parts of the region experiencing one rainy season during boreal summer (June-September), while the southern and eastern parts of the region experience two rainy seasons: the Long Rains (March–May) and Short Rains (there are varying definitions of the Short Rains (Nicholson, 2017), in this document we define them as October–December) (Figure 5). In comparison, temperatures are fairly uniform throughout the year for most of the region (Figure 6). The seasonal distribution of rainfall across East Africa has classically been linked to the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ). However, new research challenges the ITCZ paradigm, which assumes tropical rainfall to be mainly associated with localised convection (Nicholson, 2018). The spatial and temporal patterns of rainfall during the equatorial rainy seasons in Africa are now understood to be more complex than purely an association with localised convective activity; in East Africa, local geographical factors, regional circulation, coastal influences and remote forcing, must all be considered (Nicholson, 2017). It is acknowledged that a deeper understanding of the seasonal cycle in the equatorial regions of Africa still needs to be developed.

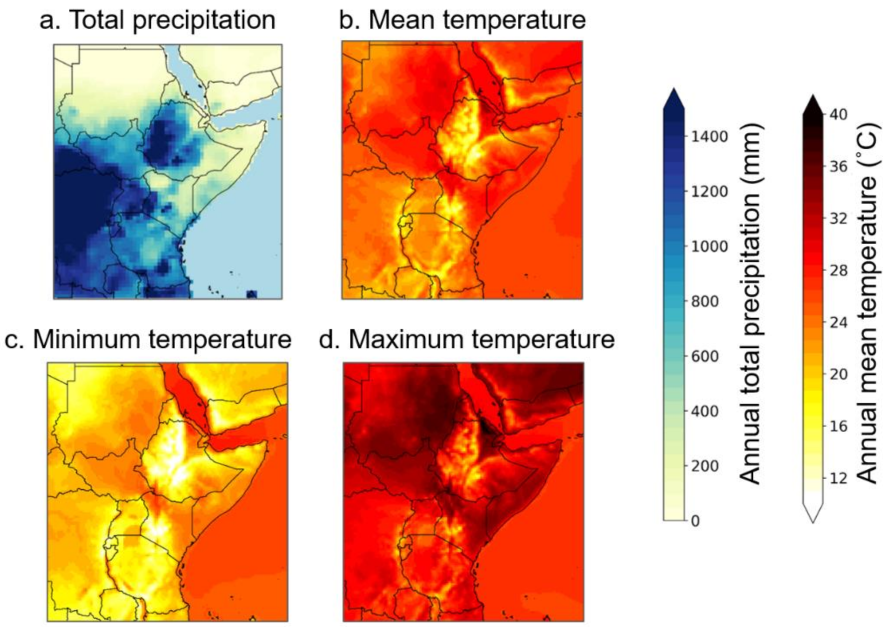


Figure 4: Baseline climate for the East Africa region for the period 1981-2010. Maps show climatological average values of annual mean a) total precipitation (mm/year), b) mean temperature (°C), c) minimum temperature (°C) and d) maximum temperature (°C). Temperature and precipitation data come from the ERA5 and WFDE5 reanalysis[3] datasets respectively.

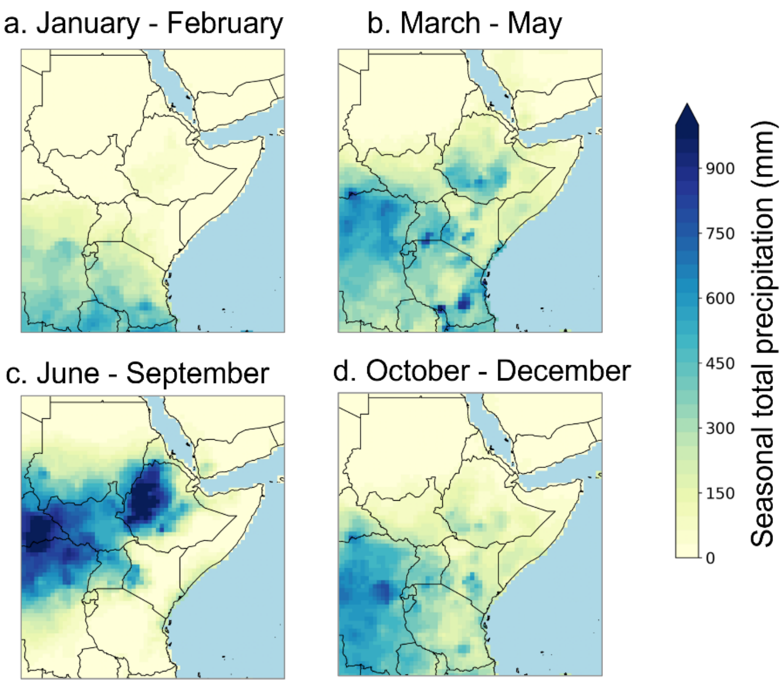


Figure 5: Seasonal total precipitation for the East Africa region over the baseline period (1981-2010) from WFDE5 reanalysis.

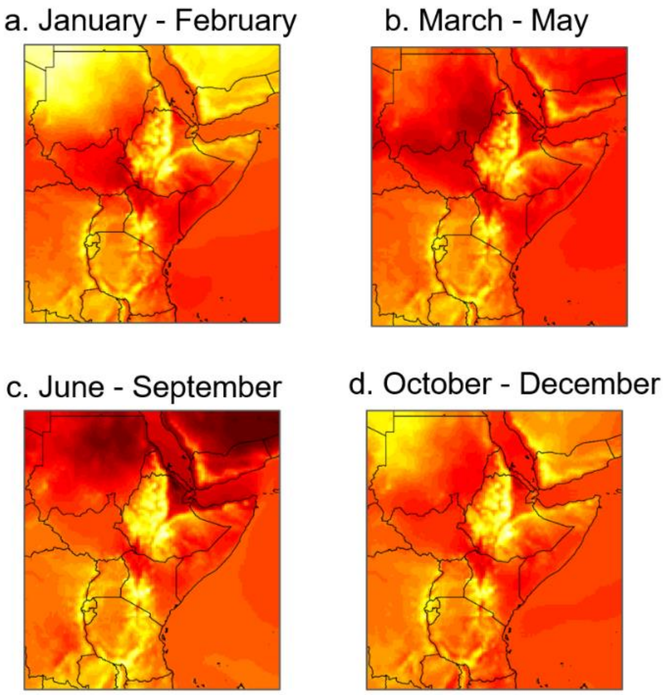


Figure 6: Seasonally averaged mean temperature for the East Africa region over the baseline period (1981-2010) from the ERA5 reanalysis.

Focus box 3: Weather, climate variability and climate change

The weather varies from day to day and season to season, with the statistics of these variations constituting the climate. These statistics are typically defined over a 30-year period. Climate change can then be characterised as the difference in these statistics between two 30-year climate periods. This will include the annual climate range through the year, from one period to another, as well as changes in the frequency, intensity and duration of extreme events, such as heavy rainfall and high temperatures.

Climate varies naturally over shorter periods of several years, and this natural variability can accentuate or dampen longer-term climate change signals. Both average conditions and the variability around that average can change and can result in increase in events that in the past were rare or extreme. It can also lead to situations where climate change increases the frequency of both heavy rainfall events and the occurrence of very dry conditions

Source: IPCC (2021)

3.1.1 Drivers of year-to-year variability

Figure 5 and Figure 6 show maps of the average values over a 30-year time period, known as a climatological mean. The actual annual and seasonal rainfall and temperature values vary from year to year, resulting in hotter, drier, cooler and wetter periods in relation to the climatological mean. This happens because the local weather is influenced by larger scale processes in the climate system that influence regional and local climate over different timescales.

East Africa experiences some of the largest interannual rainfall variations in the world and there are many different drivers of this variability (Camberlin, 2018). The main drivers and impacts on seasonal rainfall are summarised in Table 1.

Table 1: Summary of the drivers of rainfall variability in East Africa and the influence they have on seasonal rainfall. Definitions of the drivers of variability are provided in the glossary.

Season	Drivers of variability	Influence on seasonal rainfall
June – September	El Niño Southern Oscillation	An El Niño event is linked with below-average rainfall. A La Niña event is linked with above-average rainfall. (Nicholson, 2017).
October - December	El Niño Southern Oscillation	An El Niño event is linked with above-average rainfall. A La Niña event is linked with below-average rainfall. (Wolff et al., 2011; Nicholson, 2017).
	Indian Ocean Dipole (IOD)	The positive phase of the IOD is linked with above-average rainfall (Blau and Ha, 2020).
March - May	Madden-Julian Oscillation (MJO)	The relationships are more complex for the March-May season. The MJO has been linked with both above-average and below-average rainfall depending on the phase it is in, along with other influences such as the relative temperature of the tropical Pacific and Indian Oceans (Nicholson, 2017; Hogan et al., 2014, Vellinga and Milton 2018).

3.1.2 Observed climate trends

The region's current climate has already experienced 1-1.5°C of warming compared to pre-industrial times, as a result of human-induced climate change (IPCC, 2021). The frequency and intensity of hot extremes has increased and the frequency and intensity of cold extremes has decreased (IPCC, 2021).

Quantifying observed trends in precipitation is more challenging than for temperature due to the lack of reliable data and variability on multiple time and spatial scales. However, a significant decline in the Long Rains from March to May over the Horn of Africa was observed in the 1980s and 1990s (Nicholson, 2017) with a recent recovery (Wainwright et al 2019). The decline was caused by later onset and earlier cessation of the seasonal rains, rather than a decrease in daily rainfall (Wainwright et al., 2019). The decline has been linked to human-induced climate change and increases in Indian Ocean temperatures (Rowell et al., 2015), whereas the recent recovery of the seasonal rains is linked to internal variability (Wainwright et al., 2019).

Sea levels around the coast of East Africa (the Red Sea, Gulf of Aden and Indian Ocean) have been rising at a similar rate to the global mean and has rapidly increased in recent decades. For example, over the period 1900-2018 an average increase of 1.33 mm per year was observed in the Indian Ocean which increased to 3.25 mm per year from 1993-2018 (IPCC, 2021). The increase in the Indian Ocean is comparable to the global mean sea level rise. However, Semi-Enclosed Seas such as the Red Sea respond more rapidly to climate change and sea levels have risen faster than the global mean at a rate of 6.20 mm per year since 2000.

Coastal erosion has increased with sandy shorelines retreating at a rate of up to 1 m per year between 1984 – 2015 (IPCC, 2021). Sea surface temperatures (SSTs) have also increased, resulting in an increase in the occurrence of marine heatwaves (MHWs) at a rate of 0.5-2 per decade in the Horn of Africa (IPCC, 2021).

3.1.3 Summary of future projections at the regional scale

Temperature projections

Climate model projections for East Africa show high confidence for an increase in average annual temperatures. The magnitude of increase varies across climate models and is dependent on the future emissions scenario: ranging from an average of 1˚C under a low emissions scenario to an average of 2˚C under a high emissions scenario in the 2050s relative to the baseline period (1981-2010). Daily minimum and maximum temperatures are also projected to increase at roughly the same rate as the daily mean. The intensity and frequency of hot extremes is also projected to increase, whereas the intensity and frequency of cold extremes is projected to decrease (IPCC, 2021).

Precipitation projections

Projected changes in mean precipitation for East Africa for the 2050s are mixed, and there is large uncertainty in the direction and magnitude of the projected trend. Climate models from the CMIP5 and CORDEX generation of climate modelling project both increases and decreases in annual mean precipitation across the region, though with a larger number of models depicting a projected increase. This appears inconsistent with the recent drying trend in the Long Rains (Rowell et al., 2015, Wainwright et al., 2019). Research into the reasons for the paradox has not constrained the uncertainties in the future projections meaning that decreases in annual precipitation cannot be ruled out (Rowell et al., 2015). The recent CMIP6 climate model projections show better representation of the East Africa climate compared to CMIP5 (Ayugi et al., 2021) and generally project increases in mean precipitation, giving more confidence in an upward trend (IPCC, 2021).

On seasonal timescales there is high confidence in a projected increase in the June-September seasonal precipitation over the Ethiopian highlands. This is significant, as the rivers draining the north-eastern Ethiopian highlands, particularly the Blue Nile, are the dominant source of downstream main Nile flows (Conway, 2017), and the rivers originating in the south-eastern Ethiopian highlands flow into Somalia (as the Jubba and Shebelle). There is also evidence for long-term projected trends in amounts and timings for the Long and Short Rains. Earlier onset and cessation of the Long Rains is projected, with uncertain changes in seasonal totals (Dunning et al., 2018). Later onset and cessation of the Short Rains is projected, with the majority of models projecting an increase in seasonal totals (Dunning et al., 2018). However, in the 2050s natural variability will continue to be a dominant feature of the future climate of the region.

In particular, year-to-year variability in seasonal precipitation amounts and timings will continue in the future climate as the larger-scale influences continue to remain active. ENSO events are projected to become more frequent (Cai et al., 2021) resulting in increased variability compared to the baseline. Thus there is a clear signal for an increase of wetter and drier years relative to the mean despite a lack of clear signal in average precipitation. Projected changes in drought are complex and are discussed further in Focus Box 4.

Although models are very broad scale and still too coarse to adequately resolve local, convective rainfall events, the dynamics of the hydrological system mean that in a warmer world the frequency and intensity of heavy precipitation events are projected to increase (IPCC, 2021; Tabari, 2020). There is also an indication that the frequency and duration of dry spells may increase (Kendon et al 2019; Finney et al 2019).

Ocean projections

There is high confidence for sea levels to continue to rise in the Red Sea, the Gulf of Aden and the Indian Ocean by around 0.3m by the 2050s, relative to the 1995-2014 average (IPCC, 2019, 2021). Sandy shorelines are projected to retreat by 30-35m by the 2050s around the Horn of Africa (IPCC, 2021).

Sea surface temperatures are also projected to continue increasing as the climate warms, with high confidence. By the 2050s the oceans around East Africa are projected to be 1-2˚C warmer on average, with slightly larger increases in the Red Sea. As a result, MHWs are also projected to increase in frequency and intensity, and there is also high confidence for an increase in ocean acidification.

Projected increases in average wind speeds and associated precipitation of tropical cyclones will result in a higher proportion of category 4 and 5 cyclones, which already affect the southwest Indian Ocean coastline. Combined with sea level rise, storm surges are projected to increase in severity, particularly in low-lying areas.

Focus box 4: Drought in East Africa

A drought is broadly defined as a temporary period of abnormally dry weather which is long enough to cause a hydrological imbalance. This is separate from aridity, which is a permanent climatic feature associated with low levels of rainfall that lead to permanent water shortages. Droughts can be defined in several different ways (Table 1) according to their properties, and the intended use of the information. The various drought definitions indicate different approaches used to assess water availability by incorporating information about variations in rainfall and temperature. Observed changes in meteorological droughts (precipitation deficits) and hydrological droughts (streamflow deficits) are distinct from those in agricultural and ecological droughts (IPCC 2021).

Table 2: Definitions of the different types of drought (Taylor et al., 2013).

Type of drought	Definition
Meteorological drought	Reduction in precipitation relative to average values for that region
Hydrological drought	Reduction in surface and subsurface water supply
Agroecological drought	Insufficient water for plant growth. This links meteorological and hydrological droughts to the agricultural impacts of these conditions

How drought conditions are projected to change in the future is dependent on how drought is defined, but also how variables such as temperature, precipitation and evapotranspiration interact with each other. In East Africa, where there is large uncertainty in the direction and magnitude of the trend in precipitation, this is particularly challenging, especially compared to other regions where the climate signal is clearer. The IPCC AR6 report (IPCC, 2021) concludes that there are inconsistent trends in all types of drought in the East Africa region, with the exception of a reduction in meteorological drought conditions in northern East Africa at higher levels of global warming. This is likely due to the clearer signal for increasing precipitation in this region. However, the projected trends in hydrological and agroecological drought are unclear.

Despite the lack of a clear signal from future climate models, droughts have been a major feature of life for East Africa's rural poor. The last 20 years have been marked by a number of severe droughts, such as the 2002-2003 in Ethiopia, in 2005-2006 over equatorial east Africa, 2008-2010 over Sudan, northern Kenya, and the Horn of Africa, the 2010-11 in the Horn of Africa, in 2015-16 in Ethiopia, amongst others (Hastenrath et al., 2007; Nicholson, 2014; Haile et al., 2019). As this report was being drafted (November 2021), the Kenyan Government declared a disaster as successive poor rainy seasons and a locust invasion have devastated livelihoods in the arid and semi-arid lands, a crisis that ECHO has called a 'drought' in their humanitarian appeal (ECHO, 2021).

Drought appears over and over again as a key source of vulnerability across East Africa and remains a top priority for national disaster management agencies in the region. Yet there remains a tension between meteorological parameters of drought and the experience of people living in these contexts. Though a dry spell may not qualify as a meteorological drought, drought impacts are felt acutely by rural poor because factors including: deforestation, land degradation, and growing water demand due to population growth have exacerbated the consequences of variations in climate (Haile et al., 2019). While our analysis of climate models cannot credibly conclude whether meteorological drought events will become more common or not, it is clear that without stronger coping capacities, poor rainy seasons or increasingly variable precipitation are likely to continue to be *felt* as drought by East Africa's most vulnerable.

3.2 Spatial analysis zones approach

To assess the magnitude and direction of projected climate trends at a sub-regional scale it is useful to spatially aggregate gridded climate data over climatologically similar regions. As the East Africa region represents a large, meteorologically diverse area, it is also important to reflect this. Averaging the climate data by country borders is often not useful, as these do not reflect the climate and some countries may experience a range of climate types. Therefore, the region is divided into six sub-regional spatial analysis zones that reflect the different climate types.

The zones were selected using a combination of the Köppen-Geiger climate classifications (Figure 7), the baseline climatology (Figure 4), information about elevation, population density and livelihoods (Figure 1), and the Natural Earth[8] country borders (v4.1.0).

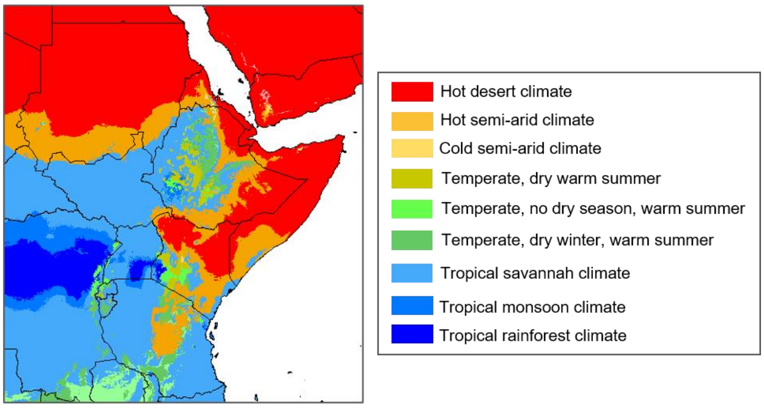


Figure 7: Köppen-Geiger climate classification map for the East Africa region, adapted from Beck et al. (2018)

The six zones used for the spatial analysis are shown in Figure 8. Zone 1 represents the desert climates in the north of Sudan and Eritrea, while Zone 4 represents the arid and semi-arid regions of the Horn of Africa. Zone 2 includes the wetter tropical regions of Sudan, South Sudan and Ethiopia, and Zone 6 includes the wetter lowlands of Tanzania. Regions with higher elevation, and therefore cooler climates, are represented by Zone 3 (the Ethiopian and Eritrean highlands) and Zone 5 (the Great Rift Valley). Table 1 relates the countries to the spatial analysis zones for reference.

[8] https://www.naturalearthdata.com/

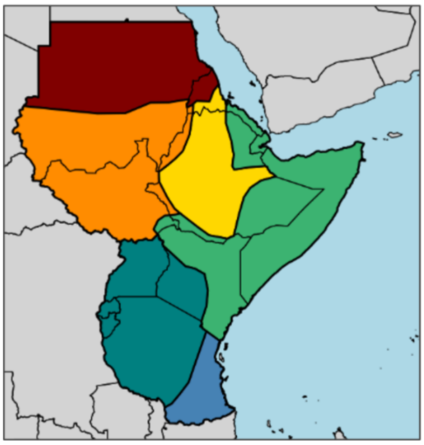


Figure 8: The six spatial analysis zones across the East Africa region

Table 3: Countries in the East Africa region and the spatial analysis zones (defined in Figure 8) that cover them

Country	**Climate analysis zones that cover the country**
Burundi	Zone 5
Djibouti	Zone 4
Eritrea	Zones 1, 3 and 4
Ethiopia	Zones 2, 3 and 4
Kenya	Zones 4 and 5
Rwanda	Zone 5
Somalia	Zone 4
South Sudan	Zones 2 and 4
Sudan	Zones 1 and 2
Tanzania	Zones 5 and 6
Uganda	Zone 5

Baseline and future climate data analysis is conducted in each of these six spatial analysis zones. Here, the baseline is the period between 1981-2010, and the future is the period 2041-2070. The analysis focuses specifically on temperature and precipitation climate variables (more detail and plots provided in Appendix B). For other relevant climate variables and metrics, such as sea level rise and sea surface temperature, information is gathered from relevant scientific literature. In the following sections, summaries of the baseline climate and future projections relevant to the socio-economic context are presented for each of the spatial analysis zones.

3.3 Baseline and future climate by zone

In this section the climate in context analysis for the baseline and future climate is presented by zone. Summaries of the findings are presented in the zone summary infographics the following two pages.

Zone summary: **Baseline climate in context**

Zone 1: Desert regions of Sudan and Eritrea

Current climate:
Hot, dry desert climate. Single rainy season from July – September, concentrated in the south.

Geographic and socio-economic context:
- Shoreline along the Red Sea
- Reliance on River Nile and groundwater as primary water source
- Livelihoods include irrigated crop production and pastoralism
- Large proportion of the population have poor access to safe drinking water and moderate to severe food insecurity

Zone 2: Tropical regions of Sudan, South Sudan and Ethiopia

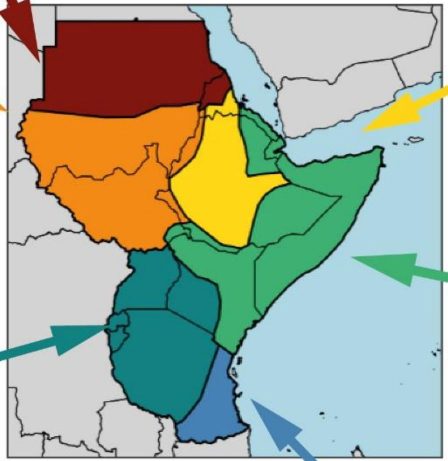
Current climate:
Mostly tropical savannah climate, with a semi-arid climate in the northern area. Hot throughout the year, with a single rainy season from March – November.

Geographic and socio-economic context:
- Blue Nile and White Nile rivers bisect this zone, with the White Nile moving through the Sudd wetlands
- Livelihoods include rainfed agriculture and agropastoralism
- Flood plain created by the White Nile provides important grazing for livestock and fertile land for agriculture
- Flooding a key risk impacting crop production, livestock rearing and spread of disease.

Zone 3: Highland regions of Ethiopia and Eritrea

Current climate:
Mostly temperate climate: cooler and wetter than other zones. Main rainy season June – September with southern part of the zone receiving two rainy seasons: February – May and October - January.

Geographic and socio-economic context:
- Small coastline with Red Sea
- Great Rift Valley and high elevation, densely populated
- Ethiopian highlands source Blue Nile that flows into Zones 1 and 2
- Livelihoods include rainfed agriculture and agropastoralism
- Key crops include cereals and coffee
- Growing pressure on arable land due to population growth



Zone 5: Highland regions of the East African Rift

Current climate:
Tropical climate with a single rainy season from September – May. Some parts (Uganda and western Kenya) have more pronounced rainy seasons within this period.

Geographic and socio-economic context:
- Densely populated and economically important areas of the region, supporting vital export crops (tea, coffee, flowers, vegetables)
- Millions of subsistence and semi-subsistence households farming increasingly small plots of land
- Rich ecosystems, including rainforests, gallery forests, savannah woodland, wetlands and aquatic habitats vital for biodiversity and livelihoods.
- Lake Victoria, bordered by Kenya, Uganda and Tanzania, is Africa's largest lake and the only outflow is the Nile River

Zone 4: Arid and semi-arid regions of the Horn of Africa

Current climate:
Hot desert climate in the north and a semi-arid climate in the south. Two key rainy seasons: March – May and October – December.

Geographic and socio-economic context:
- Long coastline with the Red Sea, Gulf of Aden and Indian Ocean
- Juba and Shabell rivers flow from the Ethiopian Highlands into southern Somalia, creating irrigated agricultural zones
- Sparsely populated compared to other zones, with higher population density in cities.
- Livelihoods include agropastoral, pastoral and nomadic pastoralism. Some fishing livelihoods around Lake Turkana (Kenya)
- Sensitive to rainy season timings and vector-borne diseases.

Zone 6: Lowland regions of Tanzania

Current climate:
Hot, tropical climate region with a single rainy season from October to May.

Geographic and socio-economic context:
- Coastline bordering the Indian Ocean
- Livelihoods include maize-mixed inland and coastal fishing, with shift to fishing in recent years
- Dar Es Salaam is the largest and most populated city in Tanzania, and home to one of the region's most important ports

Zone summary: **Future climate trends and relevant risks**

Zone 1: Desert regions of Sudan and Eritrea

Future climate trends:

- Hotter throughout the year, larger increases during hottest months and days above 40˚C more frequent
- Small increase in June-September seasonal rainfall. Higher interannual variability and more frequent and intense heavy rainfall events.
- Sea level rise in the Red Sea and rising sea surface temperatures

Relevant risks:

- Crop production and livestock impacted by heat stress, increased rainfall variability and river flow seasonality. Increased risk of locust outbreaks linked to flooding
- Water scarcity may increase due to increased interannual variability in rainfall, higher temperatures and increased demand for water
- Heat stress and dust storms, particularly in cities such as Khartoum, and increased transmission of diseases linked with flooding

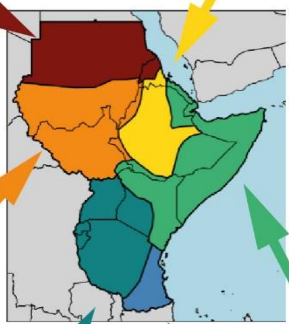
Zone 2: Tropical regions of Sudan, South Sudan and Ethiopia

Future climate trends:

- Hotter throughout the year and days above 40˚C more frequent
- Increase in annual rainfall, with the largest increases during June-September. Higher interannual rainfall variability and more frequent and intense rainfall events

Relevant risks:

- Crop production and livestock impacted by heat stress, particularly maize. Increased rainfall variability and flooding impacts crops, livestock and fishing over Sudd wetlands and along Nile.
- Water scarcity may increase due to increased interannual variability in rainfall, higher temperatures and growing demand for water
- Heat stress, particularly in cities such as Juba, and increased transmission of diseases linked with flooding.



Zone 3: Highland regions of Ethiopia and Eritrea

Future climate trends:

- Hotter throughout the year and days above 30˚C more frequent
- Increase in June-September seasonal rainfall. Higher interannual variability and more frequent and intense heavy rainfall events

Relevant risks:

- Crop production impacted by heat stress, particularly coffee and wheat, and increased rainfall variability
- Water scarcity may increase in drier years and during June when water demand is high
- Malaria transmission at higher altitudes where temperatures were previously too low
- Urban environments affected by landslides and flooding due to heavy rainfall events

Zone 4: Arid and semi-arid regions of the Horn of Africa

Future climate trends:

- Hotter throughout the year and days above 40˚C more frequent
- Increase in October-December seasonal rainfall. Higher interannual variability and more frequent and intense heavy rainfall events
- Sea level rise in the Indian Ocean, increases in intensity of coastal storms and rising sea surface temperatures

Relevant risks:

- Crop production and livestock rearing impacted by heat stress and increased rainfall variability. More drier years affecting water and pasture availability
- Increasing water stress, exacerbated by increasing dry years. Flooding risks around Lake Turkana due to increase heavy rainfall
- Heat stress, and risk of increased outbreaks of Rift Valley Fever Disease due to increased flooding and higher temperatures
- Coastal risks including flooding, increased storm surges, saline intrusion, and marine heatwaves affecting fish stocks

Zone 5: Highland regions of the East African Rift

Future climate trends:

- Hotter throughout the year and days above 30˚C more frequent
- Increase in annual rainfall, with the largest increases during October-December. Higher interannual rainfall variability and more frequent and intense heavy rainfall events

Relevant risks:

- Crop production negatively affected by heat stress, particularly maize, potato and coffee.
- Water scarcity may increase due to increased interannual rainfall variability, higher temperatures and growing demand for water. Flooding risks in the Great Lakes region due to increases in heavy rainfall.
- Urban flooding due to heavy rainfall events, particularly in cities such as Kigali

Zone 6: Lowland regions of Tanzania

Future climate trends:

- Hotter throughout the year and days above 35˚C more frequent
- Uncertain changes in rainfall: both wetter and drier futures plausible. Higher interannual variability and more frequent and intense heavy rainfall events
- Sea level rise in the Indian Ocean, increases in intensity of coastal storms and rising sea surface temperatures

Relevant risks:

- Crop production impacted by drought conditions, heat stress and increased rainfall variability
- Risk of increased outbreaks of cholera and malaria due to increased flooding and higher temperatures
- Flooding in cities such as Dar es Salaam due to heavy rainfall, and associated impacts on infrastructure and services
- Coastal risks including flooding, increased strength of tropical cyclones and marine heatwaves affecting fish stocks

3.3.1 Zone 1: Desert regions of Sudan and Eritrea

3.3.1.1 Baseline climate in context

Zone 1 is comprised of the Nile Valley and the desert regions of Sudan and Eritrea, with a shoreline along the Red Sea where Sudan's major seaport is located (Figure 8). It is a dry region with rainfall concentrated in the south, and is one of the hottest zones in the region (Figure 9). The current climate has a distinct seasonal pattern with a hot and relatively wet summer period and a cooler, drier winter period. The hottest period of the year occurs in the summer season (June – August) with daily mean temperatures between 30 °C -35 °C (Figure 8), and daily maximum temperatures consistently above 35 °C, sometimes exceeding 40 ˚C (Appendix B). The lowest temperatures occur during the winter months (December - February) with daily mean temperatures ranging between 15 °C-20 °C (Figure 8), and daily minimum temperatures ranging between 10–15 °C. There has been an observed warming trend in mean, minimum, maximum temperature over the duration of the baseline period (1981-2010).

This zone experiences a single rainy season from July – September (Figure 9). Encompassing the desert regions, this zone experiences very little rainfall in the winter months, with the vast majority of rainfall falling between June and August in the southern part of the zone, although this rarely reaches 100 mm. The northern desert landscapes are arid with too little rainfall to support settled populations, though groundwater storage (with episodic recharge via wadi flows) is considerable.

Scarce precipitation means that populations in the majority of this zone rely on the Nile or groundwater pumping as their primary water source. In the Nile Valley, home to 31.4 million people in Sudan, livelihoods depend on annual flooding, which sustains some small-scale sorghum, millet, sesame, wheat production.[9] Compared with other countries in the region, a relatively large share of cultivated land in Sudan is equipped for irrigation. Covering nearly two million hectares, this is by far the largest irrigated area in East Africa (FAO, 2018).

Pastoralists in the Northern Kordofan and Northern Darfur areas that this zone cuts through, primarily raise shoats and camels, as the dry, hot conditions are not suitable for cattle. Traditionally, these pastoralists move south into Zone 2 following patterns of rainfall, as northern pastures cannot support most herds for much of the year. Also situated in this zone is Khartoum, Sudan; one of the hottest cities in the world, with an annual mean temperature of 30 °C. Throughout the 1980s and 1990s, Khartoum underwent an economic boom driven by oil exports, but the wealth in the city was concentrated amongst an elite and over 60% of the urban population lives in poverty (Pantuliano et al., 2011). When South Sudan gained independence from Sudan in 2011, the oil producing regions of the country went with it. The loss of oil revenue has since caused an economic crisis in the country (Ille & Steel, 2021).

[9] Nile Basin Initiative: https://atlas.nilebasin.org/treatise/estimated-and-projected-total-population-in-nile-basin-countries/

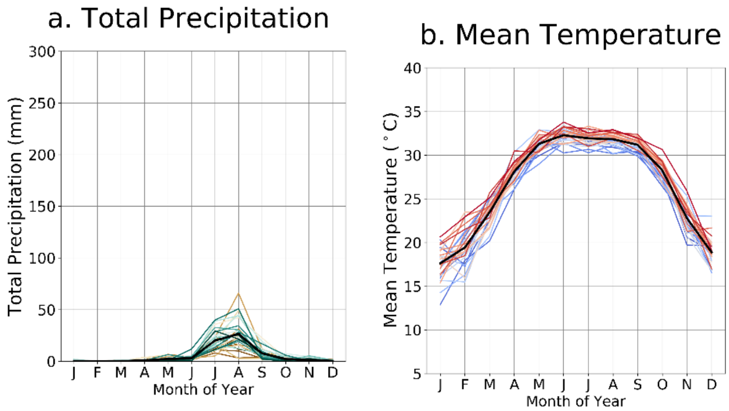


Figure 9: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 1. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period). The bold black line indicates the average of the 30-year period.

Key climate sensitivities in Zone 1 include flooding along river systems and in Khartoum, Sudan, which devastated the country in 2021; desert locust infestations stimulated by extreme rainfall events in the region; extreme heat stress; and water insecurity, especially for the 40% of the population lacking access to basic water supply in Sudan, and 48% in Eritrea (WHO/UNICEF, 2021).

3.3.1.2 Future climate projections

Climate model projections for Zone 1 show high confidence[10] in a projected increase of 2-4˚C in annual mean temperatures in the 2050s relative to the 1981-2010 baseline under a high emissions scenario (Figure 10). Temperatures are projected to increase in all months of the year, with larger increases during the hottest months of the year when average daily maximum temperatures already exceed 40˚C (Appendix B). There is uncertainty in the direction of the projected trend in annual precipitation with most climate models projecting an increase and some projecting a decrease (Figure 10). The projected changes occur during the June-September rainy season where the majority of models project a small increase (Appendix B). Very little change is projected in the other seasons.

Rising temperatures in this already hot region will increase the risk of heat-related risks, particularly in urban environments such as Khartoum due to the Urban Heat Island (UHI) effect. Heatwaves and dust storms have already increased in frequency and intensity (Mahmoud et al., 2014; Babiker, 1982); higher temperatures for longer periods in the future climate may further increase their incidence.

Higher temperatures will also exacerbate heat stress on crop production. Irrigated cotton crops fail at temperatures exceeding 35˚C and daily maximum temperatures already exceed this threshold between March and October. In the 2050s this threshold will be exceeded earlier in the year and for longer through the year. Rainfed agropastoral systems and pastoralists are particularly vulnerable to delayed onset and failure of the July-September rains as this causes scarcity of pasture and water for crop production and livestock rearing. Interannual variability of amounts and timings of the seasonal rains will remain large in the future and is projected to

[10] High confidence is assigned when the majority of models agree on the direction of change.

increase relative to the present-day, resulting in a higher frequency of wetter and drier years relative to the mean, which could further exacerbate these agricultural stresses.

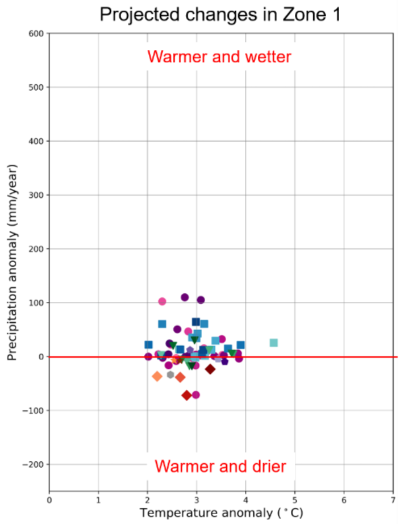


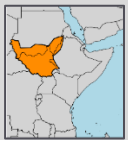
Figure 10: Projected change in average annual precipitation and temperature in Zone 1 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e. no change in precipitation. Similar plots for projected trends in seasonal means are in Appendix B.

Flooding events from heavy precipitation can result in livestock deaths and loss of agriculture, and heavy precipitation events are projected to increase in frequency and intensity. Intense rainfall events may also exacerbate flooding in urban areas, such as Khartoum (Zerboni et al, 2020), and the spread of water-borne diseases, stressing health systems. Heavy precipitation has also been linked to recent outbreaks of desert locusts which have devastated crop production in many parts of the region (Maynard et al., 2020).

Although most models project a small increase in annual precipitation in Zone 1, rising temperatures and increased evaporation rates, along with increasing interannual variability, may mean that water availability does not increase and will remain a key issue. Water supply to the irrigated areas along the Nile comes from rainfall in the Upper Nile Basin. Projected increases in annual mean rainfall and interannual precipitation variability at the source of this basin in the Ethiopian highlands (see Zone 3, Section 3.3.3) could result in the variability of Nile River streamflow increasing. Although projections show an increase in rainfall in the Upper Nile Basin, there is also a projected increase in the frequency of hot and dry years (Coffel et al., 2019), which will result in higher rates of evapotranspiration and higher water demands for crops – the main consumptive use of water. The mix of increasing demand, combined with supply variability, may therefore increase water scarcity during low flow periods and in basin hot spots of intensive use further upstream, causing ripple effects in the Lower Nile Basin (Egypt and Sudan). There is also a large interannual and interdecadal variation in rainfall in the Nile basin, which is expected to increase in future. This may result in a greater frequency of flood and drought periods affecting water availability downstream and in the wider sub-catchments and tributaries (Coffel et al. 2019) and the reliability of hydropower generation from dam storage (see Section 4). We note that projections from older models reported in the available literature show that mean precipitation may decrease and along with increased evaporation will result in declining streamflow for the Nile (Roth et al., 2018), however in this report, using more recent models, there is low confidence of a decrease in mean precipitation affecting this region.

Semi-Enclosed Seas (SESs) such as the Red Sea will respond more rapidly to climate change than other larger ocean areas and are highly vulnerable to global temperature changes, due to their small volume and land-locked nature (Abdulla et al., 2021). Sea levels in the Red Sea have been rising at a faster rate than the global mean in recent years (Abdullah et al., 2021).and are projected to continue to rise in the future (around 0.3m by the 2050s) resulting in increased coastal flooding in the coastal regions of Zone 1. High sea surface temperatures (SSTs) pose risks to coral reef fisheries in this region, and these are projected to increase in the future climate. Marine heatwaves (MHWs) have been linked to death of coral reefs, and MHWs are projected to increase in both frequency and intensity.

3.3.2 Zone 2: Tropical regions of Sudan, South Sudan and Ethiopia



3.3.2.1 Baseline climate in context

Zone 2 includes the tropical regions of Sudan, South Sudan and the Western fringes of Ethiopia (Figure 8). Most of this zone experiences a tropical savannah climate, with a semi-arid climate in the northern area. This is a hot region with daily mean temperatures of 25 °C-30 ˚C throughout the year (Figure 11) and daily maximum temperatures sometimes exceeding 40˚C during the hottest months (Appendix B). The hottest period of the year occurs during March-May with average daily maximum temperatures reaching 40 °C, followed by a second period of high daily maximum temperatures of >35 °C in September-November (Appendix B). There has been an observed warming trend in mean, minimum, maximum temperature over the duration of the baseline period (1981-2010).

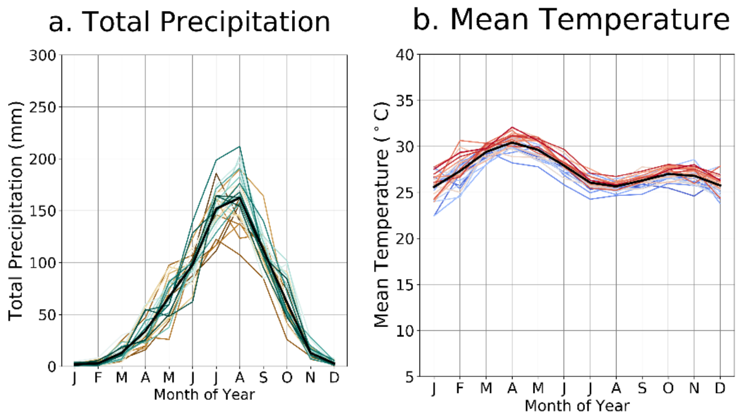


Figure 11: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 2. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period). The bold black line indicates the average of the 30-year period.

This zone has a single rainy season from March – November, and a very dry period from October-February with almost no rain (Figure 11). Precipitation experiences a much higher variability from year to year compared to temperature.

Rainfed agriculture and agropastoralism are the dominant livelihoods in this region. Maize, sorghum and millet are major staple crops. In the northwest of Zone 2, in Western Darfur, the volcanic Murrah Mountains drain enough water onto the surrounding plain to support a settled population that depends on rainfed agriculture, unlike northern or eastern Darfur where streams dry out seasonally and the land is more arid (Chapin Metz, 1991). In the southeast bordering Western Ethiopia, the savannah is arid and drought-prone, with grasslands that support pastoralism during the June – November rains. The foothills of the mountains along the South Sudan-Uganda border in the south of this zone provide relatively fertile soil, with the southwest considered an area of high potential for cereal production.

The Blue Nile and White Nile bisect this zone, with the White Nile moving through the Sudd wetlands – an expanse of lakes and lagoons. The flood plain created by the White Nile provides important grazing for livestock and fertile land for rainfed agriculture, though historic grazing areas have shrunk as the Gezira irrigation scheme has expanded and sugar plantations have been established in the White Nile State (Abdul-Jalil, 2018). Though the Gezira scheme (which sits at the southern end of Zone 1 and northern part of Zone 2) still produces about half of Sudan's agricultural output, the scheme's efficiency has deteriorated over time. This is in part due to increased sedimentation in canals due to increased erosion in the Blue Nile catchment in Ethiopia, diversion of too much water, and reduced trapping of reservoirs (Goelnitz & Al-Saidi, 2020).

Zone 2 has been the site of displacement and violent conflict, particularly in Southern Kordofan and Darfur, which did not end with the partition of Sudan into Sudan and South Sudan in 2011. Famine conditions have occurred repeatedly since 2015, attributed predominately to frequent violence across the Zone (WFP, 2021).

Key climate sensitivities in Zone 2 include extreme precipitation and extensive flooding over the Sudd wetlands, which can cut off important pastureland and damage crops, pushing households into food insecurity. Along the Nile and its tributaries, intense rains can manifest in destructive flash flood events in August and September. Major floods are sources of waterborne disease, compounding malnutrition in young children. Another major climate sensitivity is heat stress, which can reduce livestock productivity and cause crop failure, particularly for maize in mixed livelihood systems.

3.3.2.2 Future climate projections

Climate model projections for Zone 2 show high confidence for a projected increase of 1-4˚C in annual mean temperatures in the 2050s relative to the 1981-2010 baseline under a high emissions scenario (Figure 12). Temperatures are projected to increase by similar amounts in all months and seasons. Projected changes in annual precipitation are uncertain but the majority of climate models project an increase, with some projecting a decrease (Figure 12). The largest changes are projected for the summer months (June - September) where most models show an increase in precipitation compared to the baseline (Appendix B). Smaller increases are projected for the October – December season, and there is a small change projected during the March – May season but the models do not agree on the sign of change (Appendix B).

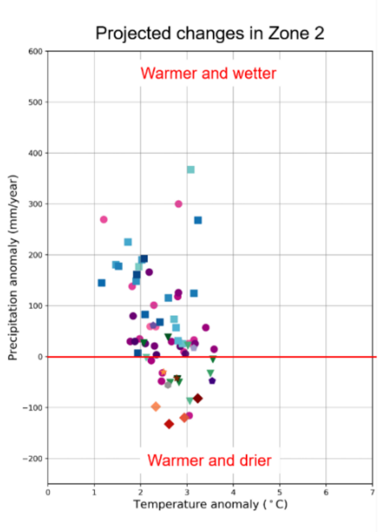


Figure 12: Projected change in average annual precipitation and temperature in Zone 2 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e. no change in precipitation. Similar plots for projected trends in seasonal means are in Appendix B.

The projected temperature increase and associated increase in hot extremes will result in more days of the year exceeding critical heat-health thresholds; temperatures above 31°C are related to increased mortality. This is important for urban areas where the UHI effect exacerbates these impacts, and particularly in Juba where populations are vulnerable and ill-equipped to adapt (Lamanna, 2019).

Higher temperatures also have the potential to negatively impact crop production, particularly for maize. Rainfed crop production is particularly vulnerable to delayed onset of the rains. Rainfall variability also affects availability of water and pasture for livestock within pastoral communities and affects their migration patterns. Interannual variability in seasonal rainfall amounts and timings is projected to increase relative to the present-day, further exacerbating these agricultural impacts.

Heavier rainfall events may also lead to crop failure and livestock death, and has also been linked with outbreaks of desert locusts. Heavy rainfall can cause flooding, and recurrent and persistent flooding is linked with a range of health impacts such as waterborne diseases, malnutrition and upper respiratory tract infections[11]. Malaria transmission is also of concern, with transmission occurring throughout the year and peaking in September – November at the end of the rainy season. Increased temperatures may increase the spatial extent of malaria transmission into the mountainous regions in the south (Mukhtar et al., 2019; see section 4.3).

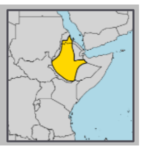
Water availability for irrigation and energy production comes from the Upper Nile Basin where projected increases in annual mean rainfall and interannual variability in the Ethiopian highlands (see Zone 3, Section 3.3.3) could result in increased variability of Nile River streamflow. Although projections show an increase in rainfall in the Upper Nile Basin, there is

11 https://www.climatelinks.org/sites/default/files/asset/document/USAID_The%20Cadmus%20Group_South%20Sudan%20Climate%20Vulnerability%20Profile%20to%20Improve%20Resilience.pdf

also a projected increase in the frequency of hot and dry years (Coffel et al., 2019), which will result in additional evapotranspiration and increased demand for water for irrigation and other livelihoods. There is also a large interannual and interdecadal variation in rainfall in the Nile basin, which is expected to increase in future. This may result in a greater frequency of flood and drought periods affecting water availability downstream and in the wider sub-catchments and tributaries (Coffel et al. 2019), though much will depend on the filling strategies for dams and their subsequent operation (Wheeler et al, 2020).

As well as impacting water availability, increasing temperatures, uncertain rainfall and changes in Nile flow rates will impact the extent and seasonal fluctuation of the Sudd wetland, which is an important source of fish and biodiversity. We note that projections from older models reported in the available literature from show that mean precipitation may decrease and along with increased evaporation will result in declining streamflow for the Nile (Roth et al., 2018), however in this report, using more recent models, there is low confidence of a decrease in mean precipitation affecting this region.

3.3.3 Zone 3: Highland regions of Ethiopia and Eritrea



3.3.3.1 Baseline climate in context

Zone 3 comprises the tropical highlands of Eritrea and Ethiopia, which are split by the Great Rift Valley, and also has a small coastline in Eritrea and the Red Sea (Figure 8). The altitude of the region results in cooler than average temperatures when compared to the other zones. Annual daily mean temperatures are around 20 ˚C with little variation throughout the year (Figure 13). The hottest period of the year is the spring season (March – May) when daily maximum temperatures sometimes exceed 30˚C (Appendix B). The coolest period occurs during November – January when daily minimum temperatures drop to around 10 ˚C (Appendix B). There has been an observed warming trend in mean, minimum, maximum temperature over the duration of the baseline period (1981-2010).

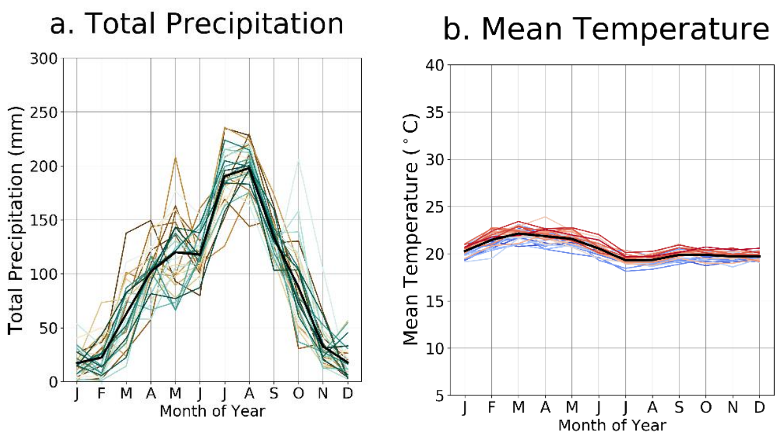


Figure 13: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 3. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period). The bold black line indicates the average of the 30-year period.

This zone is one of the wettest across the East Africa region (Figure 13). Most of Zone 3 has one main rainy season which occurs from June to mid-September in north-western parts of the zone (known as the Kiremt season in Ethiopia), and during late July to early September in northern parts of Eritrea. The southern part of Zone 3 receives two rainy seasons during February to May (known as the Belg season in Ethiopia and linked to the East African Long Rains) and October to January (known as the Bega season in Ethiopia and linked to the East African Short Rains). There is large variability in year-to-year rainfall amounts and the timing of the onset of the rainy seasons. Rainfall amounts and timings are further influenced on longer timescales by ENSO: during July-September an El Niño event results in drier conditions in Zone 3, and a La Niña results in wetter conditions[12]. The East African Long Rains that affect the southern part of Zone 3 have observed a decline in seasonal rainfall caused by delayed onset and earlier cessation of the rains rather than a reduction in daily rainfall amounts.

The rivers that originate in Ethiopia's highlands flow through deep gorges, largely in westward directions towards Zone 1 and 2. The largest of these is the Blue Nile, which accounts for two-thirds of the River Nile flow below Khartoum. Population density and population growth in the highlands means that arable land per capita is small and declining, and young rural households face particularly severe land constraints (Headley et al., 2014). Conflicts between highland farmers and lowland pastoralists and agro-pastoralists moving upland for pasture are occurring more frequently as traditional pasture lands become more fragmented, and/or are appropriated by government or private enterprises.

Five cereals (barley, maize, wheat, sorghum, and tef) account for 75% of the total area cultivated in Ethiopia and much of the production in Eritrea. The highlands are also an important area for coffee production, which remains the zone's most important export crop. Rising temperatures threaten the quality and productivity of temperature-sensitive coffee and may also expand the range of crop pests such as the coffee berry borer beetle. The agropastoral and agricultural livelihoods in the highlands are largely rainfed and production is generally sensitive to drought (Taffesse et al., 2012).

Key climate sensitivities in Zone 3 include dry spells mid-rainy season or early cessation of the rainy season, which affects Ethiopia's cereal production, intense precipitation events which lead to erosion in highland farming systems and damage agriculture, and high temperatures which surpass the maximum thresholds for highland crops, particularly key cash crops such as coffee.

3.3.3.2 Future climate projections

Climate model projections for Zone 3 show high confidence in a projected increase in average annual temperatures of 1.5-3.5˚C in the 2050s relative to the 1981-2010 baseline under a high emissions scenario (Figure 14). Similar increases are projected in each season and month. As this zone is the coolest across East Africa due to the higher elevation, future temperatures will not be as high as in other zones. However, the climatological shift in temperature does mean that the range of temperatures in the future climate will generally be higher than the range of temperatures experienced in the baseline climate (1981-2010). Future temperatures may be conducive to malaria transmission at higher altitudes where temperatures were previously too low. Optimal crop growth thresholds for important crops such as teff (Yumba et

[12]https://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/el-nino-la-nina/enso-impacts

al., 2014), and Arabica coffee (Moat et al., 2017) may also be exceeded. Wheat is also potentially affected as the increasing temperatures will shorten the growth period.

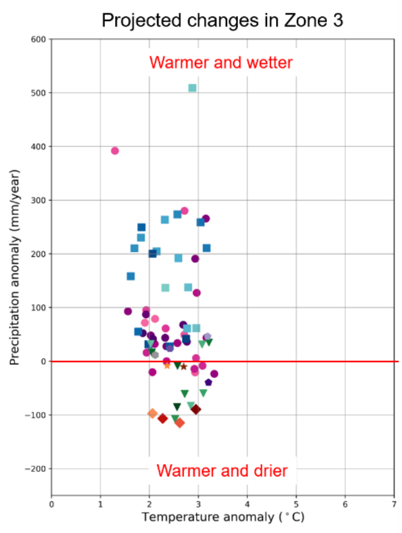


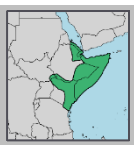
Figure 14: Projected change in average annual precipitation and temperature in Zone 3 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e. no change in precipitation. Similar plots for projected trends in seasonal means are in Appendix B.

There is uncertainty in both the direction and magnitude of projected trends in annual precipitation for Zone 3, although the majority of climate models project increasing precipitation (Figure 14). This zone receives most of its precipitation during the June-September boreal summer rains and there is medium confidence that seasonal rainfall totals are projected to increase (Appendix B; Dunning et al., 2018; IPCC, 2021). The Long and Short Rains that affect the southern part of Zone 3 will continue to be highly variable from year-to-year in amounts and timings. In the 2050s natural variability will dominate seasonal rainfall amounts and timings in this zone, and this is expected to be larger than in the current climate, resulting in a higher frequency of wetter and drier years relative to the mean. However, there are longer term climate change trends projected at longer timescales or higher levels of global warming (Dunning et al., 2018). These include a projected long-term trend for earlier onset and cessation of the Long Rains, resulting in a shorter season in some areas. Similarly, a long-term trend for later onset and cessation of the Short Rains and a potential increase in seasonal rainfall totals is projected.

Crop production in this zone is particularly vulnerable to rainfall variability, especially the delayed onset of the March-May rains and prolonged dry spells. This not only affects the production of Belg crops, but also failed Belg rains affects soil moisture and decisions around the types of crops and time of planting for the main Kiremt season. Increased variability in amounts and timings, and a potential increase in dry spell duration and frequency will further exacerbate these risks. This region is particularly prone to meteorological droughts during El Niño events and these are projected to become more severe as ENSO teleconnections strengthen in the future (IPCC, 2021; Endris et al, 2019; Rifai et al 2019). Increases in drought may increase the risk of water scarcity, particularly during June at peak consumption, and also increase the prevalence of malnutrition and stunting.

Heavy rainfall events can trigger landslides and urban flooding such as in Addis Ababa. An increase in the frequency and intensity of heavy precipitation events may further exacerbate these risks.

3.3.4 Zone 4: Arid and semi-arid regions of the Horn of Africa (Djibouti, Eritrea, Ethiopia, Somalia and Kenya)



3.3.4.1 Baseline climate in context

Zone 4 covers the arid lands of the Horn of Africa, spanning north-eastern Kenya, Somalia, eastern and north-eastern Ethiopia, Djibouti, and southern Eritrea (Figure 8). The region has a long coastline with the Red Sea in the north, the Gulf of Aden to the north-east, and the Indian Ocean to the east. This zone experiences a hot desert climate in the north (including southern parts of Eritrea, Djibouti, eastern Ethiopia and northern Somalia), and a semi-arid climate in the southern part (including southern parts of Ethiopia and Somalia, and northern/eastern Kenya). Temperatures are hot and fairly uniform throughout the year, with daily mean temperature ranging between 25 ˚C – 30 ˚C (Figure 14), and daily maximum temperature often exceeding 35 ˚C across most of the region, particularly in the north of the zone (eastern Ethiopia, southern Eritrea and Djibouti) where daily maximum temperatures exceed 40 ˚C during the summer months (Appendix B). There has been an observed warming trend in mean, minimum, maximum temperature over the duration of the baseline period (1981-2010).

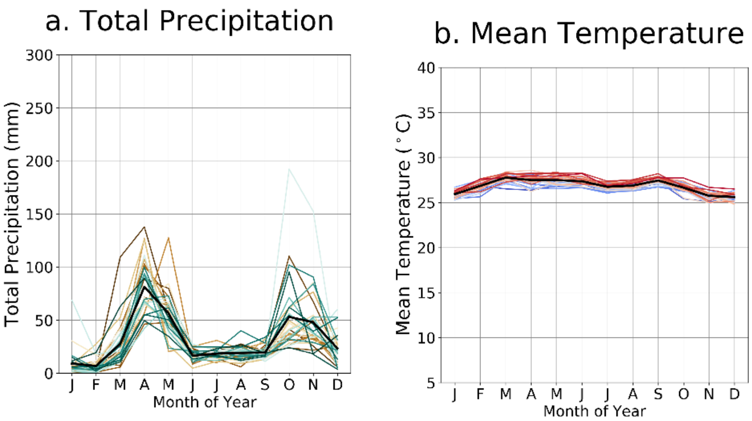


Figure 15: Observations of: a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 4. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period). The bold black line indicates the average of the 30-year period.

The zone receives rainfall in two key rainy seasons: the East African Long Rains (March – May) and the East African Short Rains (October – December). Seasonal rainfall totals are typically larger for the Long Rains than the Short Rains (Figure 15). The timing and amounts of seasonal rainfall are highly variable from year-to-year, and there has been an observed decline in rainfall during the Long Rains linked to delayed onset and early cessation (Wainwright et al. 2018). The Short Rains are influenced by ENSO which results in wetter conditions during an El Niño event[12].

The region is more sparsely populated than the neighbouring highlands and supports agropastoral and pastoral livelihoods. The Juba and Shabell rivers flow from the south-eastern Ethiopian Highlands into southern Somalia, creating the country's most productive agricultural zone. In much of the rest of the zone, rainfall is sparse, and most of the region has a semi-arid to arid environment suitable for the nomadic pastoralism practiced by a portion of the population. Bimodal seasonal rainfall supports pasture regeneration, though essential dry season grazing has been encroached on by major agricultural holdings, leaving pastoralists to focus on more marginal lands. In agro-pastoralist areas, the staple crops are primarily sorghum and millet, while khat is the primary cash crop. Food insecurity has increased in recent years, driven partially by climatic factors such as droughts and floods. For pastoralists, successive failed *Gu* rainy seasons (April – June) are devastating. Peak pasture and water availability is typically in May, and delays in the onset of rains disrupt this pattern and force pastoralists to change migration patterns.

In Kenya, the arid and semi-arid lands contain Lake Turkana, which supports fishing incomes alongside the pastoral community. The impact of hydropower dams and climate change on the Omo River, feeding the lake, are contested by the Kenyan and Ethiopian governments.

In Djibouti, over 80% of the population is urban, with most of the population living near the port that drives Djibouti's economic activity (World Bank Group, 2021). Most of Eritrea's population is concentrated in the highlands area in Zone 4, which represents only about 10% of Eritrea's landmass (Ghebru et al., 2012). Other major cities in Zone 4 include Mombasa in Kenya and Mogadishu in Somalia.

Key climate sensitivities in Zone 4 are high temperatures and heat waves, which lower livestock productivity and stress pastoral livelihoods, late onset or early cessation of the rainy seasons, which can degrade pasture and force longer and further migrations, and extreme precipitation events, which can cause catastrophic flooding along Lake Turkana or in savannah ecosystems in which desert locusts, African Rift Valley Fever, tsetse fly, or the spread of other vector-borne diseases sensitive to climatic changes and which thrive in humid environments.

3.3.4.2 Future climate projections

Climate model projections for Zone 4 show high confidence in a projected increase in average annual temperatures of 1.5-3.5˚C in the 2050s relative to the 1981-2010 baseline under a high emissions scenario (Figure 16). Temperatures are projected to increase in all months of the year (Appendix B). The range of future temperatures will be outside that experienced during the baseline period (1981-2010). Higher temperatures may cause heat stress impacts on crop production and livestock rearing in this region.

Average annual precipitation is also projected to increase in Zone 4; most climate models project an increase and there is higher consensus across the models on this direction of trend compared to the other zones (Figure 16). The projected increase in annual precipitation occurs during the Short Rains (October-December) where there is a climate change signal for an increase in precipitation by the 2050s (Appendix B; Dunning et al 2018; IPCC, 2021). Changes in seasonal rainfall totals during the Long Rains (March-May) are uncertain.

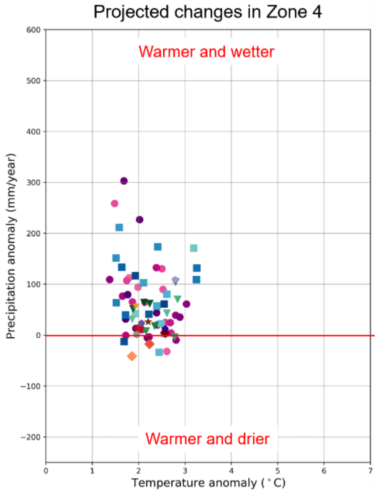


Figure 16: Projected change in average annual precipitation and temperature in Zone 4 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e. no change in precipitation. Similar plots for projected trends in seasonal means are in Appendix B.

Agropastoral and pastoral livelihoods in Zone 4 are vulnerable to drought conditions, in particular delays in the onset of the seasonal rains and interruption or dry spells during the season. This causes insufficient water for crop production and lack of water and pasture for livestock rearing (Omoyo et al., 2015; Vreiling et al., 2016). Variability in the amounts and timings of seasonal rainfall from year-to-year will continue to be a key feature of the future climate, dominating over any climate change trend. This interannual variability is also projected to increase relative to the present-day, resulting in a higher frequency of wetter and drier years relative to the mean. Heavy rainfall events are projected to increase in frequency and intensity, and there is an indication that dry spells may also increase in frequency and duration. Longer term climate model projections show a trend for earlier onset and cessation of the Long Rains and later onset and cessation of the Short Rains. This could result in a longer dry season and a change in the ratio of the seasonal rainfall amounts due to the projected increase in the Short Rains seasonal total.

This increased variability in seasonal rainfall and subsequent impacts on water availability for agricultural production will also affect incidence of malnutrition across the region. Other health related impacts include outbreaks of Rift Valley Fever Disease which are linked to widespread flooding. The frequency and intensity of heavy precipitation events that can exacerbate flood risk could result in an increase in the outbreaks of this disease. Heavier precipitation events may also increase flood risks around Lake Turkana in Kenya.

Sea levels in the Indian Ocean have been rising and are projected to continue to rise with increasing greenhouse gas concentrations (IPCC, 2021). Along with rising sea levels, wind speeds and precipitation associated with coastal storms and tropical cyclones will lead to increased storm surges (IPCC, 2021). This is particularly important for low-lying areas and coastal populations, including areas such as Somalia where coastal populations are projected to increase significantly (Neumann et al., 2015). Rising sea levels also increase the risk of saline intrusion in coastal aquifers, already a significant problem in Djibouti, exacerbated by over-pumping that draws saline water inland. Parts of Kenya are also vulnerable to saline intrusion, the impacts of which vary with the seasonal rainfall.

Marine heatwaves (MHWs) have increased in frequency in the Horn of Africa and are projected to continue to increase in both frequency and duration (IPCC, 2021). This causes severe thermal stress to coral reef fisheries in Kenya and negatively impacts availability of fish stocks.

3.3.5 Zone 5: Highland regions of the East African Rift (Uganda, Rwanda, Burundi, Kenya and Tanzania)

3.3.5.1 Baseline climate in context

Zone 5 includes all of Uganda, Rwanda and Burundi, plus the south-western highlands of Kenya and the central plateau and Great Lakes (western highland) areas of Tanzania (Figure 8). This zone experiences a largely tropical climate with a wet and dry season, influenced by the variation in topography. Zone 5 generally experiences cooler temperatures than Zones 1, 2, 4 and 6, with lower temperatures at high altitudes. Daily mean temperatures in Zone 5 are below 25 °C throughout the year (Figure 16). Daily maximum temperatures rarely exceed 35˚C due to the higher elevation, although maximum temperatures do consistently reach or exceed 30 °C from October to February during the wet season where precipitation is highest (Appendix B). There has been an observed warming trend in mean, minimum, maximum temperature over the duration of the baseline period (1981-2010), particularly during the wet season.

The majority of Zone 5 has a single rainy season (September – May), but some parts (Uganda and western Kenya) have more pronounced rainy seasons within this period (Figure 17). Western Kenya receives rainfall in March – May (MAM) and October – December (OND), and also during boreal summer June – September (JJAS). MAM is the wettest season, followed by the summer months of June - August and the Short Rains of October - December, with December-January being the driest season in the year. In Uganda the wet season is March – November with drier period from June - August. Precipitation has a much higher variability from year to year compared to temperature particularly during the wet season.

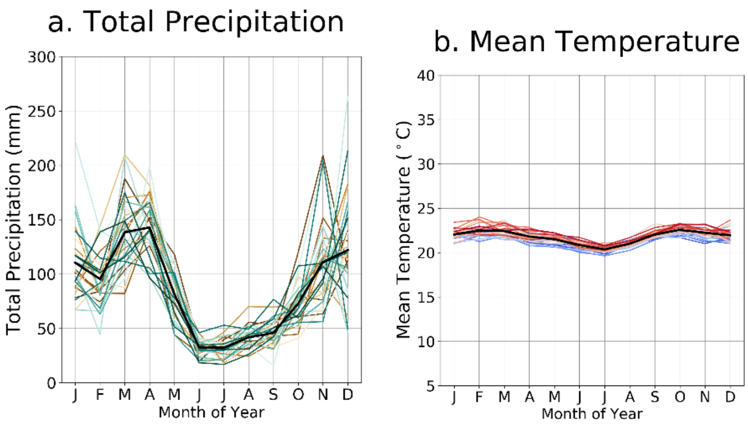


Figure 17: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 5. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period). The bold black line indicates the average of the 30-year period.

In economic and demographic terms, this zone contains some of the most densely populated and economically important areas of the region, supporting vital export crops (tea, coffee, flowers, vegetables), as well as millions of subsistence and semi-subsistence households farming increasingly small plots of land. The region also supports rich ecosystems, including rainforests, gallery forests, savannah woodland, wetlands and aquatic habitats vital for both biodiversity and livelihoods. Lake Victoria, bordered by Kenya, Uganda and Tanzania, is Africa's largest lake and the only outflow is the Nile River, exiting near Jinja in Uganda. Smaller rivers and lakes forming part of the Rift Valley system, also support agriculture, fisheries, power generation and tourism, as well as important ecological habitats.

Population pressures are increasing, with annual national growth rates of between 2.3% (Kenya) and 3.3% (Uganda). Tanzania's relatively low growth rate of 2.9% will still push its current population from 59 million (2020) to around 130 million by 2050 (World Bank, 2021). Populations are overwhelmingly rural, engaging mainly in rainfed agriculture and with limited access to safe water and sanitation, health care, education and electricity. Conservation agriculture, agro-forestry/reafforestation and the extension of basic services such as electricity, will all be important in managing risks from repeated droughts and floods, and to ease pressure on the natural resource base. Flooding in the Lake Victoria basin in 2020 displaced over 200,000 people and disrupted transportation, drinking water supply, sanitation, and power systems. Problems were particularly severe in Kenya, which has more rivers draining into the Lake Victoria and are susceptible to 'backflow' (Focus Box 8 in Section 4).

3.3.5.2 Future climate projections

There is high confidence in a projected increase in annual average temperatures of 1-3.5 ˚C in the 2050s relative to the 1981-2010 baseline under a high emissions scenario (Figure 18). There is uncertainty in the direction and magnitude of projected changes in annual precipitation, but most climate models project an increase in annual average rainfall (Figure 18).

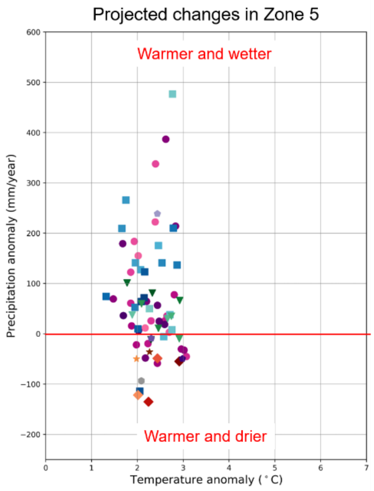


Figure 18: Projected change in average annual precipitation and temperature in Zone 5 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e. no change in precipitation. Similar plots for projected trends in seasonal means are in Appendix B.

Temperatures are projected to increase in each month of the year, and similar increases are also projected in daily minimum and daily maximum temperatures. The frequency and intensity of hot extremes is also projected to increase, which means that heatwave conditions may increase. This will exacerbate heat-health related illness and heat-related mortality, particularly for vulnerable people and in urban environments (Scott et al., 2017).

Increased temperatures may also cause heat stress impacts on maize production, potato production in Kenya and Tanzania, and coffee production. The threat of the coffee berry borer may also become a serious threat in coffee-growing regions of Ethiopia, Kenya, Uganda, Rwanda, and Burundi (Jaramillo et al., 2011). Wheat crops may also be impacted due to shortening of the growth period.

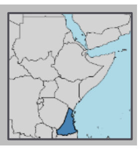
The majority of the climate models project increases in precipitation throughout the year, with the largest increases in October-December (Appendix B; Wainwright et al., 2021). In parts of the region that receive both the boreal summer and Long and Short Rains, e.g. western Kenya, the projected increase in the Short Rains suggests potential changes in seasonality so the Short Rains season (October -December) becomes wetter than the boreal summer wet season (June – September) (Wainwright et al., 2021). Interannual variability in rainfall amounts and timings will remain large in the future climate and is projected to increase relative to the present-day. This will result in a higher frequency of wetter and drier years relative to the mean. In the 2050s, natural variability in amounts and timings will dominate over any climate change signal.

Projected increases in annual mean rainfall and interannual precipitation variability could result in increased variability of Nile River streamflow. Most of the Nile's water supply comes from rainfall in the Upper Nile Basin (Ethiopia, South Sudan, Uganda). Although projections show an increase in rainfall in the Upper Nile Basin (see Zone 3, Section 3.3.3), there is also a projected increase in the frequency of hot and dry years (Coffel et al., 2019), which will result in higher rates of evapotranspiration and higher water demands for crops – the main consumptive use of water. The mix of increasing demand, combined with supply variability, may increase water scarcity during low flow periods and in basin hot spots of intensive use, despite higher regional rainfall in the Upper Nile Basin. There is also a large interannual and interdecadal variation in rainfall in the Nile basin, which is expected to increase in future. This may result in a greater frequency of flood and drought periods affecting water availability downstream and in the wider sub-catchments and tributaries (Coffel et al. 2019).

Precipitation is the largest contributor of water to Lake Victoria (80%) (Olaka *et .,*2019) and mean precipitation is projected to increase in this region, particularly during the Short Rains season. Projections show that the intensity of extreme precipitation will increase in the future, with storms projected to release extreme precipitation more in the eastern part of the lake, leading to an eastward shift of intense precipitation (Thiery et al*.,* 2016). More intense precipitation events could exacerbate current flood risks in the Great Lakes region, particularly for Lake Victoria and Lake Tanganyika. Projections from older models reported in the available literature show that mean precipitation may decrease (Thiery et al*.,* 2016), however in this report, using more recent models, there is low confidence of a decrease in precipitation in the future in this region.

Flooding risk in other parts of the region, particularly in cities such as Kigali (Mind'je et al., 2019) and Kampala (Lwasa, 2016), is also expected to increase due to the projected increase in the frequency and intensity of heavy precipitation events.

3.3.6 Zone 6: Lowland regions of Tanzania



3.3.6.1 Baseline climate in context

Zone 6 includes the lowland region of Tanzania and is comprised of the country's 1424 km coastline bordering the Indian Ocean, stretching from the southern border of Kenya in the northernmost part of the zone to the coast of Lake Malawi in the southwestern corner of the zone (Figure 8). This is a hot region with daily mean temperatures ranging between 20 ˚C - 25 ˚C (Figure 18), and maximum daily temperatures often exceeding 35 ˚C during the hottest months (March – May). The coolest part of the year is during March to August where daily minimum temperatures fall between 15 ˚C-20 ˚C (Appendix B). There has been an observed warming trend in daily mean, minimum, maximum temperature over the duration of the baseline period (1981-2010).

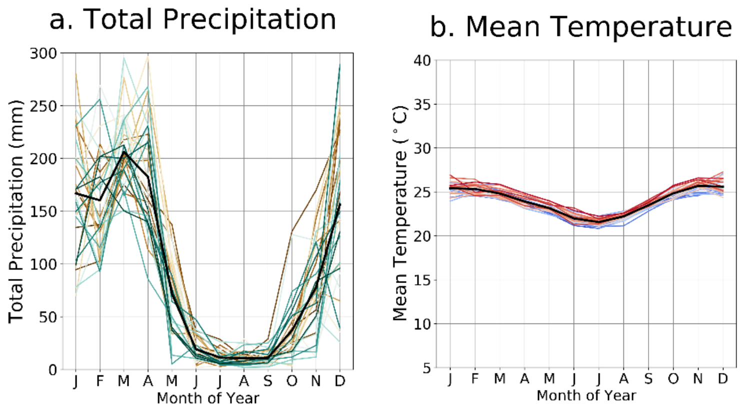


Figure 19: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 6. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period). The bold black line indicates the average of the 30-year period.

This zone experiences a tropical climate with a single rainy season from October to May (Figure 19). The northern part of Tanzania/border with Kenya also experiences some of the bimodal Long Rains/Short Rains. Precipitation has a much higher variability from year to year compared to temperature, with mean precipitation at its highest (above >200mm) in March, and at its lowest (0-50mm) during June to September. Precipitation patterns in Tanzania are highly variable, largely due to topographical variations, coastal influences, and presence of lakes.

Much of the inland, lowland areas of Zone 6 are dominated by maize-mixed livelihoods, with medium farm sizes (2.7 ha) (Blackie et al., 2020). The majority of the maize grown in the zone is not improved varieties that might be more resilient to climate stresses (Blackie et al., 2020).

Cassava is another key crop, which is relatively well adapted to high temperatures and water scarcity (Adhikari et al., 2015).

This zone is largely comprised of the hot and humid coastal belt, where Tanzania's biggest cities lie. Dar Es Salaam is by far the largest and most populated city in Tanzania, and home to one of the region's most important ports. Due to droughts and climate-induced pressures on agricultural livelihoods, people have abandoned agricultural livelihoods and migrated to the coast to take up fishing, which has resulted in a fourfold increase in the fisher population (Silas et al., 2020).

Zone 6's climate sensitivities are primarily derived from the coastal characteristics of the zone. The zone is sensitive to storms and storm surge, because most of the fishery sector is limited to shallow coastal areas and practiced by small-scale fishers (Silas et al., 2020). Heavy rainfall can cause severe flooding in Dar Es Salaam, where people living in informal housing are extremely exposed and vulnerable to flood impacts because they lack adequate sanitation and drainage infrastructure. Sea-level rise threatens coastal infrastructure and water quality in the aquifer. Because of high levels of pumping of groundwater, seawater intrusion is a significant risk to water supply in Zone 6's coastal cities.

3.3.6.2 Future climate projections

There is high confidence in a projected increase in annual average temperatures of 1-3˚C in the 2050s relative to the 1981-2010 baseline under a high emissions scenario (Figure 20). Projected changes in annual precipitation are uncertain, with models projecting both increases and decreases on annual timescales and during the rainy season months in this zone (Figure 20; Appendix B).

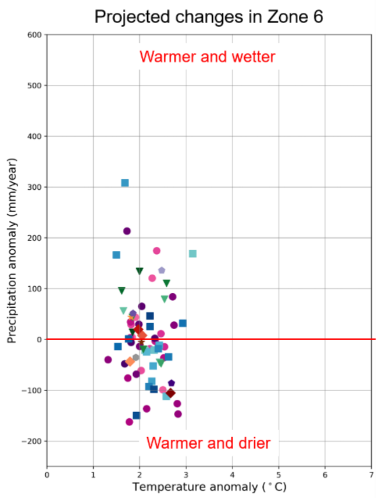


Figure 20: Projected change in average annual precipitation and temperature in Zone 6 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e. no change in precipitation. Similar plots for projected trends in seasonal means are in Appendix B.

Temperatures are projected to increase in all months of the year, and similar increases are projected in daily minimum and daily maximum temperatures. This could mean that average monthly temperatures in the 2050s may be hotter than the highest temperatures experienced in the current climate. Hot extremes are also projected to increase in frequency and intensity, leading to an increase in heatwave conditions. The UHI effect exacerbates these impacts in urban areas such as Dar es Salaam, where overnight temperatures already cause discomfort due to heat stress (Pasquini et al., 2020). Increasing temperatures may also mean that some regions are at risk of malaria transmission that were historically malaria-free, such as Tanga, Kilimanjaro and the Arusha highlands[13], and a shift in Tsetse Fly habitats to higher elevations changing the geographical risk of African Trypanosomiasis (Nnko et al., 2021).

Agricultural production is vulnerable to rainfall variability and especially drought conditions which can cause crops to fail and a shortage of pasture. Rainy season amounts and timings are currently highly variable from year-to-year and interannual variability is projected to increase in the future. This will result in there being a higher frequency of wetter years and drier years relative to the mean. In the 2050s natural variability dominates rainy season onset and amounts over any climate change signal. However, longer term trends suggest later onset and cessation of the rains resulting in a shorter season overall (Dunning et al., 2018).

Flooding due to heavy rainfall, especially during the peak of the wet season in April, causes multiple impacts in Dar es Salaam. Impacts include damage to infrastructure, transport disruption, power cuts, and direct impacts on households with poor access to drainage infrastructure. The projected increase in the frequency and intensity of heavy precipitation events may mean that flood risk will increase. Increased flooding may also increase the risk of diseases such as cholera and malaria.

In addition to heavier precipitation events, coastal inundation is also projected to increase as sea levels rise, and the strength of tropical cyclones and associated precipitation is also projected to increase (IPCC, 2021). This will further increase the risk to coastal infrastructure which is already a key issue[14].

Marine heatwaves (MHWs) have increased in frequency in the Horn of Africa and are projected to continue to increase in both frequency and duration (IPCC, 2021). This causes severe thermal stress to coral reef fisheries in Tanzania and negatively impacts availability of fish stocks. Additional impacts on fish stocks include a four-fold increase in those fishing since 1980 due to farmers moving to fishing livelihoods from agricultural livelihoods as a result of increased drought and marginalisation of farming lands (Silas et al., 2020).

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[13] https://www.climatelinks.org/sites/default/files/asset/document/20180629_USAID-ATLAS_Climate-Risk-Profile-Tanzania.pdf

[14] https://www.climatelinks.org/sites/default/files/asset/document/20180629_USAID-ATLAS_Climate-Risk-Profile-Tanzania.pdf

Image location: Rwanda

4 Climate risk impacts and interpretation for the East Africa region

This section examines some of the key climate risks identified in this analysis relevant to development themes. The themes analysed include agriculture and food security (4.1), water resources and water-dependent services (4.2), human health (4.3), urban environments and infrastructure (4.4) and fisheries and coasts (4.5).

4.1 Agriculture and food security

Summary of risks relevant to agriculture and food security

- **Agricultural production in East Africa will be severely impacted by climate change. Many livelihoods across the region are heavily dependent on agriculture and as such food security will be negatively affected, especialy for marginal rainfed farming and fragile pastoral livelihoods which are particularly vulnerable.**
- **Higher temperatures will increase water and heat stress for crops and livestock, lowering the productivity of pastoral livelihoods and negatively impacting the production of important crops such as maize, wheat, cotton, and coffee.**
- **Increased temperatures and heavy precipitation will result in the growth of pest populations, such as desert locusts which can devastate crops affecting both agricultural livelihoods and food availability across the region.**
- **Land degradation and soil erosion will be exacerbated by more intense rainfall events, posing risks to the natural resource base, agricultural productivity and subsequently food security, particularly in already degraded areas.**

4.1.1 Overview of relevant socioeconomic trends

East Africa has seen impressive economic growth over the last decade, yet structural changes in the economy have been slower to materialize. Agricultural production still accounts for around 25% of regional GDP (over 30% in Ethiopia, Somalia, Kenya and Burundi), and most farming systems are highly vulnerable to climatic shocks, as rainfed agriculture dominates farming practices (FAO, 2018; UNECA, 2020). The region hosts some of the world's most food-insecure populations; in 2020, Ethiopia, Sudan and South Sudan were among the ten countries most affected by food crises (GRFC, 2021). During times of drought or floods, agricultural production fluctuates sharply, as it did in 2016 in Ethiopia, Kenya, Uganda, Rwanda, and Somalia (UNECA, 2020). In keeping with the rest of Sub-Saharan Africa (SSA), East Africa's poor are overwhelmingly rural, making climate-resilient agriculture a key priority for addressing rural poverty (OECD, 2017).

Food insecurity is not uniform across the region and are unique to each livelihood at a sub-regional level. While the FAO describes the Horn of Africa (parts of Zones 3, 4) as "*one of the most food insecure regions in the world*", the highland perennial systems of Central Kenya, Southern Tanzania, Southwestern Ethiopia, and Rwanda, Burundi, and Southern Uganda

(Zones 3, 5) are highly productive, and make significant contributions to the food security and economic output of East Africa (Lynam, 2020).

Across the region, there are a range of farming systems: pastoral (Zone 4), agropastoral (Zones 2, 3, 4, and 5), maize mixed (Zones 2, 3, 5, 6), highland perennial (Zones 3, 5), highland mixed (Zone 3), cereal-root crop mixed (Zone 2), arid pastoral and oasis farming systems (Zones 1, 4), and large-scale irrigated farming systems along the Nile (Zone 1). In an analysis of food security potential of various livelihoods up to 2030, Dixon et al. (2020) analyse these food systems based on farm size, food crop productivity, food purchase entitlements, and prospects for change. The authors characterise pastoral and arid pastoral and oasis-based farming systems as low potential, agropastoral and highland mixed as medium potential, and highland perennial, root and tuber crop, maize mixed, and irrigated livelihood systems as high potential for food security.

The fragmentation of farms poses a serious constraint to agriculture in the region. The average cultivated area is between 1-1.5ha per household, but in some places, it is lower (Lynam, 2020). In Rwanda, the average plot size is already 0.75 ha, while in southern Ethiopia it is 0.5 ha (Ndayambaje, 2013; Lynam, 2020). In many highland areas, there are no suitable adjacent areas in which to expand cultivation, leaving only migration, livelihood diversification, or intensification to absorb population growth (Lynam, 2020). Evidence from highland perennial farming systems, where the region's tea and coffee are produced, demonstrates that farm size is critical to living above the international poverty line (Neven et al., 2009). Though these livelihood systems are considered as having high potential for household food security, the population density and significant prevalence of extreme poverty have forced many to migrate to nearby urban areas (Dixon et al., 2020). In East Africa, the rural population is projected to continue growing through 2050, making the challenge of increasing farm productivity under an uncertain climatic all the more pressing.

Conflict in the region plays a major role in food insecurity. For example, South Sudan was hit by famine in 2017 and again in 2021 has 2.5 million people living on the brink of famine yet is endowed with an area of high agroecological potential (WFP, 2021). These conflict-affected parts of Zone 2 have been called a 'bread basket', where cereal-root crop mixed livelihoods can raise maize, sorghum, millet, and livestock (Kassam et al., 2020). In times of conflict, however, farming is disrupted and pastoral mobility is restricted. Rural people are forced to flee, prioritizing their physical security over food security (Eloff, 2021). The same dynamic plays out in other conflict-affected regions of East Africa; violence is currently driving severe food insecurity in the Tigray region of Ethiopia, and conflict has been tied to food insecurity in Uganda. Focus Box 5 below looks at some of the links between conflict, displacement and environmental change.

Agropastoral livelihoods have a wide geographic spread across the region, from the semi-arid lowlands of Ethiopia's Central Highlands, the semi-arid regions of Somalia, the dry areas from central to southern Kenya, southwestern Uganda, and the central region of Tanzania. Though they are scattered through the region, agropastoral livelihoods are linked by similar vulnerabilities: high levels of poverty, exposure to pests, variability in precipitation, degraded soil fertility, and market fluctuations (Buffa et al., 2020).

Although pastoralism (predominantly found in Zone 4) is generally considered the most productive and resilient farming system available in arid regions, customary pastoral systems face significant challenges in East Africa. Forage production (and access to water) is disrupted by interannual variations in precipitation, particularly in dry years that occur during La Niña events (de Leeuw et al., 2020). In bimodal rainy systems like those of East Africa, this variability can be significantly greater than in single systems which, in turn, causes greater volatility in forage production and availability (De Leeuw and Tothill 1990).

Mobility is the natural pastoralist response to scarcity, and the key factor that makes pastoralism in East Africa resilient to climate variability. Over decades, some important dry season grazing areas in East Africa have been fragmented or appropriated by commercial farms. More often than not, development policies and approaches to land tenure have marginalised pastoralists, favouring crop-based land use at the expense of traditional pastoral livelihoods. As a result, rangelands are shrinking and livestock holdings per capita now fall far short of subsistence requirements for a large proportion of pastoralist populations (De Leeuw et al., 2020; Lind et al, 2020). This undermines the economic sustainability of pastoralism, with increasing numbers of families with insufficient animals to support a viable livelihood. Nonetheless, regional trade in livestock and meat is still economically significant (and growing) at over US$1 billion/year for the Horn of Africa (Lind et al, 2020).

At the time of drafting this report (November 2021), the Horn of Africa faces a severe food security crisis. The current struggles with drought are emblematic of the challenges that the region will face more frequently in a changing climate – not one single dramatic event, but the cumulative impact of consecutive poor rainy seasons, pest infestations and economic instability, with forecasts of a worsening crisis (OCHA, 2021). The severely food insecure have little capacity to cope, and few options to build assets and break out of poverty in economies that are fragile, stagnating and vulnerable to multiple threats.

4.1.2 Summary of relevant climate projections

There is high confidence for a projected increase in average annual temperatures of 1-4˚C in the 2050s relative to the 1981-2020 baseline, across the region and throughout the year. Daily minimum, mean, and maximum temperatures are projected to increase at approximately the same rate. As a result, hot extremes are projected to increase in frequency and intensity, whereas cold extremes will decrease in both frequency and intensity. Higher temperatures on average will result in crop heat stress, especially in the hottest parts of the region (Zones 1 and 4) where the projected increase in these already hot regions will result in critical thresholds being exceeded earlier and for longer periods throughout the year, impacting crops such as irrigated cotton in Zone 1. Other regions where average temperatures may not be as high, but optimal temperature thresholds for crops are lower, such as maize in Zone 2, teff and Arabica coffee in Zone 3, and maize and potato in Zone 5, are also at risk of the rising temperatures causing negative impact on key crops. While impacts will be broadly negative, rising temperatures (and higher levels of atmospheric CO_2) could potentially benefit some crops in some areas.

Projected changes in mean precipitation for East Africa are mixed, and there is large uncertainty in the direction and magnitude of the projected trend across the region. However, on seasonal timescales there is high confidence in a projected increase in the June-September seasonal precipitation over the Ethiopian highlands (Zone 3), and also a projected increase in the Short Rains (October – December) seasonal total. However, natural variability will continue to be a dominant feature of the future climate in the 2050s.

Variability in rainy season onset and precipitation amounts are particularly important for rainfed crop production (Zones 2, 3, 4, 5 and 6) and the availability of water and pasture for pastoral livestock rearing (Zones 1, 2, 4 and 6). These activities are particularly sensitive to delayed onset and lower than expected season totals resulting in drier than average conditions. Dry years occur as part of the natural variability in the climate system, linked with large-scale drivers such as ENSO and the IOD. Interannual variability in rainy season onset and amounts will remain high in the future climate and is also projected to increase relative to the present-day. This will mean there will be a higher frequency of wetter and drier years relative to the mean, further exacerbating current vulnerabilities to interannual rainfall variability.

Dry spells may increase in frequency and duration, and the projected increase in temperature may also increase evapotranspiration and hence crop water demand. This is particularly important in regions which are currently vulnerable to rainy season delays and deficits, such as Zones 3 and 4 where drought conditions have been more prevalent in recent years. Although rainy season amounts and timings will be dominated by natural variability in the 2050s, there is also evidence for long-term projected trends in amounts and timings for the Long and Short Rains (mainly affecting Zones 3-6). Earlier onset and cessation of the Long Rains is projected, with uncertain changes in seasonal totals (Dunning et al., 2018). Later onset and cessation of the Short Rains is projected, with the majority of models projecting an increase in seasonal totals (Dunning et al., 2018). This may result in a longer dry season between the Long and Short Rains in the future.

Irrigated crop production in the Nile Basin in Zones 1, 2 and 5 is less dependent on local rainfall variability. Projected increases in annual mean rainfall at the source of the Nile Basin (Zone 3) as well as projected increase in interannual precipitation variability could result in the variability of Nile River streamflow increasing. There is also a projected increase in the frequency of hot and dry years (Coffel et al., 2019), which will result in higher rates of evapotranspiration and higher water demands for crops – the main consumptive use of water in more intensively irrigated zones (Zones 2 and 5). Increasing variability may result in a greater frequency of flood and drought periods affecting water availability (Coffel et al. 2019). Groundwater irrigation, typically farmer-led rather than planned, is potentially more resilient to rainfall variability because of the storage groundwater aquifers offer and because recharge is strongly linked to heavy rainfall events (see Section 4.2).

The frequency and intensity of heavy precipitation events is projected to increase as the climate warms. This could increase flood risk causing livestock deaths and crop losses, and accelerate already high levels of soil erosion and land degradation across the region. Heavy precipitation has also been linked to recent outbreaks of desert locusts which have devastated crop production in Zone 1 and affected up to 2.5 million people in 2020 and a further one million in 2021 across the Horn (FAO 2021).

4.1.3 Key risks to agriculture and food security in the East Africa region

4.1.3.1 Risks of heat stress and high temperatures on livelihood systems

As temperatures creep up, heat stress will put pressure across all of the region's livelihood systems. Higher temperatures have two-pronged impacts on agriculture. Firstly, the high temperatures themselves can affect crops that reach their thermal maximum temperature, ultimately reducing yields. Secondly, high temperatures result in increased evapotranspiration and reduction of soil moisture, which increases the amount of water crops will need. The impacts of high temperatures follow similar patterns for livestock. Direct heat stress increases livestock mortality, lowers milk production and reproduction, and increases needs for water. With lower seasonal yields, households will be forced to purchase more food to meet the household food security needs. As these shocks tend to affect agriculture across the region, price volatility is likely to require households to spend a larger percentage of their income on meeting food needs.

In cotton crops (produced in Sudan in Zone 1, as well as in parts of Tanzania in Zone 5), high temperatures decrease boll maturation, reduce boll size, reduce the number of seeds per boll, reduce fiver length, and reduce cotton yield (Ton, 2011). Cotton is known to fail completely at temperatures above 35°C. In Zone 1 where cotton is dominant, temperatures are expected to peak over 40°C during the summer rainy season. Lower productivity will compromise a key source of revenue for the Sudanese economy; the commercial cotton industry in Sudan generates significant foreign exchange, worth $134 million in 2019, and represents the biggest agricultural export after livestock (OEC, 2019).

Where temperatures reach above 35°C throughout the year, maize mixed livelihoods will fare worse than cereal-root crop-based livelihoods, as sorghum and millet are more resilient to projected temperature increases and dry periods than maize (Sultan et al. 2013, Abera et al. 2018). Studies of maize growing in Gambella, Ethiopia, which comprises the western tip of Zone 2, found that heat stress is likely to be responsible for major reductions in maize yield, affecting both irrigated and rain-fed maize crops (Degife et al., 2021). In Kenya's arid and semi-arid lands, maize yields have already been lowered by increasing temperatures and high evapotranspiration (Zone 4) (Omoyo et al., 2015). Research has shown that maize yields at lower altitudes, as in Kenya and Somalia's agropastoral areas, are likely to fall by as much as 20 - 50% as conditions become warmer (Bergamaschi et al., 2004). In South Sudan's highlands where wheat is grown, it will not be resilient to climatic changes, as optimum wheat-growing temperatures fall between 15-20°C (Liu et al. 2008).

Pastoral livelihoods (dominant in Zones 2 and 4), face thermal stress under climate change, in which the reproduction rate and milk production of animals slows or stops entirely under higher temperatures. Livestock kept by pastoralists or agro-pastoralists will be affected by heat stress, particularly cattle (USAID, 2019). Higher temperatures are also likely to reduce the reproduction rate of goats, even if they are relatively more physiologically and behaviourally adapted to heat stress compared to sheep and cattle (Sejian et al., 2021). At the same time, rising temperatures and prolonged dry periods could be expected to negatively affect pasture productivity and drinking water provision for livestock.

Coffee production is dominant in the temperate highlands of Zone 3, which is an important cash crop in the region for household income. The optimum growing temperatures range from 18-23°C for arabica and 22-26°C for Robusta varieties (Adhikari et al., 2015). Coffee crops are highly sensitive to changes in climate, which can decrease the quantity and quality of coffee beans (Adane & Bewket, 2021). Currently, the majority of coffee-growing areas in Ethiopia are in the south-west and south-east, with minor production in the north. A study examining the relationship between temperature and coffee production in Ethiopia found that current coffee growing areas will cease to be suitable, but there is likely to be a substantial increase in areas suitable for coffee production in higher elevation areas, particularly in Ethiopia's south-west (Moat et al., 2017). The principal factor defining which areas will remain productive is the interaction between rainfall and temperature. Coffee producing areas that have low rainfall cannot tolerate an increase in temperature (ibid).

Bananas, the most important food crop in Uganda and Rwanda and a key crop in perennial highland farming systems, are sensitive to extended exposure to extreme temperatures (above 35°C) and low soil moisture, but are likely to withstand the stresses of increased temperatures through 2050 (Thorton & Cramer, 2012). Cassava, too, is tolerant of high temperatures. In fact, cassava thrives in areas where other crops fail, so root crop production has been considered a strategy for adapting to changing climates (Adjei-Nsiah et al., 2020). Potato, which is a major root crop in the Kenyan, Rwandan, and Tanzanian highlands, is more sensitive to climate change. Potato yield is expected to decline due to heat and water stress in most East Africa countries (Adhikari et al., 2015). In contrast to most parts of East Africa, maize may see yield gains in Kenya and Rwanda, as highland areas become more suitable to optimum maize growing temperature of 25°C (Thorton et al., 2010).

Artisanal fisheries such as those in Kenya and Tanzania are affected by marine heat waves, endangering local food security as temperatures rise (Zone 4,6). Though data at the national level show that Tanzania has relatively low per capita consumption of seafood, coastal communities have a high dependence on fisheries for food security (Cinner & Bodin, 2010). See section 4.5.3.3 for more details on climate risks to coastal fisheries.

4.1.3.2 Risks of variability of precipitation on livelihood systems

For pastoralists, such as those in Zone 1 and the Great Horn of Africa in Zone 4, rain failure during the rainy season can be catastrophic. Late onset of the rainy season and poor rainfall in the Nile Valley, leading to low River Nile levels, results in scarcity of pasture, water availability, crop production, and livestock conditions. To cope with these conditions, pastoral households' resort to migrating further, hand-feeding livestock and, when conditions are particularly poor, selling livestock and taking loans. In some parts of Sudan, pastoralists move seasonally, as the southern parts of the Kordofan region are generally too wet for livestock in the rains, while the northern areas lack forage and water in the dry season. But in future years with increasing rainfall variability, these migration patterns are likely to be insufficient, and pastoralists may be forced to go further south into Zone 2, where they may be in conflict with agricultural livelihoods.

In the Greater Horn of Africa (Zone 4), rangelands have become continuously degraded due to persistent droughts and overgrazing. With the additional pressures of late onset or poor rainy seasons, camel and cattle conception rates are likely to fall, leading to low calving, kidding, and low milk availability, all crucial for household income, food security, and children's nutrition in particular. Not only is insufficient rainfall a problem, but extreme rainfall affects forage yield, perhaps more than any other changes in the mean annual precipitation (de Leeuw et al., 2020).

Sorghum and millet are considered relatively resilient to climate change compared to other crops, though variability can severely affect production. For sorghum, early-, mid-, or late season soil water deficits are responsible for major reductions in yields (Adhikari et al., 2015). In areas that are already semi-dry zones, some areas may no longer be cultivable at all (such as in Zone 2). Combined with high temperatures, desertification may increase, particularly in the north and south-east of South Sudan (USAID, 2019). Conversely, wetland areas like the Sudd wetland may see even more intense precipitation. The majority of climate models predict an increase in summer rainfall in the future, and also the frequency and intensity of extreme precipitation events such as the floods of 2020, which resulted in flooded agricultural fields and the deaths of livestock.

For farmers in the highlands of Zone 3, poor performance of the belg rains affects crop production during the crucial windows for planting maize and sorghum, which are vital for highland mixed livelihoods, along with teff, pulses, and livestock. To adapt, farmers will increasingly need to shift to short-maturing varieties (Amede & Lemenih, 2020). In highland perennial livelihoods, where farmers rely on a mix of coffee production and enset production (a type of banana that is an important root crop), increasing population density has threatened the sustainability of systems despite relatively favourable climatic and agroecological conditions, resulting in food insecurity (see Focus Box 5).

Focus Box 5: The importance of public works programmes for coping with and mitigating risks

The highland areas of south-western Ethiopia enjoy favourable agroecological conditions for mixed farming systems but are known for high levels of food insecurity. Farm sizes have fallen below sustainable thresholds and farm productivity has stagnated. As farm sizes have shrunk, households have had to reduce livestock numbers, reducing the availability of manure critical for fertilizing enset plots. To meet immediate household income needs, some households have shifted to maize cultivation, but this has exacerbated nutrient depletion and disrupted the coffee-enset balance that underpinned farming system sustainability.

In 2000, the region ranked last in measures of food security in Ethiopia. A decade later, the index had improved. This improvement has been attributed to the Productive Safety Net Programme (PSNP), which has had a positive impact on household food security and, through its focus on land and soil management, the ability of households to build assets and strengthen long-term resilience.

Public works or public employment programmes such as the PSNP are attracting growing interest in the region because of their ability to meet immediate consumption/income needs (coping capacity) and for strengthening livelihoods over the longer term (adaptation and resilience). Beyond Ethiopia, other examples include the Tanzania Social Action Fund and Northern Uganda Social Action Fund. Since rural livelihoods are typically dependent on the natural resource base, public works often focus on land, soil and water management, usually on common land. The objective is to create a *productive* safety net, and break the link between repeated cycles of deprivation and humanitarian assistance.

Public works programmes are an expensive way of delivering social protection. Because of the administrative, capital and technical inputs required to manage land restoration, the cash transfer (wage) component typically accounts for only half their cost. Hence the justification rests heavily on their promise of future benefits and risk reduction, and the 'graduation' of households out of the safety net/humanitarian cycle.

Sources: McCord (2012); Tenzing (2019); Amede and Lemenih (2020) and ; Norton et al, (2020).

In Zones 2 and 4, more variable precipitation is also linked to a serious risk of locust outbreaks. The desert locust upsurge that started in 2018/19 foreshadows how climate risks will grow with forecasts of increasing rainfall intensity, as these conditions render desert locust upsurges more common. Though these transboundary pests are endemic to the region, populations can usually be controlled. In times when excess population growth results in swarms, as they have done in recent years, they devastate crops and pasture. This poses a major threat to agriculture and livestock sectors.

In the highland perennial, maize mixed, root and tuber crop, and agropastoral livelihoods of Zone 5, all livelihood systems (besides agropastoralism) are considered high potential for food security (Dixon et al., 2020). Still, in highland perennial systems, major cash crops will be affected by changes in rainfall intensity and timing. For instance, optimal tea-growing areas in Rwanda, Uganda, and Kenya will move to higher altitudes, mirroring climate pressures on Zone 3's coffee production. Increased variability is likely to result in increased runoff and greater flood risks, which creates undesirable conditions for tea cultivation; studies have shown that high, low, and uneven distribution of rainfall reduces yield (Jayasinghe & Kumar, 2021).

Agropastoralism is the only livelihood system in Zone 5 that is considered medium potential for food security, lower than maize mixed, root and tuber crop, and highland perennial. Zone 5's agropastoral systems are particularly vulnerable to changes in rainfall onset, as rainfall is already highly unreliable and Western and Central Tanzania are prone to droughts which affect grazing and water availability for livestock (Mkonda, 2017; Sewando et al., 2016). Conversely, excessive rainfall is associated with outbreaks of Rift Valley Fever and destruction of livestock feed (ibid). In these cases, access to irrigation and diversified sources of income will be crucial to maintaining food security as rainfall variability becomes more pronounced.

4.1.3.3 Water management and control - opportunities and risks

Water management and control is a prerequisite for increasing agricultural productivity throughout much of the semi-arid and sub-humid savannahs with strongly seasonal rainfall and high levels of inter-annual variability. Yet irrigation development remains limited, despite the potential it offers to buffer variability, improve productivity and lift farmers out of poverty. Across the 11 countries, cultivated land equipped for irrigation averages 5%. Over 50% of that land is in Sudan (FAO, 2018). Through a mix of government expenditure, foreign direct investment (FDI), donor support and farmer-led investment, the landscape is changing, with many countries in the region prioritising irrigation as a means of 'climate-proofing' and commercialising agriculture. For example, Ethiopia's Growth and Transformation Plan (GTP 11) and Climate Resilient Green Economy strategies call for an additional 400,000 ha of new irrigation; Uganda's National Irrigation Strategy aims to irrigate 1.5 million hectares within the next two decades; and the Southern African Growth Corridor of Tanzania (SAGCOT) plans to quadruple the irrigated area in its 300,000 km^2 basin, transforming southern Tanzania into a regional food exporter (Siderius et al, 2021).

While irrigation offers potential, there are also major risks. Specifically, major irrigation investments risk under-estimating not only the water management needs of agricultural production (agriculture is the major *consumptive* user of water), but also impacts upon existing water users (Woodhouse and Ganho, 2011; Calow et al, 2018; Siderius et al, 2021). The history of land deals and FDI, actively solicited by governments, indicates that the designation of rights to use land usually confers prior rights to draw water from rivers, lakes or groundwater. If water balances are estimated, they are typically based on average conditions, failing to account for low flow periods when demand for irrigation and other uses (e.g. hydropower) peaks. Hence the risk that irrigation investments, catalysed in part by climate change concerns, become 'stranded assets' during periods of water scarcity, or simply appropriate water from competing users and uses. In pastoral contexts, water infrastructure development risks encouraging long-term settlement, which can amplify livestock health problems, erosion, overgrazing, and alter livelihood patterns (Nassef & Belayhun, 2012).

Intensive water development in the Awash basin in Ethiopia illustrates some of the pitfalls of unmanaged development. The combined diversions of Merti, Matahara and Wonji sugar plantations (generating foreign currency) account for over 75% of water releases from the upstream Koka hydropower dam. The expansion of existing schemes, plus downstream investments in horticulture and floriculture, will further reduce flows. Meanwhile, rapidly growing towns such as Adama and Matahara are struggling to meet demand and deteriorating water quality is pushing costs up. At the tail end of the system, pastoralists have seen their traditional grazing lands and water sources diminish, or appropriated for irrigation (Mosello et al, 2015) - see Figure 21. Similar tensions are emerging in the Rufiji basin in Tanzania, another basin 'hot spot' where competition between irrigation, urban and hydropower users is likely to grow (Siderius et al, 2021).

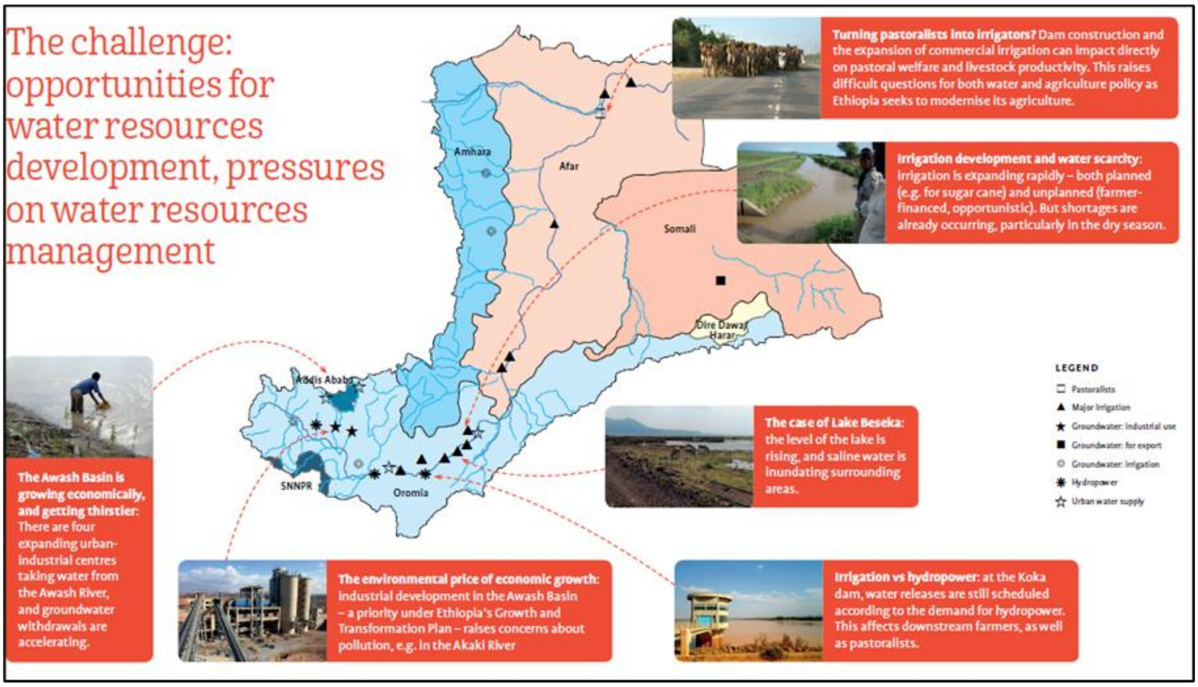

Figure 21: Unmanaged water development fuels tensions in the Awash basin, Ethiopia Source: Mosello et al. (2015).

The lesson here is that the 'success' of irrigation development, whether farmer-led and 'atomistic' or project/scheme-based, can bring unforeseen risks. Over the coming decades, new management challenges and adjustment pressures will emerge around (re)aligning supply and demand within the frontiers of environmental sustainability, balancing the claims of competing users.

More effective water management and control is not limited to irrigation, and the last decade has seen growing interest in water conservation within rainfed systems (FAO, 2020). The aim is to raise agricultural productivity by collecting or harvesting more rainwater and infiltrating it into the root zone, and increase uptake by plants via reductions in (for example) evaporative losses. Interventions include a wide range of agronomic, vegetative and physical/structural measures, often falling under the banner of 'climate-smart agriculture' (Pretty, 2018;

Rosenstock et al, 2019).[15] While such interventions are scale-neural, in that they can be applied to any size of land area or enterprise, they often form part of watershed restoration or management plans designed to generate multiple benefits at scale, including soil conservation, ecosystem protection, flood mitigation, sediment control, groundwater recharge and carbon sequestration (FAO, 2017).

Focus Box 6: Climate change and migration

The impact of climate change on the movement and distribution of people has been much debated. Globally, commonly cited articles have put the number of 'climate migrants' at 200-300 million by 2050. But repetition does not make the figures accurate. The empirical basis for this scale of displacement is thin (Gemenne, 2011; Dercon, 2012) with the emerging consensus now pointing to climate as one of many possible drivers of conflict and migration, with no simple causal chain or robust estimates (Peters et al, 2020).

What about East Africa? A rapid evidence review commissioned by FCDO (Selby and Daoust, 2021) reinforces the view that almost all forms of migration are multi-causal, and affected by complex combinations of 'push' and 'pull factors' as well as by migrant agency, aspirations and capabilities. Attribution is tricky. Climate change coincides with other transformations and hazards, many of which may be exacerbated by climate change but typically have roots elsewhere – job losses, land acquisition, land degradation, declining farm sizes, conflict and so on. Drawing mainly on studies from Tanzania, Kenya and Ethiopia, Selby and Daoust (ibid) conclude as follows:

- Evidence on the impacts of drought and short-term changes in rainfall is mixed, with some studies finding that longer, more intense droughts are associated with increased internal and international migration (Ethiopia), and another (in Tanzania) concluding otherwise.
- Very few studies look at the impact of flooding on migration and findings are inconclusive. However, there is a limited body of evidence (from rural Ethiopia) suggesting that good rains, and good harvests, tend to reduce internal labour migration.
- Adaptations to climate-related changes can both reduce migration pressures and generate the resources needed to move. Again, a mixed, context-specific picture.

A recent study in Somalia looking at the dynamic links between climate change, displacement and urbanisation draws more clear-cut conclusions. Specifically, linking climate change with environmental degradation and food insecurity, and connecting these drivers with rural-urban migration to cities such as Baidoa that receive large numbers of internally-displaced persons – IDPs (IOM/UNEP, 2021)

Overall, however, the picture is murky. Lower wealth accumulation in rural settings may hinder *large-scale* migration from marginal areas, contributing to spatial poverty traps, although conflict and drought can drive displacement. Given the pace of urbanisation in East Africa, migration *into* climate-vulnerable areas is clearly an issue, with millions of people living in informal settlements exposed to flood-related risks and other hazards linked to poor sanitation, inadequate housing and health care, and unsafe water supplies.

Sources: Gemenne (2011); Dercon (2012); Peters et al. (2020); Selby and Daoust (2021); IOM/UNEP (2021).

4.2 Water resources and water-dependent services

Summary of risks relevant to water resources and water dependant services

- **Mobilising and manging water for lives and livelihoods remains a key challenge in East Africa and will likely become more difficult as rainfall variability increases.**
- **The impacts of climate change on freshwater availability will likely be modest compared with with demand-side pressures; localised 'hot spots' of over-exploitation are likely to grow in number, particularly in and around fast-growing urban centres.**
- **Greater rainfall variability may challenge hydropower generation across East Africa, with periods of low rainfall and river flow potentially affecting multiple sites across the region with concurrent reductions in electricity production.**
- **The impacts of climate change on water quality will be broadly negative and transmitted through rising temperatures and high flow/flood-related sediment and pollution loads, posing threats to health across both urban and rural areas.**

4.2.1 Overview of relevant socioeconomic trends

The East Africa region is not short of water, at least in terms of water availability. The region has roughly 1400 m^3/capita of available water averaged across 11 countries[16], with metrics excluding large volumes of groundwater held in storage (Taylor et al, 2013; Cuthbert et al, 2019). With the exception of Sudan, all countries fall within the low or no 'water stress' categories used for monitoring Sustainable Development Goal 6.4.2.[17] However, regional and country-scale metrics conceal major problems with distribution and variability, and long-standing difficulties associated with mobilising and managing water for lives and livelihoods - difficulties that may be exacerbated by climate change.

The region's freshwater is distributed very unevenly between areas and over time. High interannual and multiannual rainfall variability results in many areas experiencing large variations year-on-year, much greater than in the temperate climates of Europe and North America (Foster and Garmendia, 2010; see also Section 3). Runoff is also very low. Coupled with high rainfall variability, this helps explain the volatility of river flows and the dependence of major lakes such as Lake Victoria on direct rainfall rather than catchment flows. It also helps explain why groundwater is so important as a source of climate-resilient storage, especially for rural water supply (Taylor et al, 2013; Calow et al, 2018; MacDonald et al, 2021).

Per capita water withdrawals are extremely low, reflecting modest levels of investment in water development, storage and distribution, and very rapid population growth. This is mainly because the big water-using sectors, particularly irrigation, remain under-developed, though developing fast (see below). For example, although water control is vital for agriculture, providing insurance against rainfall variability, only around 5% of East Africa's cultivated land is irrigated, mostly in Sudan and Ethiopia (FAO, 2018).

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[16] 2018 data from FAO Aquastat.
[17] Water stress measured as water withdrawals as a percentage of available water. FAO (2018) data.

Rainfall variability and the lack of storage and conveyance needed to smooth spatial and temporal variability has a measurable impact on growth (Brown and Lall, 2006). In Ethiopia, hydrological variability is estimated to cost the country roughly one-third of its growth potential; over the coming decades best and worst-case scenarios for climate change impacts are predicted to reduce GDP growth by 2% and 10% per year, respectively (World Bank, 2010). In Tanzania, Uganda and Ethiopia, the 2015-16 El Niño drought disrupted hydropower and led to widespread outages and economic impacts, while also contributing to environmental degradation as more trees were cut for fuel wood and charcoal. Economic and social impacts fall disproportionately on the poor: those dependent on increasingly volatile rainfed agriculture, those dependent on unsafe water and sanitation, and those exposed to more frequent floods and droughts (Foster and Garmendia, 2010; Niang et al, 2014; Calow et al, 2018).

The combination of changes in streamflow and rising temperatures is expected to have broadly negative impacts on freshwater ecosystems and water quality (Cisneros et al, 2014). Higher water temperatures encourage algal blooms and increase risks from cyanotoxins and natural organic matter in water sources. Increased runoff results in greater loads of fertilisers, animal wastes and particulates. Low flows, meanwhile, reduce the capacity of rivers to dilute, attenuate and remove pollution and sediment. Reductions in raw water quality pose risks to drinking water quality, even with conventional treatment, though the extent and nature of changes remain uncertain and very dependent on rainfall seasonality, land cover and soil management practices (*ibid*).

As the region emerges from its economic slowdown, we would expect infrastructure investment to pick up. The region has massive gaps to fill in terms of power, water supply, irrigation and flood control, as well as transport and IT (Rozenberg and Fay, 2019; Hallegatte et al, 2019). As countries seek to harness their water resources for green growth, however, new risks will emerge. In particular, we would expect to see competition for water intensifying within basin hot spots such as the Awash in Ethiopia and the Rufiji in Tanzania, as well at the rural-urban interface, driven largely by demand-side pressures.

4.2.2 Summary of relevant climate projections

Future changes to rainfall are largely uncertain, at least in terms of direction and magnitude of long-term averages. However, the majority of climate models project an increase in mean precipitation across the region. There is medium confidence for an increase in June-September precipitation in Zone 3 (Section 3.3.3) and in the Short Rains (October-December) affecting Zones 3 – 6 (Sections 3.3.3 – 3.3.6).

Interannual variability in rainy season onset and amounts will remain high across the region, and is projected to increase relative to the present-day. This will mean there will be a higher frequency of wetter and drier years relative to the mean. The frequency and intensity of heavy precipitation is projected to increase, increasing the proportion of total rainfall that falls in heavy events (Allan and Soden, 2008; Cisneros et al, 2014; IPCC, 2021). Temperatures are also expected to increase across the region, affecting evaporation and transpiration rates.

Predicting impacts on the availability, reliability and quality of water resources and water-dependent services remains challenging. This is partly because of the difficulties of downscaling climate models to the local level where planning decisions are made, but also about attribution. Untangling the climate signal from the many other drivers of change affecting water resources and services is tricky, particularly given the lack of observational data needed to establish baselines and project impacts.

Simulating projected changes in hydrological impacts is particularly challenging in this region where there is large uncertainty in the direction and magnitude of mean precipitation, and many studies do not sample the full range of projections. Much of the available literature on river basin impacts uses older generations of climate models with an emphasis on projected decreases in mean precipitation resulting in declining streamflow for the Nile (e.g. Roth et al., 2018). Our analysis, however, uses more recent climate models and concludes that there is low confidence of decreasing mean precipitation and streamflows affecting this region.

Precipitation and potential evapotranspiration are the main climatic drivers controlling freshwater resources (Cisneros et al, 2014). How changes in these variables impact water resources depends on local conditions, specifically, the relationship between evapotranspiration, soil moisture and land use change. Impacts on groundwater conditions are also difficult to predict, although a growing body of evidence highlights the importance of episodic groundwater recharge from heavy rainfall events (see below). An increase in the frequency and intensity of heavy rainfall events could therefore benefit groundwater recharge and storage.

Drawing on the above, we can conclude that heavier rainfall events will likely increase flood risk, posing threats to land, soils, plant cover and infrastructure, with potential negative impacts on water quality. As exposure to floods increases, socio-economic losses will likely increase. At the same time, more intense rainfall events could generate more groundwater recharge in environments where groundwater storage already provides a vital buffer against rainfall variability, particularly for rural water supplies.

Projected increases in annual mean rainfall and interannual precipitation variability in the Eastern Nile Basin (see Zone 3, Section 3.3.3), together with a projected increase in the frequency of hot and dry years, could result in the variability of downstream River Nile streamflow increasing. This may result in a greater frequency of flood and drought periods affecting water availability downstream (Coffel et al. 2019), the reliability of hydropower generation from dam storage (see below), irrigation potential and flows to key wetlands such as the Sudd. Rising temperatures leading to increases in evapotranspiration may mean that overall water availability does not change significantly. Drought definitions and impacts are discussed in Focus Box 4.

Greater rainfall variability also has the potential to affect the availability of water and pasture for livestock within pastoral communities. This could affect livestock holdings and migration patterns. Interannual variability in rainy season amounts and timings is projected to increase relative to the present-day, further exacerbating these impacts.

Higher intensity rainfall events may also increase flooding risks in the Great Lakes, which may exacerbate lake level fluctuations, with impacts on surrounding communities and infrastructure.

4.2.3 Key risks to water resources and water-dependent services in the East Africa region

In this section we focus on two key risks: threats to basic drinking water and sanitation services, with a focus on rural areas (threats to urban systems and services are dealt with under Section 4.3 on urban environments and infrastructure), and threats to hydropower generation. Water for agriculture (irrigation) is covered in the agriculture section above (4.1.3.3).

4.2.3.1 Risks to rural water and sanitation – basic services

Secure water and sanitation, often abbreviated to water, sanitation and hygiene (WASH), provide a first line of defence against climate change (Howard et al, 2016; Calow et al, 2018). Investments in safe water and sanitation are, by their nature, risk-reducing, since they lessen people's dependence on more climate-vulnerable, poorer quality sources (rivers, streams, ponds etc), and free up time – particularly for woman and girls – for more productive activities, as well as improving long-term health and nutrition (*ibid*). Links with income generation and food security are also well rehearsed, since water sources built for drinking water supply often serve a range of productive needs, from watering livestock and small garden irrigation, to brewing and brick making. The relationship between climate change, water security and state fragility is more complex, but a growing body of evidence suggests that carefully designed investments in water security can provide a tangible demonstration of governments' ability and willingness to meet the needs of its citizens, strengthening state legitimacy (Sadoff et al, 2017).

It follows that an initial assessment of climate risk looks firstly at how countries and regions perform in terms of extending and sustaining services. The data, at least for the former, have improved significantly over the last three decades.

For East Africa, progress differs significantly by country. As for the rest of SSA, however, some overall patterns emerge. First, rural populations are more poorly served than urban ones. Second, within both urban and rural areas, the poorest wealth groups (the bottom 40%) have the poorest services. Third, sanitation coverage lags well behind water – a significant issue in terms of contamination-linked flood risk. And finally, the region as a whole is not on-track to meet the SDG target for WASH, potentially leaving millions without access to safer, more resilient services and contributing to state fragility (World Bank, 2017; Sadoff et al, 2017; WHO/UNICEF, 2021)

Looking at the latest country data, and setting the bar low in terms of access to at least basic services[18], there are significant differences across the region. South Sudan, Ethiopia and Eritrea have the lowest levels of water and sanitation coverage and, by implication, the most exposure to climate-related (WASH) hazards. Beyond proxy indicators, the evidence linking climate change with service outcomes is thin, mainly because WASH programmes typically measure progress in terms of systems built rather than outcomes over time[19] (see ICAI, 2016).

In terms of the water resources that support services there are grounds for cautious optimism, at least in terms of water availability. In contrast to agriculture, which accounts for most water withdrawals in the region (roughly 70%, despite low investment), domestic needs are relatively modest. And in rural areas in particular, groundwater is the dominant source of supply,

[18] An improved source with collection times of less than 30 minutes
[19] In terms of access, service levels, behaviour change and sustainability.

providing over 70% of people with ‘point source’ water supplies through springs, wells and boreholes.

Groundwater has major advantages over surface water in terms of climate resilience because of the storage aquifers offer. This makes groundwater less sensitive to annual and inter-annual rainfall variability. Moreover, even if rainfall *were* to decline over areas of east Africa, intense rainfall events can still produce substantial (episodic) groundwater recharge, challenging the model-driven IPCC consensus that drying climates will decrease water resources in most dry subtropical regions (Taylor et al, 2013; Cuthbert et al, 2019; MacDonald et al, 2021). Further, countries with low recharge typically possess significant groundwater storage (Zones 1, 2 and 3), whereas countries with lower storage experience higher and more regular recharge (Zones 4, 5 and 6), supporting widespread security of supply (MacDonald et al, 2021). That said, hot spots of over-exploitation are emerging where demand is rapidly increasing, particularly in urban areas. Addis Ababa, Nairobi and Dar es salaam are all experiencing aquifer depletion, but driven by rapid population and economic growth rather than climate-related supply constraints (Oiro et al, 2020). Groundwater resources across most of SSA remain poorly characterised, with ongoing monitoring thin or non-existent (Calow et al, 2018). This makes management more difficult, including for transboundary management of shared aquifers (e.g. the Merti system between Kenya and Somalia) where cooperation remains weak (Nijsten et al, 2018).

In terms of water services and sustainability the picture is less favourable because many fail periodically or completely over time. Across SSA, anywhere between 10% and 65% of water points are ‘non-functional’ at a given time, and simple narratives have emerged to explain problems and indicate solutions, most recently focussing on climate change (Calow et al, 2017). However detailed audits in Ethiopia conducted during the 2015-16 El Niño drought (Zone 3) paint a more nuanced picture, with some sources and systems affected more than others. In particular, initial suspicions that the drought caused a widespread decline in water availability and storage affecting all commonly used technologies proved unfounded (see Focus Box 7). In-depth functionality surveys conducted in Uganda and Ethiopia indicate that many of the functionality problems experienced on rural water supply programmes are attributable to poor design, siting, construction and maintenance – problems that can be magnified by climate variability and change but are not directly caused by it (Calow et al, 2017).

Climate change is arguably more of a significant factor for water *quality* rather than quantity - specifically the link between flooding, poor sanitation and water contamination in environments where water sources are poorly constructed, and sanitation is rudimentary or non-existent. This is because floods can destroy latrines, spread faecal matter and cause widespread (and enduring) contamination of the surface environment, soils, water resources and water sources. This issue is explored in further detail under the urban environments and infrastructure (Section 4.4).

Focus Box 7: Learning lessons from the 2015-16 El Niño drought in Ethiopia

The El Niño triggered drought of 2015-16 caused one of the worst humanitarian crises in East Africa for decades, and was the worst meteorological drought recorded since 1983-84. By April 2016, the Government of Ethiopia reported that 10.2 million people across six regions needed humanitarian assistance, with around nine million people affected by acute water shortages and water-related illness.

The response of government and its partners in averting a much bigger catastrophe was broadly commended. A range of measures beyond food aid were employed - keeping schools and clinics running, and dispatching teams of engineers into the field to repair and rehabilitate water systems. Nonetheless, the drought raised questions about the viability of existing approaches and technologies for rural water supply in the face of growing climate variability.

An analysis of performance data from over 5000 water points collected during the drought - probably the largest water audit undertaken in SSA - revealed that problems were mainly confined to those areas classified as 'unserved' (i.e. dependent on rivers, streams and ponds), those areas relying on hand-dug wells and springs, and those relying on deep motorised boreholes that broke down or ran out of fuel as demand increased. In these areas, daily water collection times could reach 12 hours, with volumes collected falling to 3-5l/capita/day. Violent conflict, missed meals, reduced school attendance and lost farm activity were all reported. In contrast, shallow boreholes equipped with simple handpumps proved much more resilient – if they could be maintained.

A key lesson is that some simple technologies are resilient to climate extremes and can continue working as long as they are well built and properly maintained. Getting the basics right is key.

Sources: Calow et al, 2018; MacDonald et al, 2019; ; MacAllister et al, 2020.

4.2.3.2 Risks to hydropower: growing dependence, growing threats?

One of the biggest problems facing SSA, and East Africa in particular, is access to reliable electricity. More than two-thirds of the global population without electricity live in SSA, and although the picture varies considerably by country, large areas of central and east Africa (especially South Sudan, Burundi and Somalia) remain seriously offtrack as demand for electricity infrastructure accelerates[20] (Lakmeeharan et al, 2020). The result is not just poorer social and economic outcomes, but serious environmental degradation as rural people meet their energy needs with charcoal and firewood. Against this background, developing clean

[20] Comparing access to electricity in the region (percentage of population with access), the bottom three ranked countries are South Sudan (7%), Burundi (11%) and Somalia (36%). Access is highest in Kenya (70%), followed by Djibouti (61%) and Sudan (54%). Data (for 2019) from World Bank;s World Development Indicators database.

energy is a clear priority (Foster and Briceno-Garmendia, 2010; Rozenberg and Fay, 2019; Hallegatte et al, 2019).

In SSA as a whole, hydropower accounts for over 70% of the renewable electricity share and 15-20% of installed electricity production capacity, rising to over 90% in some countries (Ethiopia, DRC, Malawi, Mozambique, Namibia, Zambia) (Conway et al, 2017; IAH 2020). In eastern and southern Africa, areas with significant hydropower potential, capacity is set to increase rapidly. Hydropower capacity in East Africa will grow by a factor of two if all plants currently being built, or planned, are completed. Some 82% (28.78 GW) of forecast capacity is located in the Nile Basin, increasing from 62% at present (Conway et al, 2017).

Ethiopia stands out as the country developing most new hydropower, aiming to triple capacity by 2030 and increase its level of contribution to around 90% of energy production, mostly from rivers draining the Ethiopian highlands – particularly the Blue Nile[21] This level of ambition is also evident in the plans of other countries, including Uganda[22] and Tanzania (Conway et al, 2018; Figure 22). In Tanzania, a decision was taken in 2017 to proceed with the Julius Nyere Hydropower Project on the Rufiji River. Once completed, this will be the third largest hydropower dam by energy-generating capacity in Africa (Siderius et al, 2021).

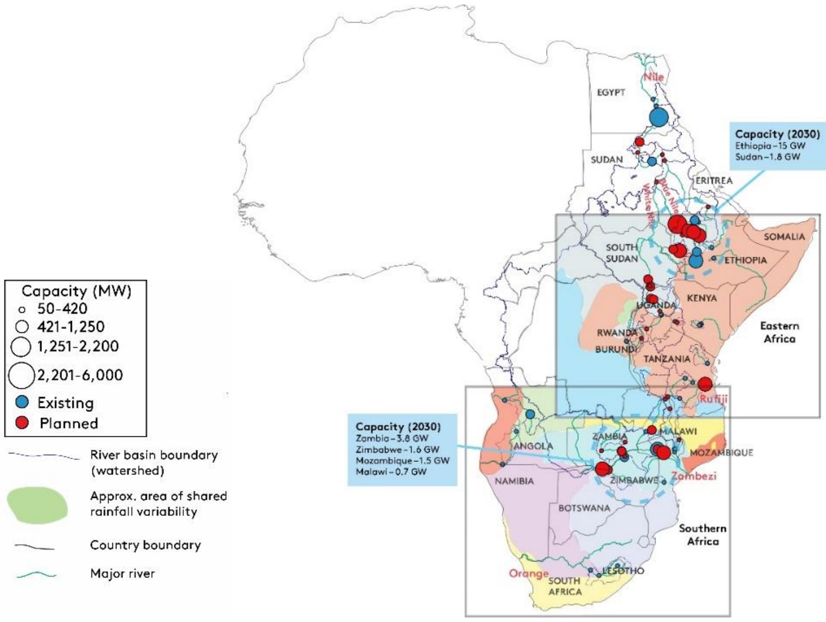

Figure 22: Rainfall zones and existing and planned hydropower capacity in eastern and southern Africa. Source:: Conway et al, 2018 adapted from Conway et al, 2017.

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[21] According to the latest (2021) IAH annual report, work is continuing on the 6350 MW Great Ethiopian Renaissance Dam (GERD), despite pressure from Egypt and Sudan to agree a legally binding agreement on the amount of water retained in the reservoir. Elsewhere, part of the Genale Dawa basin development, the 254 MW Genale-Dawa 111 multipurpose dam, connected to the grid in February 2020.

[22] In Uganda, the 600 MW Karuma hydropower project has reached 98% completion and was expected to be operational in May 2021. The government's grid development plans forecast electricity demand more than doubling by 2030, with hydropower accounting for almost 70% of the power mix.

What are the risks? Hydropower generation is clearly dependent on climate and river flows, and we know that rainfall variability *already* acts as a drag on performance. Time series data on hydropower production are scarce, and difficult to compare between sites and countries. This makes it difficult to assess the link between climate variability and energy production over time. Nonetheless, studies of specific climate events have highlighted the consequences of drought-related reductions in electricity production. In Kenya for example, a 25% reduction in hydropower in 2000 resulted in an estimated 1.5% fall in GDP. More recently, the 2015-16 El Niño drought led to widespread power disruption across SSA with outages linked to low rainfall in Tanzania[23], as well as Malawi, Zambia, Ethiopia and Zimbabwe.

In East Africa, risks are amplified by a number of other related factors. Hydropower in the region is dominated by large, irreversible schemes with a design life of at least 50 years, but the storage capacity and management regimes for most reservoir schemes are designed for historical patterns of (poorly characterised) hydrological variability. This poses significant risks to performance (Sridharan et al, 2019; Siderius et al, 2021). Yet with projected increases in the interannual and multiannual variability[24] of Nile River flows for the 21st Century, maintaining reliable power production from reservoirs would require major increases in storage capacity (Siam and Eltahir, 2017). Focussing on the Grand Ethiopian Renaissance Dam, Wheeler et al (2020) highlight the importance of regional cooperation on dam filling strategies and ongoing contingency planning to deal with multi-year droughts. Guidelines that incorporate climate change into infrastructure planning are emerging (Ray and Brown, 2015; Watkiss et al, 2020) but are not widely used.

Large schemes are concentrated in areas of similar rainfall variability and in linked river basins, creating spatial interdependencies (Figure 22). If all hydropower plants underway or proposed by 2030 are built, 70% of generating capacity in eastern Africa will be dependent on areas with similar rainfall patterns, concentrating risk of concurrent low flows and power disruption (Conway et al, 2017). Hence risk sharing and trading arrangements between countries, e.g. through the East African Power Pool (EAPP)[25] may do little to mitigate risk within a climatically similar region. Power sharing across regions and power pools, and diversifying the power mix with solar, thermal and wind, would go some way to mitigating climate risk (Conway, 2017; Siderius, 2021).[26]

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[23] In Tanzania, hydro-electricity generation fell to 20% of installed capacity as low rainfall and water levels made it difficult for turbines to operate (BBC News, 2015).

[24] In basins such as the Nile, responses to changes in rainfall intensity are dampened by the large size of the basin. Key are therefore changes in interannual to multiannual variability (Siderius et al, 2021).

[25] The EAPP currently includes 11 countries: Rwanda, Djibouti, Tanzania, Kenya, Burundi, Uganda, Sudan, Ethiopia, Egypt and Libya and DRC. According to the EAPP website, Eritrea, South Sudan and Somalia may join in future. Currently, most trade in the EAPP is bilateral and there is no fully inter-connected power grid.

[26] Concerns about an over-reliance on climate-sensitive hydropower have led to policy shifts in some countries and efforts to diversify supply. In Tanzania, for example, there are plans to invest in natural gas. Kenya has invested in a mixed portfolio of projects, including geothermal, thermal, In kenya,

Finally, we note the tendency across SSA to prioritise isolated investments in big water-dependent infrastructure (especially hydropower and irrigation) without considering broader governance issues around basin management under a changing climate. For hydropower, that means working out how river flows can be managed within and across years for a range of competing uses in ways that maintain power generation, but also protect downstream users and uses, including ecosystems (Moran et al, 2018).

4.3 Health

Summary of risks relevant to health

- **Changing rainfall patterns and rising temperatures will affect the geographic range and incidence of vector-borne diseases, increasing incidence of malaria in highland areas that are currently not suitable for transmission, and increased Rift Valley Fever.**
- **Increasing temperature extremes will result in more days of the year exceeding critical heat-health thresholds; temperatures above 31°C are related to increased mortality and risks of non-communicable diseases which disproportionately affect children, the elderly, migrant workers, and those working outdoors.**
- **Higher temperatures are known to impact the nutritional value of crops which is associated with lower nutritional status for children, increasing the disease burden as the under-18 population is projected to increase considerably.**
- **More flood events that contaminate water sources and longer stretches of higher temperatures that facilitate bacterial growth increase the likely incidence of diarrheal and other water-related diseases.**

4.3.1 Overview of relevant socioeconomic trends

The pressures brought on by climate change are likely to slow progress made through rising socioeconomic conditions. East Africa has seen steady increases in life expectancy since the 1960s, today boasting the second-highest life expectancy rate on the continent at nearly 80 years of age (AfDB, 2013). There have also been major gains in child survival, with East Africa expected to see some of the largest reductions in child mortality, primarily driven by the declining impact of HIV/AIDS through increased provision of ARVs (ibid). In Ethiopia, Eritrea, Kenya, Sudan, Uganda, Rwanda, and Burundi, health spending has increased in the last 15 years, bringing with it progress in reducing neonatal, infant, and under-five deaths (Bein et al., 2017).

Despite significant health progress, the population of East African countries are vulnerable to preventable deaths from childbirth, malnutrition, and infectious diseases such as malaria and tuberculosis. By 2030, however, non-communicable diseases are projected to overtake communicable, neonatal, and maternal mortality as the leading causes of death in Sub-Saharan Africa (Kraef et al., 2020). In low-income countries in particular, health systems are not currently well-equipped to manage the transition to a larger burden of non-communicable diseases (Siddharthan et al., 2015). Urbanization may exacerbate these challenges, as the environmental conditions in East Africa's rapidly growing urban slums, such as poor air quality, stressful conditions, access to lower quality foods and water, are associated with poor health status of people living there (Gulis et al., 2004).

4.3.2 Summary of relevant climate projections

Climate model projections show high confidence in a projected increase of between 1-4 ˚C across the region in annual mean temperatures in the 2050s relative to the 1981-2010 baseline. Climate projections show a strong and consistent signal for further warming, with the greatest temperature increases during the hottest periods of the year. High temperatures are already a significant issue in this region, particularly during the summer months, with daily maximum temperatures already exceeding 40°C during May-September (Zones 1,2 and 4). Given the physiological limits of humans to withstand extreme heat, heat stress and even the basic habitability of some regions are a factor (Raymond et al., 2020).

While high temperatures and heat stress are a risk throughout the region, in urban areas the impacts are exacerbated by the urban setting itself. High daytime maximums affect the amount of time that can be spent in productive work, but overnight minimums are important for the body's ability to cool down, and so also have a critical relationship with overall mortality and morbidity. In urban areas, the large thermal mass of buildings reduces the diurnal range by trapping daytime heat and releasing it slowly overnight. This urban heat island effect means that cities are often 2-3˚C warmer than the surrounding area. In coastal cities, higher humidity, associated with proximity to the sea rather than climate change, is an important climatic factor. The climatological shift in temperature means that the range of future temperatures in the future climate will generally be higher than the range of temperatures experienced in the baseline climate. Future temperatures may be conducive to malaria transmission at higher altitudes where temperatures were too low previously (Zone 3 and 6). As temperatures increase, malaria is projected to occur in higher altitudes (above 2000m) where temperatures were previously too low to support malaria transmission.

Future changes to rainfall are more uncertain than the projected increases in temperature. However, combined with increases in temperature, water availability and quality is another consistent risk across the region. Rainfall events are projected to be more intense in the future, rising flood risks, especially in urban environments (see also Section 4.4) which could exacerbate the spread of water-and vector borne diseases such as cholera and malaria, and cause damage to the healthcare system (Zone 1,2,4 and 6). Interannual variability in rainy season amounts and timings is projected to increase relative to the present-day, further exacerbating these impacts. Projected increases during OND (Zone 5) could have a large impact on malaria transmission with peaks towards the end of the rainy season from September to November.

Another feature of the region's climate that is important for air quality with impacts on health is dust storm events known locally as 'haboob' (Zone 1). There is little direct evidence on these events, particularly as little is known about how winds may change in the future. However, as with extreme rainfall, there is good indirect evidence to indicate that dust storms could be more frequent in the future as they are linked with high temperatures which are projected to increase. With increasing evapotranspiration and increasing variability in seasonal rainfall resulting in more drier years which may increase the occurrence of dust sources that cause dust storm events, contributing to the poor air quality in many of the cities in East Africa.

Variability in seasonal rainfall amounts and timings is projected to increase, along with a potential increase in the frequency and duration of dry spells. Longer term climate model projections show a trend for earlier onset and cessation of the and later onset and cessation of the Short Rains. This could result in a longer dry season and a change in the ratio of the seasonal rainfall amounts due to the projected increase in the Short Rains seasonal total. This increased variability in seasonal rainfall and subsequent impacts on water availability for agricultural production will also affect incidence of malnutrition across the region (see Section 4.1 and Focus Box 4).

4.3.3 Key risks for health services in the East Africa region

4.3.3.1 *Increased risks of communicable disease and shifts in transmission patterns*

Some of climate changes' most devastating impacts will play out through human health, and many of these health burdens fall disproportionately on children. As Africa's under-18 population is projected to increase by two-thirds from 2015 levels by 2050, increases in morbidity amongst children is likely to add significant pressure on national health systems (UNICEF, 2014). In East Africa's drought-prone, arid lands, malnutrition already poses serious health risks to children. Higher ambient temperatures in Sub-Saharan Africa are linked to lower nutritional status in both the short term and the long term; in the short term, high temperatures may reduce a child's ability to absorb nutrients through appetite loss, increased dehydration, or increased diarrhoea, all of which could contribute to weight loss. In the longer term, higher temperatures during growing seasons could reduce total agricultural yields. A study which isolated these effects found large effects of temperature on rural children's weight-for-height in the growing season, especially in maize and wheat-producing areas in SSA (Baker & Antilla-Hughes, 2020). In Somalia, areas of Zone 4 with lower vegetation cover due to drought were correlated with higher rates of malnutrition.

Across East Africa, precipitation is projected to become more variable, with more intense periods of rainfall and longer dry spells at the start of and interrupting the rainy seasons. More intense rainfall will lead to localized flooding events, in East Africa's cities, wetlands, and settlements adjacent to major river systems. Floods may contaminate drinking water sources, causing excess cases of diarrhoea. Across all age groups, diarrheal diseases were in the top five leading causes of mortality in Ethiopia, Eritrea, Somalia, Burundi, Djibouti, Uganda, and South Sudan in 2019. As temperatures rise, this disease burden is likely to get worse; common bacterial pathogens associated with diarrhoea replicate more rapidly and survive longer in higher ambient temperatures (Carlton et al, 2016). These risks spike seasonally; in the highlands of Northwest Ethiopia, the highest risk periods for childhood diarrhoea were towards the end of the dry season and at the commencement of rains (Azage et al., 2017). This coincides with the hottest point in the year when bacteria that cause infectious diarrhoea tend to multiply under higher temperatures, and when the first rains wash accumulated faecal matter into poorly built or unprotected water points (ibid).

Counter-measures to anticipate these windows of diarrhoeal illness will need to grapple with climate projections for a hotter and wetter Zone 3, which could come with more intense flood events or longer stretches of high temperatures that facilitate bacterial growth. Access to improved sanitation and clean drinking water facilities is a critical mediating factor for protecting against childhood diarrheal diseases and should be prioritised as a key climate adaptation.

In East Africa, with its varied topography, research points to an increased geographic spread of malaria epidemics in highland areas that are currently not suitable for malaria transmission (Zones 2, 3, 5). Disease behaviour is already shifting with changes in the local climate, and this can be expected to worsen as temperatures rise. Malaria transmission peaks at 25°C and declines above 28°C (Lunde et al., 2013). Though in many places in East Africa, malaria transmission is perennial, it often intensifies towards the end of the rainy seasons when freshwater pools support mosquito breeding. A study of the effect of temperature and precipitation on malaria transmission in South Sudan found that daily rainfall of about 20mm and warmer temperatures played a significant role in aggravating the spread of the disease (Mukhtar et al., 2019). Malaria transmission is common in the shores of Lake Victoria, as well as in the highlands of Kenya, Uganda, and Tanzania (Zone 5), and is likely to worsen with greater rainfall intensity and higher temperatures.

As with malarial outbreaks, Rift Valley Fever (RVF) epidemics are linked to altered rainfall patterns, particularly when there is widespread flooding that facilitates the hatching of infected mosquito eggs. In East Africa, RVF is concentrated in Zone 4's arid and semi-arid areas where pastoralists live (Muga et al., 2021). RVF can be devastating for pastoral livelihoods, affecting both their health and the health of their livestock. In previous outbreaks, a few weeks after major floods, sheep and goats in begin to get sick and die. Roughly two weeks after livestock are affected, humans began falling ill, causing fatalities (ibid). As flood events become more common in semi-arid areas, this analysis suggests that RVF will pose a more serious risk to poor and marginalized populations without access to adequate health services.

Predicted rises in temperature are expected to affect the patterns of the Tsetse fly, which is the primary vector for African Trypanosomiasis, a disease that is fatal to livestock and humans if not treated. Currently, the tsetse fly occurs in rangeland savannah ecosystems, particularly affecting cereal-root crop mixed farming systems, such as those of Zone 2. Tsetse flies are sensitive to high temperatures, however, and current lowland areas that are suitable for their reproduction are projected to shrink considerably (Nnko et al., 2021). Conversely, highland areas that are not currently suitable for the Tsetse fly are likely to grapple with African Trypanosomiasis by 2050, as warming forces Tsetse fly out of former habitats in savannah areas (Nnko et al., 2021). One such example is the Kisumu area in the Rift Valley and north along the Kenyan/Ugandan border, which has shown a decrease in tsetse abundance likely due to warmer temperatures and lower rainfall (Moore & Messina, 2010). Conversely, highland areas that are likely to receive more precipitation will see tsetse flies shifting into these habitats, as higher rainfall enables the vegetation and humidity for the tsetse fly to thrive.

Besides changing patterns of disease transmission, an increase in extreme weather events will affect access to health care services as households are temporarily displaced by floods or forced to migrate out in search of pasture, water, or income under severe drought conditions. As it stands, the Horn of Africa (Zone 4) is already affected periodic displacement, though the relationship between climate stress and migration is complex (see Focus Box 6 above).

4.3.3.2 Increased risks of non-communicable diseases

As temperatures rise, and days of extreme temperature become more common, heat stress is likely to worsen. This effect is more pronounced in cities due to the Urban Heat Island (UHI) effect, but the temperatures in rural areas of the Horn of Africa, Sudan, and various arid lowlands in the region are already reaching the upper limits of human habitability (Zone 1, 5). The risks from heat stress are particularly pronounced for children, the elderly, migrant workers, as well as those working outdoors, particularly in agriculture, construction, utility workers, refuse collectors, and the informal sector (Modenese & Korpinen, 2018). Beyond direct effects of high temperatures in causing heat strokes, high temperatures are linked to a range of other health issues. High temperatures can exacerbate cardiovascular disease, stroke, renal diseases, neurodegenerative diseases, and type-2 diabetes (Cook et al., 2011; Cosselman et al., 2015; Barraclough et al., 2017; Killin et al., 2016). Without targeted adaptation strategies to help vulnerable workers, children, and the elderly limit their exposure to extreme temperatures, the burden these health issues pose in urban populations will be further compounded as extreme weather conditions increase.

In East Africa, published evidence linking climate change with non-communicable diseases (NCDs) is thin. Environmental risk factors are known to exacerbate disability and deaths related to NCDs and these are increasingly known to be 'climate-sensitive' (i.e. symptoms can be exacerbated by temperature or precipitation changes) (Rother, 2020). Currently, air pollution is the second-greatest environmental factor contributing to NCDs death globally (Dhimal et al., 2021). There have been significant increases in air pollution in major East African cities, pushing cities like Nairobi, Addis Ababa, and Kampala above World Health Organisation's recommended upper limits for air quality (Singh et al., 2021). The current global interventions for reducing NCD disease burden while mitigating emissions, such as promoting bicycles, walking, use of less polluting vehicles or public transportation, are often impractical in urban SSA contexts due to costs and security concerns (Rother, 2020). This is an area for urban-focused climate finance to prioritise, particularly as SSA undergoes an epidemiological transition from infectious diseases to NCDs.

4.4 Urban environments and infrastructure

Summary of risks relevant to urban environments and infrastructure

- **More intense rainfall events will increase flood risk in both rural and urban areas, with densely populated, low-lying urban areas particularly vulnerable.**
- **People and businesses in 'informal' settlements and fast-growing towns with poor infrastructure are exposed to multiple threats, including damage to housing, power, communications and water and sanitation systems.**
- **More intense flooding events and extreme heat can also damage roads and bridges, potentially leaving wide areas and large numbers of people without a connection to markets, supply chains and essential services.**
- **New infrastructure investments needed to unlock growth and reduce poverty that don't account for the changing climate potentially lock-in climate risk, particularly for long-lived investments designed for historical and/or average climate conditions.**

4.4.1 Overview of relevant socioeconomic trends

East Africa has seen its urbanisation rates increase from 23% in 2000 to 39% in 2015, with rates expected to rise further over the coming decades (OECD, 2020). East Africa now has the highest urban land cover of any region in Africa, driven largely by smaller agglomerations developing in densely populated rural areas. Table 4 summarises population distribution by town-city size, showing how most of east Africa's urban population now lives in towns and cities of less than one million people.

Table 4: Distribution of urban population in East Africa by town and city size, 2015 (OECD/SWAC, 2020)

	Size of urban agglomeration					
People living in city or town of that size	Over 3M	1-3M	300,000 – 1M	100,000 – 300,000	30,000 – 100,000	10,000 – 30,000
Number of people in East Africa living in city /town of that size, in 2015	32.4M	17.5M	16.7M	19.6M	21.7M	17.8M
Totals	Cities >1M: 49.9M		Towns & cities 10,000 – 1M: 75.8M			

There is a considerable infrastructure gap facing East Africa. Current infrastructure, including water and sanitation, electricity, transport, irrigation, and flood protection, falls short of what is needed to address public health, economic and environmental needs (Foster and Garmendia, 2010; Rozenberg and Fey, 2021). At the same time, new investments needed to unlock growth and poverty reduction risk locking in climate risk, particularly when those investments are long-lived and difficult or impossible to reverse (Hallegatte, 2019).

Traditionally, attempts to quantify and incorporate climate uncertainties into infrastructure planning tools have assumed no change in the climate from historical trends (Ray and Brown, 2015; Conway et al, 2017). While useful for establishing context, climate models are found to have given 'relatively low value added' and have not been able to inform most investment and policy choices in the context of hydropower and irrigation planning (IEG 2012, 69, Conway et al. 2017). This can be attributed to the difficulties associated with downscaling climate projections to local, decision-making scales. In addition, the challenge of incorporating climate information into a broader (all-uncertainty) assessment of a project's probability of success in circumstances where many other drivers of change (demographic, land use, economic etc) can shape project outcomes, possibly dwarfing the climate signal (Niang et al, 2014; Ray and Brown, 2015; Calow et al, 2018).

Risks to infrastructure and the services it supports are most obvious in urban areas – the region's major cities, but also the growing numbers of smaller towns and cities where planned infrastructure provision (often piecemeal) lags behind urban expansion, leaving residents to self-provision or rely on unregulated and unintegrated informal/private services. Water supply, flood control and sanitation are key areas lagging behind. While larger utilities have the *potential* to draw on significant human and financial resources to address vulnerabilities and invest in new infrastructure, this is often not the case in fast-growing towns and villages.

Based on the number of people affected over the last 30 years, droughts and floods have the largest humanitarian impacts in SSA. But while agricultural drought (in particular) and its impact on food security remain the main focus of research, over the last decade or so floods have overtaken droughts in terms of the numbers of people impacted (Lumbruso et al,2016). This is attributable to both the frequency and intensity of heavy rainfall events but also people's exposure, with rapid population growth (amongst other drivers) pushing people into more marginal areas, including informal settlements and flood-prone areas. In Tanzania, for example, 75% of the urban population live in informal settlements exposed to both water scarcity and flooding (USAID, 2018).

Flood-related risks to infrastructure are both direct and indirect. For example, floods can damage or destroy roads, bridges, houses and water supply and sanitation systems, but heavy rains can also cause landslides, and lead to widespread contamination of the environment with attendant health risks. In this section we focus on urban water and sanitation (see section 4.2.3.1 for rural WASH), urban WASH includes larger, longer-lived investments in (for example) water treatment and supply, and wastewater/stormwater conveyance and disposal. We also look briefly at wider threats to transport with a focus on raods.

4.4.2 Summary of relevant climate projections

In coastal cities, higher humidity, associated with proximity to the sea rather than climate change, is an important climatic factor. Additionally, sea level rise and coastal erosion are both projected to increase with climate change, with consequences for coastal city sea defences. The East Africa region has coastlines with the Red Sea (Zones 1, 3 and 5), the Gulf of Aden (Zone 4), and the Indian Ocean (Zones 4 and 6). Sea levels in this region have been rising at a faster rate than the global mean and are projected to continue to rise with increasing greenhouse gas concentrations (IPCC, 2021). Rising sea levels increases the risk of coastal inundation, particularly in low-lying regions. Coastal erosion is also a key issue in this region and the combined impacts of sea level rise and retreating shorelines will further exacerbate coastal inundation as shorelines continue to retreat. As sea levels rise, saltwater intrusion is projected to increase which can negatively affect water supply from coastal aquifers.

The southwest Indian Ocean coastline is exposed to tropical cyclones (Zone 6). In the future climate both the average wind speed and associated precipitation of tropical cyclones is projected to increase resulting in a higher proportion of category 4 and 5 cyclones (IPCC, 2021). Combined with sea level rise, storm surges are projected to increase in severity, particularly in low-lying areas, presenting a key risk to coastal infrastructure.

High temperatures are already a significant issue in urban areas in this region, particularly during the summer months. Climate model projections show high confidence[27] in a projected increase of between 1- 4 ˚C across the region in annual mean temperatures in the 2050s relative to the 1981-2010 baseline. Climate projections show a strong and consistent signal for further warming, with the greatest temperature increases during the hottest periods of the year. In urban areas the impacts of increased temperatures are exacerbated by the urban setting itself (Zone 1,2, 5 and 6). High daytime maximums affect the amount of time that can be spent in productive work, but overnight minimums are important for the body's ability to cool down, and so also have a critical relationship with overall mortality and morbidity. In urban areas, the large thermal mass of buildings reduces the diurnal range by trapping daytime heat and releasing it slowly overnight. This urban heat island effect means that cities are often 2-3˚C warmer than the surrounding area. High temperatures are also linked with dust storms which also impact urban environments (discussed in more detail in terms of impacts on health, see Section 4.3).

Future changes to rainfall are more uncertain than the projected increases in temperature. However, combined with increases in temperature, water availability and quality are also threatened. The frequency and intensity of heavy precipitation events is projected to increase. This means that areas currently prone to flooding could expect to experience more severe flooding events in the future climate (Zones 1,3 and 6).

4.4.3 Key risks for urban environments and infrastructure in the East Africa region

4.4.3.1 Threats to urban water supply and sanitation

Rapidly growing urban areas in the region typically depend on a variety of water sources and conveyance-distribution systems for water supply, and a range of different sanitation arrangements for the collection and disposal of waste. The pace of urbanisation means that many urban residents, particularly those living in unplanned, informal settlements, have neither a piped connection for water supply nor a safe means of disposing of waste. Mains access and sewerage in Africa as a whole is almost universally confined to the upper income quintiles (Foster et al, 2018). Threats from climate change arise from increasing temperatures and changes in rainfall, affecting hydrology, water supply and water demand, as well as intense rainfall events (particularly flash floods) that damage water, wastewater and power supplies (Howard et al, 2016; Calow et al, 2018). These changes may be experienced in the same location at different times, and challenge utilities charged with delivering and sustaining

[27] High confidence is assigned when the majority of models agree on the direction of change.

services, alongside the private providers and households ‘filling the gaps’ where utility provision is unreliable or absent.

In East Africa’s cities and informal settlements, less than a third of sewage produced is treated, leaving the rest to contaminate the surface and sub-surface (Odada et al., 2020). In Nairobi (Kenya), for example, flooding causes major problems in all informal settlements, but particularly in areas such Maili Saba next to the main river, where fewer than 10% of households have access to safe sanitation (Douglas et al, 2008; WSUP, 2021). The city of Mombasa has only around 15% of the water it needs to meet demand, leading to rationing and self-supply from unsafe sources, despite the fact that the country as a whole is relatively water-rich. Uganda is another relatively water-rich country facing supply-side risks. Here, the National Water and Sewerage Corporation serving Kampala has had to extend water pipes deep into Lake Victoria to ensure reliability of supply as lake levels fluctuate between wet and dry periods (see Focus Box 8 below) at a cost of Uganda Shillings 7.5 billion (approximately US$4.4 million).

Businesses are also affected by cycles of shortage and abundance that could be expected to continue under a more variable climate. In their near real-time assessment of the experience of micro, small and medium enterprises during the 2015-16 El Niño event and its aftermath, Gannon et al (2020) report that water supply disruption, power outages and flooding were the main problems faced by enterprises in Nairobi, as well as in Lusaka and Gaborone. Power outages also affect telecommunications and other essential services (Hallegatte et al, 2019). Disruptions in power, water supply and communications leave production capacity unused, reduce firms’ sales and delay the supply and delivery of goods. Longer term, they also impact the investment and strategic decisions of firms (Hallegatte et al, 2019).

Flooding is already a key risk, and one likely to grow in importance as climate change accelerates and urban areas expand in largely unplanned ways. This is because of the link between flooding and damage to onsite sanitation (e.g. pit latrines), problems gaining vehicular access to flooded areas to empty on-site systems, and because the mixing of flood water and sewage over wide areas can contaminate the environment and water supply – through ingress into leaky water pipes and the shallow groundwater often used for self-supply. In addition to contamination by pathogenic bacteria and viruses, widespread groundwater contamination by petroleum products, chlorinated hydrocarbons and other synthetic compounds harmful to health is also common (Foster et al, 2018; Calow et al, 2018).

Faecal sludge management remains largely unregulated throughout the region, and even where safe transport of faecal matter does exist, safe *disposal* at treatment facilities is a rarity (Howard et al, 2016; Calow et al, 2017). A systematic review of the health evidence highlights strong links between flood events and outbreaks of water-related disease, including cholera, hepatitis A and E, and pathogenic *E.coli* (Alderman et al, 2012), presenting a prominent risk where urban flooding is likely to occur.

Sewage systems remain the dominant form of utility-managed sanitation globally, and in East Africa. These are vulnerable to both flood and drought hazards. Where rainfall declines, sewerage systems become more difficult to operate and maintain – especially conventional sewerage with its higher water requirements. Treatment can also become more costly during prolonged dry periods if, for example, standards have to be raised to account for the lower absorptive and dilution capacity of receiving water bodies. Droughts may also increase concentrations of chemicals and pathogens in water supplies. During intense rainfall events, conversely, the separation of stormwater from sewage may become more important to reduce the risk of overwhelming collection and treatment systems. Increases in suspended solid loads in rivers associated with intense rainfall and/or catchment degradation, plus temperature increases that favour the survival of pathogens, may also mean that treatment systems require significant upgrading or re-design (Howard et al, 2016; Calow et al, 2017).

As towns and cities expand, the importance of securing and protecting water sources in the context of greater rainfall variability will grow. This has the potential to bring urban and rural users, and potentially neighbouring states, into conflict. Tensions between the city of Addis Ababa and neighbouring Oromia region have their roots, in part, in competition for resources, including water, as city planners seek additional supplies (at growing distance and cost) to meet demand. Similar 'hot spots' are emerging at the urban-rural interface in other areas, such as the lower Awash basin (Section 4.1; Figure 21; Focus Box 8). Across the region, we would expect to see rapidly growing towns and cities increasingly compete for water with neighbouring users and uses such as agricultural, as costs also increase.

4.4.3.2 Wider flood risks – threats to transport, housing, communications

Looking beyond the urban environment, the broader risks posed by floods are evident from past climate extremes.

In 2002, heavy rains and mudslides forced tens of thousands of people to leave their homes in Rwanda, Kenya, Burundi, Tanzania, and Uganda. Rwanda suffered the heaviest toll, with more than 50 fatalities, many from landslides. At least 1,557 homes were destroyed, and many cattle were killed. In Kenya, floods and mudslides killed 46 people in two weeks. In Tanzanian peri-urban communities, hundreds of families were left homeless, and damage to crops threatened food security. In August 2006, in Addis Ababa, floods killed more than 100 people, and in the east led to a further 620 fatalities, with 35,000 displaced, houses destroyed and a further 118,000 people affected after heavy rains led to flash floods - a situation repeated in 2007 (Douglas et al, 2008). More recently, record (high) water levels in Lake Victoria have destroyed houses, businesses and roads, and disrupted or destroyed basic services (see Focus Box 8).

Over the coming decades, we would expect to see repeated cycles of droughts and floods leading to the same kinds of loss and damage, but potentially exacerbated by more intense rainfall events, and greater exposure of populations living in flood prone areas. In those areas with steeper slopes and degraded catchments, landslides and mudslides will likely grow in significance. In Rwanda, for example, roughly 40% of the population currently live on slopes exposed to land slide risk, with an estimated 23% of the national budget potentially absorbed by relief and rehabilitation (World Bank, 2021). Similar risks have been highlighted for high plateau areas of Kenya and the Amhara highlands in Ethiopia, exacerbated by the loss of land cover. Catchment degradation and soil erosion, and measures to arrest it, are common concerns and policy priorities across the region.

Risks will be amplified in those countries that have yet to develop actionable early warning systems and disaster risk management plans that include flood risk. Many countries in the Horn of Africa developed sophisticated early warning and response systems, with donor support, following the major El Niño drought of 1983-84. However, these focussed on agricultural production deficits and food and nutrition needs. Flood early warning and response has received much less attention. The early warning 'sector' in general continues to be constrained by a lack of weather and climate monitoring infrastructure, limited capacity to predict future events, inconsistent use of different information across and within country borders, and very limited forecasting of climate hazards, risks and timely dissemination of warnings (Conway, 2015; GEF, 2012; Tucket et al, 2014).

Focus Box 8: Flooding displaces people and damages infrastructure around Lake Victoria

Average water levels in Lake Victoria, Africa's largest lake by area, have increased since 2007, with sharp increases in 2020 and again in 2021. Intense rainfall in 2020 overwhelmed dykes built along the Nzoia River and southern shores, causing the 'back-flooding' of rivers, and inundating fishing and farming communities. According to the Lake Victoria Basin Commission, the floods displaced over 200,000 people and disrupted transportation, drinking water, sanitation, and power systems. Problems were particularly severe on the Kenyan side, with more rivers draining into the lake and susceptible to 'backflow'.

The lake is known for its intense night-time thunderstorms, influenced by the lake's location, size, and nearby topography. The diurnal weather pattern near Lake Victoria is generally characterised by afternoon storms over surrounding land and then intense night-time storms over the lake. This means that although lake levels are partially regulated by dams at Jinja, intense rainfall over the lake can still have a disproportionate impact on lake levels. Moreover, the expansion of Nalubaale dam across the Nile and a drought in the mid-2000s drew water levels down, encouraging many communities to move homes and infrastructure closer to the shore, communities that are now more exposed to floods.

Data for 2021 indicate that the lake reached a new peak, surpassing its previous record high of 1963. Rising temperatures, higher levels of evapotranspiration and greater rainfall variability will likely amplify lake level fluctuations.

Sources: NASA (2021); News Trust (2021)

There are relatively few studies on the impact of floods on transport infrastructure. In broad terms, however, we can say that those countries with the lowest road density, and few other means of moving goods and people, are most at risk from critical outages, since networks have few redundancies (Lumbrusco, 2020). This means that loss of an individual road link or bridge as a result of a flood event can leave areas without a vital road connection to markets or essential services. In Tanzania, a sample of 800 firms across the country found that firms are incurring utilisation losses of US$668 million/year from power, water and transport disruptions, equivalent to 1.8% of the country's GDP. Disruptions to transport caused by rain and floods accounted for roughly 46% of losses (Hallegatte et al, 2019). Studies looking at the most vulnerable or critical transport links for domestic or international trade can identify specific high-risk roads, such as the coastal trunk road south of Dar-es-Salaam (*ibid*), and the Berbera Corridor through Somaliland connecting Berbera Port to the Ethiopian border (Earth Active, 2021).

Over the last five years or so, the role nature-based solutions (NBS) could play in flood management as well as catchment rehabilitation and environmental protection has been increasingly discussed. NBS now feature in many countries' climate resilience and environmental strategies, with strong links also to climate-smart agriculture and watershed management (see Section 4.1.3.3 and Focus Box 9).

Focus Box 9: Nature-based solutions for and flood management and catchment restoration

The most widely used definition of NB S is credited to the International Union for Conservation of Nature (IUCN, 2016): "Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges, effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits." All definitions recognise the fundamental role ecosystems play in addressing the challenges associated with improving degraded ecosystems, and 'working with nature' to enhance water security, manage extreme weather events and mitigate and/or adapt to the impacts of climate change.

Fluvial (river) floods, the most common, occur when the amount of water in a river exceeds the channel's capacity. They are caused primarily by the downstream flow of run-off generated by heavy rainfall on wet or impermeable ground. A flood hazard is characterised by the depth of water at locations where it may cause harm, and also by the velocity of that water, the rate of rise of water levels, the duration of inundation and flood-induced changes in water quality. Recent years have seen growing interest in the role NBS can play in reducing the frequency, magnitude and duration of flood hazards. In broad terms, NBS aim to reduce flood hazard by modifying land use and land management, river channels, floodplains and reservoirs (where present) – restoring or sustaining catchment processes that have been affected by human intervention. Importantly, they also seek to sustain or enhance other potentially significant co-benefits, including ecosystem services (aquatic, riparian, terrestrial) such as biodiversity, soil and water conditions, carbon sequestration, agricultural productivity and improved public health. Hence the close links with watershed restoration and management programmes that feature across the region either as standalone initiatives or as part of public works/social protection programmes (see Focus Box 5).

Despite their growing prevalence in policy documents, specific water-related benefits are often uncertain and/or difficult to assess. The evidence, such as it is, cautions against simplistic assumptions that directly connect changes in forest cover, land use, land management and storage with flooding, particularly in larger catchments. Indeed the greater performance variability and uncertainty around NBS, together with the sheer volume of flood waters and space limitations, means that purely 'natural' solutions will not be sufficient to deal with large floods in most catchments. That said, NBS can play a key role in retaining water (and soils) in the landscape during small and moderate rainfall events, with soil moisture and soil stabilisation benefits that can increase the productivity and resilience of rainfed agriculture. And co-benefits may be considerable, particularly where interventions fully involve local communities at the design stage and externalities (especially upstream-downstream) can be accounted for.

Payment for ecosystem service (PES) arrangements can also be explored, particularly where there is a concentration of benefits to identifiable downstream beneficiaries. A beneficiary could include an urban water utility facing water quality problems, or a hydroelectric plant challenged by dam siltation caused by upstream erosion. Experience in the Lake Naivasha basin in Kenya has demonstrated how such schemes can work. In this case a PES scheme initiated in 2006 is improving water quality in the lake, with lake users (hotels and other businesses – the 'buyers') paying for upstream conservation by farmers (the 'sellers'). The scheme is organised around 12 Water Resource User Associations (WRUAs) with over 3000 members, including 15-20 corporate members (see WWF website).

Monitoring the impacts of NBS interventions over the long periods of time needed to restore catchments and landscapes is tricky, and differences between areas makes it difficult to transfer empirical evidence from one location to another. However, remote sensing techniques are increasingly being used to monitor physical changes (e.g. vegetation cover, soil moisture conditions), reducing the need for on-the-ground monitoring of some indicators.

Sources: Dadson et al (2017); Shiao et al (2020); Acreman et al (2020).

4.5 Fisheries and coasts

Summary of risks relevant to fisheries and coasts

- **Rising sea levels, higher temperatures and more frequent and intense storm surges threaten coastal livelihoods and local economies.**
- **Rising temperatures and eutrophication pose risks to fish stocks and ecosystem health, compounded further by overfishing.**
- **Periodic flooding around shorelines and back-flooding into tributary rivers already cause problems, displacing people and disrupting transportation, drinking water, sanitation, and power systems**
- **In freshwater fisheries, rises in surface water temperature are reducing deep water nutrient upswelling and increasing thermal stratification, diminishing the productivity of pelagic fisheries.**

4.5.1 Overview of relevant socioeconomic trends

East Africa is endowed with a long coastline and significant freshwater resources, including some of the largest freshwater lakes in the world. Lake Victoria, Lake Turkana, Lake Tanganyika, and Lake Kyoga and other inland freshwater fisheries form the majority of fish production in the region, with marine fisheries and aquaculture comprising the remaining production. With the exception of Uganda, where aquaculture makes up nearly a quarter of fish production, aquaculture forms the smallest percentage of fish production in East Africa (Obiero et al., 2019). Despite the potential of the sector, East Africa has relatively low levels of fish consumption per capita (average of 5.3 kgs) compared to the rest of Africa (10.1 kg) (ibid). Still, for the East African populations that depend on fisheries, it is a major source of protein and important for local food security (Hamerlynck et al., 2020). Fisheries can also serve as a safety net for the rural poor, becoming essential for survival during conflict or drought (Benansio et al., 2021).

The fisheries in East Africa are diverse. In Zone 1 and 2, there is a floodplain-based fishery that runs the length of the Nile. Around Lake Victoria and the Rift Valley lakes of Zones 3, 4 and 5 there are lake-based fisheries, as well as floodplain-based fisheries in coastal Kenya and central Tanzania. Along the long coast, there are predominantly coral reef-based fisheries, which stretch from coastal Sudan, Eritrea, Djibouti, Southern Somalia, Kenya, and Tanzania (Zones 1, 3, 4, 6). In Somalia, Kenya, and Tanzania, there are also mangrove deltaic-based fisheries (Zones 4, 6, Hamerlynck et al., 2020).

Overfishing is the most important pressure on fishing livelihoods in the region. The fish stocks along East Africa's coral reef fisheries, particularly along the coasts of Kenya and Tanzania, are severely depleted (McClanahan, 2019). Low stocks affect production and the sustainability of fisher livelihoods, but can also have severe consequences for biodiversity (Wildlife Conservation Society, 2020). Inland fisheries face similar stresses, compounded by the introduction of invasive species and pollution (Sayer et al., 2018). The fisheries of Lake Victoria, which support four million people, are at risk of overharvesting (Mkumbo and Marshall, 2015). Declining fish stocks are forcing fishers to increase their fishing effort, which creates a negative cycle, as fishers turn to illegal fishing gear or damaging fishing methods that further undermine the sustainability of fish populations. Conversely, the Sudd Wetlands in South Sudan (Zone 2) is relatively plentiful, with high biodiversity and fishery resource potential (Benansio et al., 2021). In part, however, this is due to a fishing sector that lacks good access to roads, storage infrastructure, and perennial insecurity (ibid). How climate will impact the wetlands, especially as Zone 2 faces more frequent droughts and floods, remains understudied.

Beyond fisheries, coastlines and lakes are home to some of the region's most dynamic population centres, shipping centres, and tourism hotspots (USAID, 2018). Ports in particular are vital to the region's economy and serve as economic generators in the countries where they are based. For landlocked countries such as Uganda, Burundi, Rwanda, South Sudan, and Ethiopia, East Africa's ports are the gateway to global shipping and trade, connected by railway systems. The major ports of East Africa are Djibouti, Berbera, Lamu, Mombasa, Zanzibar, and Dar es Salaam. In studies of port efficiency in the region, Djibouti and Mombasa were deemed over twice as efficient than others (Trijillo et al., 2018). With the aim of attracting shipping containers that cannot dock in Mombasa, Kenya is currently investing into a new deep-sea port in Lamu, which will be a key route for Ethiopian and South Sudanese goods (Mishra, 2021). The ports also connect oil pipelines, which currently provide important income to South Sudan, and to a lesser extent, Sudan. Although these are economically important, how climate extremes may disrupt this infrastructure is not clear in the literature.

Dense populations are growing along lakes and coastlines, especially in Kenya and Tanzania (Rigaud et al., 2021). Since 1980, the population of the Lake Victoria basin has more than doubled (USAID, 2018). As water availability patterns change, freshwater lakes are likely to become more attractive spots for those looking to migrate. The Lake Victoria basin (Kenya, Uganda, Tanzania, Rwanda and Burundi, Zone 5) is projected to emerge as a climate in-migration hotspot as early as 2030 (Rigaud et al., 2021) Similarly, the villages surrounding Lake Turkana (Kenya, Ethiopia, Zone 4) have been a draw for pastoralist communities from upland areas. Most of these pastoralists lost the majority of their livestock during drought or raids, and who have now adapted to working as fishers (Carr, 2017). The construction of a dam (Gibe III) on the Omo River upstream in Ethiopia, however, threatens the viability of fisher livelihoods, as fishing conditions will be dramatically altered without the sediment and nutrients that the Omo River feeds into Lake Turkana (ibid).

Though Somalia (Zone 4) has the longest coastline in the region, its fisheries sector is relatively small and contributes less than 1% to the country's GDP. As it stands, there is little data on the sector. The small-scale domestic fishing communities that do exist are currently forced to complete with illegal, unreported, and unregulated fishing by foreign fishing vessels (Glaser et al., 2019). Similarly, the fishing sector along the coast of Eritrea in the Red Sea (coastal parts of Zones 1,3,4) is relatively small and lacks reliable data, though the waters in the southern part of the Red Sea are considered productive. Prior to war for independence, which significantly damaged infrastructure, a large commercial fishery existed. Today fishing is less than 0,1% of GDP (FAO, 2021).

4.5.2 Summary of relevant climate projections

The East Africa region has coastlines with the Red Sea (Zones 1, 3 and 5), the Gulf of Aden (Zone 4), and the Indian Ocean (Zones 4 and 6). Sea levels in this region have been rising at a faster rate than the global mean and are projected to continue to rise by around 0.3m by the 2050s with increasing greenhouse gas concentrations (IPCC, 2021). Rising sea levels increases the risk of coastal inundation, particularly in low-lying regions. Coastal erosion is also a key issue in this region and the combined impacts of sea level rise and retreating shorelines will further exacerbate coastal inundation as shorelines continue to retreat. As sea levels rise, saltwater intrusion is projected to increase which can negatively affect water supply from coastal aquifers.

The southwest Indian Ocean coastline is exposed to tropical cyclones (Zone 6). In the future climate both the average wind speed and associated precipitation of tropical cyclones is projected to increase resulting in a higher proportion of category 4 and 5 cyclones. Combined with sea level rise, storm surges are projected to increase in severity, particularly in low-lying areas.

Sea Surface Temperatures (SSTs) have been increasing and are projected to continue to continue to increase by 1-2˚C in the 2050s (IPCC, 2021). As a result, Marine Heatwaves (MHWs) are projected to increase in frequency and intensity, which can negatively affect coral reefs and coastal fish stocks. This is particularly important for the Horn of Africa where there has been an observed increase in the frequency of MHWs. As SSTs increase ocean acidification will also increase (IPCC, 2021).

Inland freshwater fisheries are vulnerable to rainfall variability and heavy rainfall events causing flooding. The variability in seasonal rainfall amounts and timings is projected to increase across the region, resulting in a higher frequency of wetter and drier years relative to the mean. Projected increases in the frequency and intensity of heavy rainfall events will exacerbate existing risks of flooding around freshwater lakes and inland fisheries.

4.5.3 Key risks for fisheries and coasts in the East Africa region

4.5.3.1 Increased risks of flooding around freshwater lakes

For those living around East Africa's freshwater lakes, extreme precipitation is already a major risk to their livelihoods, property, and health. Extreme rainfall can cause lakes to burst over their banks, flooding houses and sometimes causing backflow into Lake Victoria's tributary rivers, which in turn also floods riverside villages and farms. Indeed, wetter years are likely to mirror some of the impacts of flooding around Lake Turkana in 2020 (Zone 4), in which tens of thousands of people living on the shores were displaced.

In light of more extreme precipitation, exposure to floods is likely to increase, particularly as the population around Lake Victoria basin is projected to continue growing. New migrants are expected to settle into more marginal lands that are prone to flooding (USAID, 2018). Flooding in these new settlements will inevitably increase contamination of water sources and damage to homes, agriculture, livestock, and local infrastructure. Furthermore, floods are often accompanied by landslides, particularly in areas where deforested slopes have become waterlogged from extreme precipitation, posing a serious risk of death and injury to those living on or at the base of slopes. Deforestation in the catchment also reduces recharging of aquifers, as trees help absorb rainwater. In turn, rainfall in a deforested catchment results in more sediment running off into rivers, which in turn can elevate water levels by building up lake beds (Avery, 2020).

Studies in East Africa show that arid Rift Valley lakes are sensitive to rainfall variability within the catchment (Olaka et al., 2010). As rainfall persists, the lake levels become saturated, resulting in extensive floods. In Lake Tanganyika (Zone 5), flooding risks come not only from precipitation on the lake itself, but from the mountain streams that can be the source of flash floods (Kubwarugira et al., 2019). In another case, Lake Turkana, a desert lake in the Omo-Turkana basin (Zone 4), increased precipitation is projected to lead to more severe flooding events in the settlements and pastureland surrounding the lake (UNEP-DHI, 2021). For residents, this may become a further communication risk as this may seem counter intuitive, as the lake's water levels have been falling since dams were built on its tributaries (ibid).

4.5.3.2 Risks to economically important assets and coastal cities

With sea-level rise, coastal flooding is expected to worsen. The impacts will be felt more rapidly in semi-enclosed seas, such as the Red Sea, where there has already been an accelerated rate of sea level rise compared to the global rate (Abdulla et al., 2021). For Djibouti port, which sits along the Gulf of Aden at the southern end of the Red Sea, this risk is particularly acute (Zone 4). Over two-thirds of the country's population live within the coastal zone and the country's port, mining infrastructure, and livestock transport infrastructure are all located along this low-lying coastal area (World Bank Group, 2021a). Without a permanent source of surface water, Djibouti is highly reliant on its coastal aquifer for water supply (ibid). Groundwater salinity is already considered excessively high, and intensification of pumping combined with greater coastal flooding is projected to worsen the problem (Idowu & Lasisi, 2020; World Bank Group, 2021a).

Other coastal cities along the Indian Ocean similarly face exposure to sea-level rise. The impacts of sea-level rise will be compounded as storm surges become more pronounced, increasing the risks to coastal populations and infrastructure. A significant proportion of the region's tourism and port infrastructure is concentrated along low-lying coasts of Kenya and Tanzania (Zone 4, 6). In Dar Es Salaam alone, infrastructure assets of an estimated value of 5.3 billion are at risk from flooding and sea-level rise (USAID, 2018b). The port city of Mombasa is particularly exposed, with an estimated area of 4-6 km² likely to be submerged with a rise in sea level of only 0.3 meters (Zone 4) (World Bank Group, 2021b). Coastal agriculture, too, will face significant losses due to sea-level rise, as much of the Kenyan and Tanzanian cashew, mango, clove, and coconut harvests will be affected by one meter of sea-level rise (ibid). As it stands, many of the coastal plantations are already senescent, and will not continue to be productive unless replanted (Hamerlynck et al., 2020).

As in Djibouti, sea-level rise comes with risks of Saltwater Intrusion (SWI) into coastal aquifers. The extent of SWI intrusion varies significantly between locations and can worsen during the dry season, when rainwater is not recharging the aquifer and lessening the salinity of groundwater. Somalia's coastline, where the capital Mogadishu is located, has a high level of dependence on groundwater (Zone 4). In some locations, there is high salinity, while in others there does not yet appear to be seawater intrusion (Iduwu & Lasisi, 2020). In other coastal cities the risks are far better understood; in Dar Es Salaam, for instance, excessive groundwater abstraction is already driving a gradual saltwater intrusion (Zone 6). This is expected to be exacerbated under future urban sprawl (Idowu & Lasisi, 2020). To date, coastal salinisation has been driven largely by over-abstraction, though the situation may change as sea-levels rise and storm surges inundate land (ibid).

Lastly, climate stress in aquatic protected areas may compromise tourism income, which is an important economic sector in the region, boosting GDP and employment in Kenya and

Tanzania in particular. How changes in habitats affect tourism demand is not a clear relationship, however, as no tourism destination around the world will escape unaffected by climate impacts. Further study of how climate change will shape in habitat distribution, wildlife abundance, and wildlife migration patterns are vital to better manage terrestrial and marine protected areas and ensure they remain viable destinations for domestic and international tourism.

4.5.3.3 Direct and indirect stresses on coastal and freshwater fisheries

Climate-induced pressure to marine ecosystems will only exacerbate ecosystem disruption caused by anthropogenic pressures like overfishing (see section 4.5.1). Already, fishers along coasts are having to adapt to declining catches, often by resorting to fishing further offshore and upgrading to more efficient fishing nets (Silas et al., 2020). Our analysis suggests these pressures will only escalate as the frequency and duration of marine heat waves increase, alongside warmer sea-surface temperatures. Prolonged marine heat waves along the coral reefs of the Tanzanian and Kenyan coastlines (Zone 4, 5) are expected to put coral reef fisheries under severe thermal stress. During marine heat waves, coral reefs are projected to undergo mass bleaching events and face increased mortality. Under hotter sea surface temperatures, the outcomes are likely to be even more severe than the mass bleaching event in 2016 in the Western Indian Ocean, which resulted in a 20% decline in coral cover and caused algae to bloom (Gudka et al., 2020).

There is a strong correlation between reef degradation and fishing pressure. As reefs degrade from both anthropogenic and climate-stress, there is an environmental shift from coral-based fisheries to algae dominated ecosystems that are less biodiverse and productive (Hamerlynck et al., 2020). As oceans warm, ocean acidification associated with ocean warming will further contribute to the declining health of coastal marine ecosystems. In reefs along the coast of Somalia, there are already patches of low oxygen concentration, disrupting habitat formation and altering species distribution (Jacobs et al., 2021) These are likely to grow as the ocean pH continues to decrease in a warming climate.

Global warming has raised the surface temperatures of the African Great Lakes, particularly since 1960, with impacts on freshwater fisheries (Odada et al., 2020). In freshwater fisheries, a rise in surface water temperature increases the stability of the water column, which reduces deep-water nutrient upswelling vital for maintaining productive fisheries (O'Reilly et al., 2003). In Lake Tanganyika, the productivity of the lake has already been compromised by an increase in thermal stratification linked to increased temperatures (Tanzania, Burundi, Zone 5). Studies have documented a link between climate warming and diminishing productivity of the pelagic fisheries in the lake, with an estimated 30% decrease in fish yields (ibid). To date, understanding attribution of each factor behind fisheries decline in African lakes is uncertain, as pollution, eutrophication, invasive species, and overfishing all play a role. Yet as

temperatures warm from 1 – 3.5˚C in Zone 5, where many of the lakes are located, the role of direct warming and thermal stratification will increase, putting pressure on habitats and pushing some people dependent on fishing-based livelihoods into ever more precarious economic situations.

5 Summary

This report considers the exposure and vulnerability to climate and climate change within the East Africa region. It sets out a broad range of climate-related risks for the region, to support development planning.

The climate of the East Africa region is diverse, with regions of hot, dry desert conditions, and regions of higher elevation which experience cooler, wetter conditions. The patterns of seasonal rainfall across the region are complex and there is large variability in timings and amounts from year-to-year. Climate change projections for the 2050s show high confidence for a substantial warming trend. There is less confidence around the direction and trend of rainfall, but modelling suggests an increase in mean rainfall across most of the region, with high confidence for an increase over the Ethiopian highlands. Interannual variability in seasonal rainfall amounts and timings is expected to increase, as is the frequency and intensity of heavy rainfall events. This combination of increasing temperatures and increasingly variable seasonal rainfall, together with exposure of the large coastline to sea level rise and storms, means that climate change will increase stress on existing vulnerable populations in the next few decades.

Some of the key risks identified in this report include food and water security, risks to human health and to cities and infrastructure, as well as specific risks associated with coastal zones. However, climate presents just one element of risks and multiple stresses across the region. Climate change will undoubtedly test human and agricultural systems, yet not all problems across the region will be driven by climate change. Climate risks are not isolated threats; how they interact with, and compound other sources of risk can be difficult to disentangle. For example, conflict and migration across the region are more complex issues caused by a multitude of factors spanning beyond climate change. It is important to consider the climate risks presented within this report in the context of development objectives and the wide range of intersectional risks that include socio-economic stresses and other drivers of change.

Nevertheless, long-term climate risks themselves will present considerable challenges, both in terms of average climate conditions which require adaptation to new ways of living, and through climate extremes and shocks such as droughts, that exacerbate pre-existing and complex compounding risks. Development that accounts for climate risks includes low and no-regrets investments in adaptation and resilience aligned to development goals, such as sustainable agricultural intensification, environmental stewardship, social protection, water supply and sanitation and health, all of which support broader development aspirations. This kind of incremental adaptation develops climate resilience within systems, and generates widespread benefits for people across a range of plausible climate futures. However, in some areas and localised hot spots where pressures combine and intensify, agricultural, water, health and urban systems are already under stress, and in some instances functioning at the limits of climate tolerance. As climate change pushes systems further, acting as a 'risk-multiplier', transformational adaptation may be required to develop entirely new approaches to job creation and environmental management where existing ways of doing business are no longer viable.

The climate risks identified in this report demonstrate that climate change already poses a threat to development. The region contains fragile and vulnerable states and landscapes, where climate risks can amplify pre-existing pressures, particularly around food, health, water and infrastructure. These can, in turn, compound the problems facing development such as poverty, employment and gender equity. If the climate risks outlined in this report are considered within the context of the wider intersectional issues the region faces, it is possible to ensure that such risks can be effectively managed in development planning, and development goals can still be achieved despite the considerable challenges of a changing climate.

Image location: Sudan

6 References

Abdul-Jalil, M. A. (2018). Unpleasant homecoming: The predicament of returning pastoralists from South Sudan to Aljabalain area, White Nile State. Sudan Working Paper 1. Bergen: Chr. Michelsen Institute.

Abdulla, C.P.; Al-Subhi, A.M. (2021). Is the Red Sea Sea-Level Rising at a Faster Rate than the Global Average? An Analysis Based on Satellite Altimetry Data. *Remote Sens*. 13, 3489. https://doi.org/10.3390/rs13173489

Acreman, M.C.,Smith, A., Edwards, F., Acreman, S. and Sayer, P. (2020). Evidence for the effectiveness of nature-based solutions in Africa. Task 1 of the project 'scaling-up nature-based solutions across Africa. Final Report to WWF. Sayers and Partners, Hydro-Ecology Consulting Ltd, Wallingford UK. Adamo, Nasrat, Al-Ansari, Nadhir, Sissakian, Varoujan K. (2020). Global Climate Change Impacts on Tigris-Euphrates Rivers Basins, *Journal of Earth Sciences and Geotechnical Engineering*, *10*(1), 49-98.

Adane, A. and Bewket, W. (2021). "Effects of quality coffee production on smallholders' adaptation to climate change in Yirgacheffe, Southern Ethiopia", *International Journal of Climate Change Strategies and Management*, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/IJCCSM-01-2021-0002

Adhikari, U., Nejadhashemi, A.P., Woznicki, S.A. (2015). Climate change and eastern Africa: a review of impact on major crops. *Food Energy Secur* 4:110–132. https://doi.org/10.1002/fes3.6

Adjei-Nsiah, S., Asumugha, G., Njukwe, E. and Akoroda M. (2020). 'The root and tuber crop farming system: Diversity, complexity and productivity potential' in Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., with Auricht, C., Lott, R. and Mburathi, G. (eds) Farming systems and food security in Africa: Priorities for science and policy under global change. London and New York: Routledge, pp. 182-213

AfDB (2013). Health in Africa over the next 50 years. Tunis: African Development Bank Group

AfDB (2020). East Africa Regional Overview. African Development Bank Group. https://www.afdb.org/en/countries/east-africa/east-africa-overview

Alderman, K., Turner, L.R. and Tong, S. (2012). Floods and human health: a systematic review. *Environ. Int*. 47:37-47.

Allan, R., & Soden, B. (2008). Atmospheric warming and the amplification of precipitation extremes. *Science*, 321, 1481-1484.

Amede, T. and Lemenih, M. (2020). 'The highland mixed farming system of Africa: Diversifying livelihoods in fragile ecosystems' in Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., with Auricht, C., Lott, R. and Mburathi, G. (eds) Farming systems and food security in Africa: Priorities for science and policy under global change. London and New York: Routledge, pp. 248-281

Avery, S. (2020) Scientists are worried about the impact of Kenya's Rift Valley lakes flooding. Quartz Africa. https://qz.com/africa/1918674/scientists-worried-by-flooding-in-kenya-rift-valley-lakes/

Ayugi, B., Jiang Zhihong, Huanhuan Zhu, Hamida Ngoma, Hassen Babaousmail, Karim Rizwan, Victor Dike (2021). Comparison of CMIP6 and CMIP5 models in simulating mean and extreme precipitation over East Africa. *International Journal of Climatology,* doi: https://doi.org/10.1002/joc.7207

Azage, M., Kumie, A., Worku, A., Bagtzoglou, C. Anagnostou, A. (2017) Effect of climatic variability on childhood diarrhea and its high risk periods in northwestern parts of Ethiopia. PLoS ONE 12(10): e0186933. https://doi.org/10.1371/journal.pone.0186933

Babiker, A. A. G. (1982). Urbanization and desertification in the Sudan with special reference to Khartoum. *GeoJournal*, *6*(1), 69–76. https://doi.org/10.1007/BF00446596

Baker, R.E., Anttila-Hughes, J. (2020) Characterizing the contribution of high temperatures to child undernourishment in Sub-Saharan Africa. Sci Rep 10, 18796. https://doi.org/10.1038/s41598-020-74942-9

Barraclough, K, Blashki, G., Holt, S., Agar, J. (2017) Climate change and kidney disease-threats and opportunities. Kidney Int., 92, pp. 526 530, 10.1016/j.kint.2017.03.047

BBC News (2015). Tanzania closing hydropower plants. https://www.bbc.co.uk/news/world-africa-34491984

Bein, M. A., Unlucan, D., Olowu, G., & Kalifa, W. (2017). Healthcare spending and health outcomes: evidence from selected East African countries. African health sciences, 17(1), 247–254. https://doi.org/10.4314/ahs.v17i1.30

Benansio, J., Balli, J.,Dendi, D., Ajong, S., Pacini, N., Luiselli, L. (2021). Fish community composition indicates low impact of capture efforts in war-torn South Sudan. European Journal of Ecology. 7. 40-53. 10.17161/eurojecol.v7i2.14993.

Bergamaschi, H. Dalmago, G.A., Bergonci, J.I., Bianchi, C.A.M., Müller, A.G., Comiran, F. (2004) Water supply in the critical period of maize and the grain production. Pesq Agrop Brasileira: 39(9):831–9.

Berry, LaVerle (2010). Sudan : a country study (5th ed.). Washington, D.C.: Federal Research Division, Library of Congress. pp. 171–189. ISBN 978-0-8444-0750-0.

Blackie, M., Dixon, J., Mudhara, M., Rusike, J., Snapp, S. and Mekuria M. (2020) 'Maize mixed farming system: An engine for rural growth and poverty reduction' in Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., with Auricht, C., Lott, R. and Mburathi, G. (eds) Farming systems and food security in Africa: Priorities for science and policy under global change. London and New York: Routledge, pp. 67-104

Blau, M. T., & Ha, K. J. (2020). The Indian Ocean dipole and its impact on East African short rains in two CMIP5 historical scenarios with and without anthropogenic influence. *Journal of Geophysical Research: Atmospheres*, *125*(16), e2020JD033121.

Boffa, J.-M., Sanders, J., Taonda, S.J.-B., Hiernaux, P., Bagayoko, M., Ncube, S. and Nyamangara, J. (2020) 'The agropastoral farming system: Achieving adaptation and harnessing opportunities under duress' in Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., with Auricht, C., Lott, R. and Mburathi, G. (eds) Farming systems and food security in Africa: Priorities for science and policy under global change. London and New York: Routledge, pp. 105-147

Cai, W., Santoso, A., Collins, M. *et al.* Changing El Niño–Southern Oscillation in a warming climate. *Nat Rev Earth Environ* **2,** 628–644 (2021). https://doi.org/10.1038/s43017-021-00199-z

Calow, R. and Mason, N. (2014). *The real water crisis: inequality in a fast-changing world*. ODI, May 2014.

Calow, R.C., Mason, N., Mosello, B. and Ludi, E. (2017). *Linking risk with response: options for climate resilient WASH*. Technical Brief for the GWP-UNICEF Strategic Framework for WASH Climate Resilience.

Calow, R.C., MacDonald, A.M. and Le Seve, M. (2018). *The Environmental Dimensions of Universal Access to Safe Water*. Chapter 6 in: Equality in Water and Sanitation Services, edited by Tom Slaymaker and Oliver Cummings. Earthscan Water, Routledge.

Camberlin, P. (2018). Climate of eastern Africa. In *Oxford Research Encyclopaedia of Climate Science*.

Carlton, E.J., Woster, A.P., DeWitt, P., Goldstein, R.S., Levy, K. (2016) A systematic review and meta-analysis of ambient temperature and diarrhoeal diseases. *Int J Epidemiol*.; 45(1):117–30.

Carr, C.J. (2017) Turkana Survival Systems at Lake Turkana: Vulnerability to Collapse from Omo Basin Development. In: River Basin Development and Human Rights in Eastern Africa — A Policy Crossroads. Springer, Cham. https://doi.org/10.1007/978-3-319-50469-8_9

Carty, T. (2017) A Climate in Crisis: How climate change is making drought and humanitarian disaster worse in East Africa. Oxfam Media Briefing. London: Oxfam.

CDC. (2012) https://www.cdc.gov/tb/programs/laws/menu/definitions.htm

Chapin Metz, H, ed. *Sudan: A Country Study*. Washington: GPO for the Library of Congress, 1991.

Cinner, J. E., & Bodin, Ö. (2010). Livelihood diversification in tropical coastal communities: A network-based approach to analyzing 'livelihood landscapes'. *PLoS One*, 5, e11999.

Cisneros, J., Oki, T., Arnell, N., Benito, G., Cogley, J., Doll, P., et al. (2014). *Freshwater Resources. In: Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group 11 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPPC. Cambridge: Cambridge University Press.

Coffell, E. D., B. Keith, C. Lesk, R. M. Horton, E. Bower, J. Lee and J. S. Mankin (2019: Future Hot and Dry Years Worsen Nile Basin Water Scarcity Despite Projected Precipitation Increases. *Earth's Future,*7, 8,967-977 https://doi.org/10.1029/2019EF001247

Conway, D. (2011). Adapting climate research for development in Africa. *WIRESs Climate Change*, Vo. 2, Issue 3, May/June 2011, pp428-450. https://doi.org/10.1002/wcc.115

Conway, D., Dalin, C., Landman, W.A. and Osborn, T.J. (2017). Hydropower plans in eastern and southern Africa increase risk of concurrent climate-related electricity supply disruption. *Nature Energy*, Vol. 2, December 2017, 946-953.

Conway, D., Curran, P. and Gannon, K.E. (2018). *Climate risks to hydropower supply in eastern and southern Africa*. Policy Brief: Grantham Research Institute on Climate Change and the Environment, and the Centre for Climate Change Economics and Policy. August 2018.

Cook, C., Wellik, K. Fowke, M. (2011) Geoenvironmental diabetology. J. Diabetes Sci. Technol., 5, pp. 834-842, 10.1177/193229681100500402

Cosselman, K., Navas-Acien, A., Kaufman, J. (2015) Environmental factors in cardiovascular disease. Nat. Rev. Cardiol., 2015, pp. 1211-1212. https://doi.org/10.1038/nrcardio.2015.152

Cucchi, M. et al., 2020: WFDE5: bias-adjusted ERA5 reanalysis data for impact studies. *Earth System Science Data*, 27 **12(3)**, 2097–2120, doi:10.5194/essd-12-2097-2020

Cuthbert, M.O., Taylor, R.G., Favreau, G. et al (2019). Observed controls on resilience of groundwater to climate variability in sub-Saharan Africa. *Nature* 572, 230-234 (2019). https://doi.org/10.1038/s41586-019-1441-7

Dadson, S.J. et al. 2017. A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. *Proc. R. Soc*. A 473: 20160706. https://dx.doi.org/10.1098/rspa.2016.0706

de Leeuw, J., Osano, P., Said, M., Ayantunde, A., Dube, S., Neely, C., Vrieling, A., Thornton, P. and Ericksen, P. (2020) ‘The pastoral farming system: Balancing between tradition and transition’ in Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., with Auricht, C., Lott, R. and Mburathi, G. (eds) Farming systems and food security in Africa: Priorities for science and policy under global change. London and New York: Routledge, pp. 318-353

Degife, Azeb W. & Zabel, Florian & Mauser, Wolfram. (2021). Climate change impacts on potential maize yields in Gambella Region, Ethiopia. Regional Environmental Change. 21. 10.1007/s10113-021-01773-3.

Dercon, S. (2012). *Is Green Growth Good for the Poor?* Policy Research Working Paper 6231. World Bank, October 2012.

Dhimal, M., Neupane, T., & Lamichhane Dhimal, M. (2021). Understanding linkages between environmental risk factors and noncommunicable diseases-A review. FASEB bioAdvances, 3(5), 287–294. https://doi.org/10.1096/fba.2020-00119

Dixon, J., Boffa, J.-M., Williams, T.O., de Leeuw, J. Fischer, G. and van Velthuizen, H. (2020) ‘Farming and food systems potentials’ in Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., with Auricht, C., Lott, R. and Mburathi, G. (eds) Farming systems and food security in Africa: Priorities for science and policy under global change. London and New York: Routledge, pp. 535-561

Douglas, I., Alam, K., Magnenda, M., McDonnell, Y., McLean, L. and Campbell, J. (2008). Unjust waters: climate change, flooding and the urban poor in Africa. *Environment and Urbanisation* Vol.20(1): 187-205. DOI: 10.1177/0956247808089156.

Dunning, C. M., Black, E., & Allan, R. P. (2018). Later wet seasons with more intense rainfall over Africa under future climate change. *Journal of Climate*, *31*(23), 9719–9738. https://doi.org/10.1175/JCLI-D-18-0102.1

FAO (2021). *Desert Locust upsurge may be declining but remaining swarms require vigilance in East Africa and Yemen*. FAO News Room 28 October 2021: https://www.fao.org/newsroom/detail/desert-locust-upsurge-may-be-declining-but-remaining-swarms-require-vigilance-in-east-africa-and-yemen/en

ECHO (2021) ECHO Daily Flash October 2021. https://erccportal.jrc.ec.europa.eu/ECHO-Products/Echo-Flash#/daily-flash-archive/4314

Eloff, P. (2021) Armed Conflict, Organised Violence, and Food Insecurity in South Sudan. World Food Programme. https://fscluster.org/sites/default/files/documents/03022021_conflict_and_fsl_fslc_final.pdf

EOC (2019) Cotton in Sudan. Observatory of Economic Complexity Data Visualizer.

Eriksen, S.H., Nightingale, A.J. and Eakin, H. (2015) 'Reframing adaptation: the political nature of climate change adaptation' Global Environmental Change 35(2015): 523-533

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., and Taylor, K. E.: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, Geosci. Model Dev., 9, 1937-1958, doi:10.5194/gmd-9-1937-2016, 2016.

FAO (2017). Watershed management in action – lessons learned from FAO field projects. Food and Agriculture Organisation of the United Nations, Rome, 2017.

FAO (2018). AQUASTAT Core Database. Food and Agriculture Organisation of the United Nations. Data for 2018, accessed November 2021.

FAO (2020). The State of Food and Agriculture: Overcoming Water Challenges in Agriculture. Food and Agriculture Organisation of the United Nations, Rome, 2020. https://doi.org/10.4060/cb1447en

FAO (2021) Fishery and Aquaculture Profiles: The State of Eritrea. [Online] https://www.fao.org/fishery/facp/eri/en

FAO (2021). *Desert Locust upsurge may be declining but remaining swarms require vigilance in East Africa and Yemen*. FAO News Room 28 October 2021: https://www.fao.org/newsroom/detail/desert-locust-upsurge-may-be-declining-but-remaining-swarms-require-vigilance-in-east-africa-and-yemen/en

FAO, IFAD, UNICEF, WFP, WHO (2019) The State of Food Security and Nutrition in the World 2019. Safeguarding Against Economic Slowdowns and Downturns. Rome: FAO

Foster, V. and Briceno-Garmendia, C. (2010) *Africa's Infrastructure: A Time for Transformation*. AFD and World Bank co-publication. Washington DC: Agence Francaise de Development and World Bank.

Foster, S., Bousquet, A. and Furey, S. (2018). Urban groundwater use in Tropical Africa – a key factor in enhancing water security? *Water Policy* 20 (2018) 982-994.

Funk, C. (2020) Ethiopia, Somalia, and Kenya face devastating drought. *Nature* 586, 645 doi: https://doi.org/10.1038/d41586-020-02698-3

Gebre, G. G., & Rahut, D. B. (2021). Prevalence of household food insecurity in East Africa: Linking food access with climate vulnerability. *Climate Risk Management*, 33, 100333. doi:10.1016/j.crm.2021.100333

Gemenne, F. (2011). Why the numbers don't add up: a review of estimates and predictions of people displaced by environmental changes. *Global Environmental Change* 21, supplement, S41-49

Ghebru, B., Araia, W., Ogbazghi, W., Gebreselassie, M., Thomas, T. (2012) East African Agriculture and Climate Change: A COMPREHENSIVE ANALYSIS — ERITREA. IFPRI, ASRECA, and CGIAR.

Gill, P. (2010) Famine and foreigners: Ethiopia Since Live Aid. Oxford University Press.

Glaser, S.M., Roberts, P.M., Hurlburt, K.J. (2019) Foreign Illegal, Unreported, and Unregulated Fishing in Somali Waters Perpetuates Conflict. Front. Mar. Sci. 6:704. doi: 10.3389/fmars.2019.00704

Goelnitz, A., Al-Saidi, M. (2020). Too big to handle, too important to abandon: Reforming Sudan's Gezira scheme. *Agricultural water management*, 241, 106396. doi: 10.1016/j.agwat.2020.106396

GRFC (2021) Global Report on Food Crises 2021. Food Security Information Network. https://docs.wfp.org/api/documents/WFP-0000127343/download/?_ga=2.195945580.1746872541.1637135462-223389464.1636619892

Gudka, M., Obura, D., Mbugua, J. et al. (2020) Participatory reporting of the 2016 bleaching event in the Western Indian Ocean. Coral Reefs 39, 1–11. https://doi.org/10.1007/s00338-019-01851-3

Gulis, G., Mulumba, J.A.A., Juma, O., Kakosova, B. (2004) Health status of people of slums in Nairobi, Kenya. Environmental Research. 2(96):219–227.

Haile, G.G., Tang, Q., Sun, S., Huang, Z., Zhang, X., & Liu, X. (2019). *Droughts in East Africa: Causes, impacts and resilience. Earth-Science Reviews.* doi:10.1016/j.earscirev.2019.0

Hallegatte, S., Rentschler, J. and Rozenberg, J. (2019). *Lifelines: The Resilient Infrastructure Opportunity*. Sustainable Infrastructure Series. Washington DC: World Bank. Doi: 10.1596/978-1430-3.

Hamerlynck, O., Nyingi, W. D., Paul, J.-L. and Duvail, S. (2020) 'The fish-based farming system: Maintaining ecosystem health and flexible livelihood portfolios' in Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., with Auricht, C., Lott, R. and Mburathi, G. (eds) Farming systems and food security in Africa: Priorities for science and policy under global change. London and New York: Routledge, pp. 354-392

Hansen, J., Hellin, J., Rosenstock, T., Fisher, E., Cairns, J., Stirling, C., Lamanna, C., van Etten, J., Rose, A. and Campbell, B. (2019) 'Climate risk management and rural poverty reduction' Agricultural Systems, 172: 28-46

Hastenrath, S., Polzin, D., & Mutai, C. (2007). Diagnosing the 2005 Drought in Equatorial East Africa, *Journal of Climate*, *20*(18), 4628-4637. Retrieved Nov 26, 2021, from https://journals.ametsoc.org/view/journals/clim/20/18/jcli4238.1.xml

Headey, D., Dereje, M., & Taffesse, A. S. (2014). *Land constraints and agricultural intensification in Ethiopia: A village-level analysis of high-potential areas. Food Policy, 48, 129–141.* doi:10.1016/j.foodpol.2014.01.

Hogan, E., Shelly, A., & Xavier, P. (2015). The observed and modelled influence of the Madden–Julian Oscillation on East African rainfall. *Meteorological Applications*, *22*(3), 459-469

Howard, G., Calow, R., MacDonald, A. and Bartram, J. (2016). Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. *Annual Review of Environment and Resources*. 2016. 41:8.1-8.24.

IAH (2021). 2021 *Hydropower Status Report: Sector Trends and Insights*. International Hydropower Association (IAH). See https://www.hydropower.org/publications/2021-hydropower-status-report

ICAI (2016). Assessing DFID's results in Water, Sanitation and Hygiene: An Impact Review. Independent Commission for Aid Impact, May 2016

Idowu, T. E., & Lasisi, K. H. (2020). Seawater intrusion in the coastal aquifers of East and Horn of Africa: A review from a regional perspective. Scientific African, 8, e00402. doi:10.1016/j.sciaf.2020.e004

Ille, E., Steel, G. (2021) Khartoum: City Scoping Study. African Cities Research Consortium.: Manchester. https://reliefweb.int/sites/reliefweb.int/files/resources/Khartoum%20-%20City%20Scoping%20Study%20%28June%202021%29.pdf

IOM (2019) World Migration Report 2020. International Organization for Migration: Geneva.

IOM/UNEP (2021). Identifying Climate Adaptive Solutions to Displacement in Somalia: Assessment Report. International Organisation for Migration and the United Nations Environment Programme. Research led by the Samuel Hall, February 2021.

IPCC (2013) AR5 Technical Summary IPCC. (2013T). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovern-mental Panel on Climate Change. [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]: Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC (2019) IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)].

IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

IPCC Interactive Atlas (2021). Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I.V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon. *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L.Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K.Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/

Jacobs, Z. L., Yool, A., Jebri, F., Srokosz, M., van Gennip, S., Kelly, S. J., Popova, E. (2021). Key climate change stressors of marine ecosystems along the path of the East African coastal current. *Ocean & Coastal Management*, 208, 105627. doi:10.1016/j.ocecoaman.2021.

Jaramillo, J., Muchugu, E., Vega, F.E., Davis, A. Borgemeister, C. and Chabi-Olaye, A. (2011). Some Like it Hot: The Influence and Implications of Climate Change on Coffee Berry Borer (*Hypothenemus hampei*) and Coffee Production in East Africa. *PLoS One*, Volume 6, Issue 9, September 2011.

Kassam, A., Kueneman, E., Lott, R., Friedrich, T., Lutaladio, N., Norman, D., Bwalya, M., Poisot, A.-S. and Mkomwa S. (2020) 'The cereal-root crop mixed farming system: A potential bread basket transitioning to sustainable intensification' in Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., with Auricht, C., Lott, R. and Mburathi, G. (eds) Farming systems and food security in Africa: Priorities for science and policy under global change. London and New York: Routledge, pp. 214-247

Kendon, E. J., Stratton, R. A., Tucker, S., Marsham, J. H., Berthou, S., Rowell, D. P., & Senior, C. A. (2019). Enhanced future changes in wet and dry extremes over Africa at convection-permitting scale. *Nature Communications*, *10*(1). https://doi.org/10.1038/s41467-019-09776-9

Killin, L., Starr, J. Shiue, I, Russ, T. (2016) Environmental risk factors for dementia: a systematic review. *BMC Geriatr*., 16, pp. 1-28, 10.1186/s12877-016-0342-y

Kraef, C., Juma, P.A., Mucumbitsi, J. (2020) Fighting non-communicable diseases in East Africa: assessing progress and identifying the next steps. *BMJ Global Health*; 5:e003325.

Lakmeeharan, K., Manji, Q., Nyairo, R. and Poeltner, H. (2020). *Solving Africa's infrastructure paradox*. McKinsey & Company, March 2020.

Lamanna, C. (2019). Too hot to handle? Heat resilience in urban South Sudan. *South Sudan Medical Journal*, *12*(1), 24-27.

Lind, J., Sabates-Wheeler, R., Cararvani, M., Kuol, L.B.D. and Nightingale, D.M. (2020). Newly evolving pastoral and agro-pastoral rangelands of Eastern Africa. *Pastoralism: Research, Policy and Practice* (2020) 10:24 https://doi.org/10.1186/s13570-020-00179-w

Lumbruso, D., Brown, E. and Ranger, N. (2016). Stakeholders' perceptions of the overall effectiveness of early warning systems and risk assessments for weather-related hazards in Africa, the Caribbean and South Asia. *Natural Hazards*, 1-24.

Lumbruso, D. (2020). Flood risk management in Africa. Editorial in the *Journal of Flood Risk Management* 2020; 13:e12612. DOI: 101111/jfr3.12612

Lunde, T.M., Balkew, M., Korecha, D. et al. (2013) A dynamic model of some malaria-transmitting anopheline mosquitoes of the Afrotropical region. II. Validation of species distribution and seasonal variations. *Malar J 12*, 78. https://doi.org/10.1186/1475-2875-12-78

Lynam, J. (2020) 'The highland perennial farming system: Sustainable intensification and the limits of farm size' in Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., with Auricht, C., Lott, R. and Mburathi, G. (eds) *Farming systems and food security in Africa: Priorities for science and policy under global change*. London and New York: Routledge, pp. 148-181

Lwasa, S. 2016. *Urban nature that reduces risk in Kampala—The nature of cities*. TNOC *Blog Page*.

MacAllister, D.J., MacDonald, A.M., Kebede, S., Godfrey, S. and Calow, R. (2020). Comparative performance of rural water supplies during drought. *Nature Communications*, 11:1099. https://doi.org/10.1038/s41467-020-14839-3

MacDonald, A.M., Bonsor, H.C., Ó Dochartaigh, B.E. and Taylor, R.G. (2012). Quantitative maps of groundwater resources in Africa. *Environmental Research Letters*, 7 (2), 024009. 10.1088/1748-9326/7/2/024009.

MacDonald, A.M., Bell, R.A., Kebede, S., Azagegn, T., Yehualaeshet, T., Pichon, F., Young, M., McKenzie, A.A., Lapworth, D.J., Black, E. and Calow, R.C. (2019). Groundwater and resilience to drought in the Ethiopian highlands. *Environmental Research Letters* 14 (2019) 095003. https://doi.org/10.1088/1748-9326/ab2821

MacDonald, A.M., Lark, R.M., Taylor, R.G., Abiye, T., Fallas, H.C., Favreau, G., Goni, I.B., Kebede, S., Scanlon, B., Sorenson, J.P.R., Tajani, M., Upton, K.A. and West, C. (2021). Mapping groundwater recharge in Africa from ground observations and implications for water security. *Environmental Research Letters*, 16, (2021), 034012. https://doi.org/10.1088/1748-9326/abd661

Mahmoud, M. I., Elagib, N. A., Gaese, H., & Heinrich, J. (2014). Rainfall conditions and rainwater harvesting potential in the urban area of Khartoum. *Resources, Conservation and Recycling*, 91, 89–99. https://doi.org/10.1016/j.resconrec.2014.07.014

Mason, N., Le Seve, M.D. and Calow, R. (2017). *Future flows: Global trends to watch on water and sanitation*. ODI Working Paper 520, August 2017.

McClanahan, T.R. (2019). Coral reef fish communities, diversity, and their fisheries and biodiversity status in East Africa. *Marine Ecology Progress Series*; 632: 175 DOI: 10.3354/meps13153

McCord, A. (2012). Public works and social protection in southern Africa. Do public works work for the poor? Helsinki: Junta Press and UNU.

McSweeney, C., Lizcano, G, New, M. and Lu, X. (2010). The UNDP Climate Change Country Profiles: Improving the accessibility of observed and projected climate information for studies of climate change in developing countries, *Bulletin of the American Meteorological Society*, 91(2): 157-166.

Meynard, C. N., Lecoq, M., Chapuis, M., & Piou, C. (2020). On the relative role of climate change and management in the current Desert Locust outbreak in East Africa. *Global Change Biology*. doi:10.1111/gcb.1513

Mind'je, Richard & Li, Lanhai & Amanambu, Amobichukwu & Nahayo, Lamek & Nsengiyumva, Jean Baptiste & Gasirabo, Aboubakar & Mindje, Mapendo. (2019). Flood susceptibility modelling and hazard perception in Rwanda. *International Journal of Disaster Risk Reduction*. 10.1016/j.ijdrr.2019.101211

Mishra, A. (2021) A Chinese-built port in the Indian Ocean: The story of Kenya’s Lamu port. New Delhi: Observer Research Foundation.

Mkonda M.Y (2017) Are Rainfall and Temperature Really Changing? Farmers’ Perceptions, Meteorological Data, and Policy Implications in the Tanzanian Semi-Arid Zone. *Sustainability*: 9- 1412

Mkumbo, O.C. and Marshall, B.E. (2015). ‘The Nile perch fishery of Lake Victoria: current status and management challenges’. *Fisheries Management & Ecology*. 22:56–63. https://doi.org/10.1111/fme.12084

Moat, J., Williams, J., Baena, S., Wilkinson, T., Gole, T. W., Challa, Z. K., ... & Davis, A. P. (2017). Resilience potential of the Ethiopian coffee sector under climate change. *Nature plants*, *3*(7), 1-14.

Modenese, A. Korpinen, L. (2018) Solar radiation exposure and outdoor work: An underestimated occupational risk. *Int. J. Environ. Res. Public Health*, 15, pp. 1-24, 10.3390/ijerph15102063

Moore, N., & Messina, J. (2010). A landscape and climate data logistic model of tsetse distribution in Kenya. *PloS one*, 5(7), e11809. https://doi.org/10.1371/journal.pone.0011809

Moran, E.F., Lopez, M.C., Moore, N., Muller, N and Hyndman, D.W. (2018). Sustainable hydropower in the 21st century. *PNAS* Vol 115, No47, 11891-11898.

Mosello, B., Calow, R., Tucker, J., Parker, H., Alamirew, T., Kebede, S., Alemseged, T. and Gudina, A. (2015). Building adaptive water resources management in Ethiopia. ODI Report, May 2015.

Msemo, H.E., Taylor, A.L., Birch, C.E., Dougill, A.J., Andrew J., Hartley, A. and Woodhams, B.J. (2021). What Do Weather Disasters Cost? An Analysis of Weather Impacts in Tanzania. *Frontiers in Climate*, Vol. 3, 2021. DOI=10.3389/fclim.2021.567162

Muga, G.O., Onyango-Ouma, W., Sang, R., Affognon, H. (2021) Indigenous knowledge of Rift Valley Fever among Somali nomadic pastoralists and its implications on public health delivery approaches in Ijara sub-County, North Eastern Kenya. *PLoS Negl Trop Dis* 15(2): e0009166. https://doi.org/10.1371/journal.pntd.0009166

Mukhtar, A. Y. A., Munyakazi, J. B., & Ouifki, R. (2019). Assessing the role of climate factors on malaria transmission dynamics in South Sudan. *Mathematical Biosciences*. doi:10.1016/j.mbs.2019.01.002

Multi-Agency East Africa Drought Alert (2021) The Eastern Horn of Africa faces an exceptional prolonged and persistent agro-pastoral drought sequence. FEWSNET, EC, FAO, IGAD, WFP. https://reliefweb.int/sites/reliefweb.int/files/resources/multi-agency-east-africa-drought-alert-v7-f.pdf

Nassef, M., Belayhun, M. (2012) Water Development in Ethiopia's Pastoral Areas. Addis and London: Save the Children Ethiopia & Overseas Development Institute.

Ndayambaje, J.D. (2013) Trees and woodlots in Rwanda and their role in fuelwood supply. Unpublished PhD Thesis. Wageningen University.

Netherlands Commission for Environmental Assessment (2020) Advisory Review of the resubmitted Environmental and Social Impact Assessment for the East Africa Crude Oil Pipeline (EACOP). https://www.eia.nl/docs/os/i72/i7228/7228_website_versie_advisory_report_eacop_uganda_22_october.pdf

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. *PloS one*, *10*(3), e0118571.

Neven, D., M.M. Odera, T. Reardon and H. Wang. (2009) Kenyan supermarkets, emerging middle-class horticultural farmers, and employment impacts on the rural poor. *World Development* 37(11): 1802–1811.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J. and Urquhart, P. (2014). Africa. In: *Climate Change 2014: Impacts, Adaptation and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Nicholson, S. E. (2014). A detailed look at the recent drought situation in the Greater Horn of Africa. *Journal of Arid Environments*, 103, 71–79. doi:10.1016/j.jaridenv.2013.12

Nicholson, S. E. (2017). Climate and climatic variability of rainfall over eastern Africa. *Reviews of Geophysics*, *55*(3), 590-635.

Nicholson, S. E. (2018). The ITCZ and the Seasonal Cycle over Equatorial Africa. *Bulletin of the American Meteorological Society*, 99(2): 337-348. https://doi.org/10.1175/BAMS-D-16-0287.1

Nijsten, G.J., Chriselis, G., Villholth, K.G., Braune, E. and Gaye, C.B. (2018). Transboundary aquifers of Africa: Review of the current state of knowledge and progress towards sustainable development and management. J*ournal of Hydrology: Regional Studies* 20 (2018) 21-34. Https//doi.org/10.1016/j.ejrh.2018.03.004

Nnko, H.J., Gwakisa, P.S., Ngonyoka, A., Sindato, C., Estes, A.B. (2021). Potential impacts of climate change on geographical distribution of three primary vectors of African Trypanosomiasis in Tanzania's Maasai Steppe: G. m. morsitans, G. pallidipes and G. swynnertoni. *PLOS Neglected Tropical Diseases* 15(2): e0009081.

Norton, A., Seddon, N., Agrawal, A., Shakya, C., Kaur, N. and Porras, I. (2020). Harnessing employment-based social protection assistance programmes to scale up nature-based climate action. *Phil. Trans. R. Soc. B* 375: 20190127. http://dx.doi.org/10.1098/rstb.2019.0127

Obiero, K.O., Waidbacher, H., Silke Drexler, S., Meulenbroek, P., Adamneh D., Akoll, P., Odong R., Kaunda-Arara, B. (2019). The contribution of fish to food and nutrition security in eastern Africa: emerging trends and future outlooks. *Sustainability* 2019, 11, 1636; https://www.mdpi.com/2071-1050/11/6/1636

OCHA (2021). Kenya Drought Flash Appeal: Oct – Dec 2021. New York: UN Office for the Coordination of Humanitarian Affairs.

Odada, E. O., Olago, D. O., & Olaka, L. A. (2020). An East African perspective of the anthropocene. *Scientific African*, 10, e00553. https://doi. Org/10.1016/j.sciaf.2020.e00553.

OEC (2019). Observatory of Economic Complexity. Database accessed November 2021. https://oec.world/en.

OECD (2017). Social Protection in East Africa: Harnessing the Future, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264274228-en

OECD/SWAC (2020). Africa's Urbanisation Dynamics 2020: Africapolis, Mapping a New Urban Geography. OECD publishing, Paris.

Ogwang, T., & Vanclay, F. (2021). Cut-off and forgotten?: Livelihood disruption, social impacts and food insecurity arising from the East African Crude Oil Pipeline. Energy Research & Social Science, 74, 101970. doi:10.1016/j.erss.2021.101970

Oiro, S., Comte, J.C., Soulsby, C., MacDonald, A. and Mwakamba, C. (2020). Depletion of groundwater resources under rapid urbanisation in Africa: recent and future trends in the Nairobi Aquifer System, Kenya. *Hydrogeology Journal* (2020) 28: 2635-2656. https//doi..org/10.1007/s10040-020-02236-5

Olaka, L.A., Odada, E.O., Trauth, M.H. *et al.* The sensitivity of East African rift lakes to climate fluctuations. *J Paleolimnol* **44,** 629–644 (2010). https://doi.org/10.1007/s10933-010-9442-4

Omoyo, N.N., Wakhungu, J. & Oteng'i, S. Effects of climate variability on maize yield in the arid and semi arid lands of lower eastern Kenya. *Agric & Food Secur* 4, 8 (2015). https://doi.org/10.1186/s40066-015-0028-2

Opitz-Stapleton, S., Nadin, R., Kellett, J., Calderone, M., Quevedo, A., Peters, K. and Mayhew, L. (2019). Risk-informed development: from crisis to resilience. Overseas Development Institute: London

O'Reilly, C. M., Alin, S. R., Plisnier, P.-D., Cohen, A. S., & McKee, B. A. (2003). Erratum: Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. *Nature*, 424(6950), 766–768. doi:10.1038/nature01833

Pantuliano, S., Assal, M., Elnaiem, B., McElhinney, H., Shwab., M, with Elzein, Y., Motasim Mahmoud Ali, H. (2011). City limits: urbanisation and vulnerability in Sudan. Humanitarian Policy Group. London: Overseas Development Group

Pasquini, L., van Aardenne, L., Godsmark, C. N., Lee, J., & Jack, C. (2020). Emerging climate change-related public health challenges in Africa: A case study of the heat-health vulnerability of informal settlement residents in Dar es Salaam, Tanzania. *Science of The Total Environment*, 141355. doi:10.1016/j.scitotenv.2020.141355

Peters, K., Dupar, M., Opitz-Stapleton, S., Lovell, E., Budimir, M., Brown, S. and Cao, Y. (2020). *Climate change, conflict and fragility. An evidence review and recommendations for research and action*. ODI Research Report, June 2020.

Pretty, J. (2018). Intensification for redesigned and sustainable agricultural systems. *Science*, 362,eaav0294 (2018)

Ray, P.A. and Brown, C.M. (2015). *Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/22544

Raymond, C., Mathews, T. and Horton, R.M. (2020). The emergence of heat and humidity too severe for human tolerance. *Science Advances*, Vol 6, No 19. https://doi.org/10.1126/sciadv.aaw1838

Rigaud, K., de Sherbinin, A., Jones, B., Adamo, S., Maleki, D., Arora, A., Fernandez, C., Taeko, A., Chai-Onn, T., Mills, B. (2021). Groundswell Africa: Internal Climate Migration in the Lake Victoria Basin Countries. Washington, DC: The World Bank.

Rosenstock, T.S., Lamanna, C., Namoi, N., Arslan, A., Richards, M. (2019) What Is the Evidence Base for Climate-Smart Agriculture in East and Southern Africa? A Systematic Map. In: Rosenstock T., Nowak A., Girvetz E. (eds) The Climate-Smart Agriculture Papers. Springer, Cham. https://doi.org/10.1007/978-3-319-92798-5_12

Roth, V., Lemann, T., Zeleke, G., Subhatu, A. T., Nigussie, T. K., & Hurni, H. (2018). Effects of climate change on water resources in the upper Blue Nile Basin of Ethiopia. *Heliyon*, *4*(9), e00771.

Rother H.A. (2020) Controlling and preventing climate-sensitive noncommunicable diseases in urban sub-Saharan Africa. Sci Total Environ, 722:137772.

Rozenberg, J. and Fay, M. eds (2019). *Beyond the Gap: How Countries Can Afford the Infrastructure They Need while Protecting the Planet*. Sustainable Infrastructure Series. Washington, DC: World Bank. Doi:10.1596/978-1-4648-1363-4.

Sachs, J., McArthur, J.W., Schmidt-Traub, G., Kruk, M., Bahadur, C., Faye, M. and McCord, G. (2004) 'Ending Africa's poverty trap' Brookings papers on economic activity 2004(1): 117-240 .

Sadoff, C.W, Borgomeo, E. and de Waal, D. (2017). Turbulent Waters: Pursuing Water Security in Fragile Contexts. Washington D.C., World Bank.

Sayer, C.A., Máiz-Tomé, L. and Darwall, W.R.T. (2018). Freshwater biodiversity in the Lake Victoria Basin: Guidance for species conservation, site protection, climate resilience and sustainable livelihoods. Cambridge, UK and Gland, Switzerland: IUCN. xiv +226pp.

Schipper, L. and Pelling, M. (2006) 'Disaster risk, climate change and international development: scope for, and challenges to, integration', Disasters 30(1): 19-38

Sejian, V., Silpa, M. V., Reshma Nair, M. R., Devaraj, C., Krishnan, G., Bagath, M.,Bhatta, R. (2021). Heat Stress and Goat Welfare: Adaptation and Production Considerations. Animals, 11(4), 1021. doi:10.3390/ani11041021

Selby, J. and Daoust, G. (2021). *Rapid evidence assessment on the impacts of climate change on migration patterns*. London: Foreign, Commonwealth and Development Office.

Serels, S. (2021) Unequal adaptations : A history of environmental Change in the Sudan - Eritrea- Ethiopia border regions

Sewando, P.T., Mutabazi, K., Mdoe, N.Y.S.(2016) Vulnerability of agro-pastoral farmers to climate risks in northern and central Tanzania, Development Studies Research, 3:1, 11-24, DOI: 10.1080/21665095.2016.1238311

Shiao, T., Kammeyer, C., Brill, G., Feinstein, L., Matosich, M., Vigerstol, K. and Muller-Zantop, C. 2020. *Business Case for Nature-Based Solutions: Landscape Assessment*. United Nations Global Compact CEO Water Mandate and Pacific Institute. Oakland, California.

Siam, M.S. and Eltahir, E.A.B. (2017). Climate change enhances interannual variability of the Nile river flow. *Nature Climate Change* 7, 350–354 (2017). https://doi.org/10.1038/nclimate3273

Siderius, C., Kolusu, S.R., Todd, M.C., Washington, R.T., Bhave, A., Dougill, A.J., Reason, C.J.C, Mkwambisi, D.D., Kashaigili, J.J., Pardoe, J. Harou, J.J., Vincent, K., Hart, N.C.G, James, R., Washington,R., Geressu, R.T. and Conway, D. (2021). Climate variability affects water-energy-food infrastructure performance in East Africa, *One Earth*, Volume 4, Issue 3, 2021, Pages 397-410, ISSN 2590-3322, https://doi.org/10.1016/j.oneear.2021.02.009.

Siddharthan, T., Ramaiya, K., Yonga, G., Mutungi, G. N., Rabin, T. L., List, J. M., Kishore, S. P., & Schwartz, J. I. (2015) Noncommunicable Diseases In East Africa: Assessing The Gaps In Care And Identifying Opportunities For Improvement. Health affairs (Project Hope), 34(9), 1506–1513. https://doi.org/10.1377/hlthaff.2015.0382

Silas, M. O., Mgeleka, S. S., Polte, P., Sköld, M., Lindborg, R., de la Torre-Castro, M., & Gullström, M. (2020). Adaptive capacity and coping strategies of small-scale coastal fisheries to declining fish catches: Insights from Tanzanian communities. Environmental Science & Policy, 108, 67–76. doi:10.1016/j.envsci.2020.03.012

Singh, A., Ng'ang'a, D., Gatari, M., Kidane, A.W., Alemu, Z., Derrick, N., Webster, M.J., Bartington, S., Thomas, N., Avis, W.R., Pope, F. (2021) 'Air quality assessment in three East African cities using calibrated low-cost sensors with a focus on road-based hotspots', Environmental Research Communications, vol. 3, no. 7, 075007. https://doi.org/10.1088/2515-7620/ac0e0a

Sridharan, V., Broad, O., Shivakumar, A. *et al.* (2019). Resilience of the Eastern African electricity sector to climate driven changes in hydropower generation. *Nature Communications* 10**,** 302: https://doi.org/10.1038/s41467-018-08275-7

Tabari, H. Climate change impact on flood and extreme precipitation increases with water availability. Sci Rep 10, 13768 (2020) https://doi.org/10.1038/s41598-020-70816-2

Taffesse, A.S., Dorosh, P., Gemessa, S.A. (2012) Crop production in Ethiopia: Regional patterns and trends. In Food and Agriculture in Ethiopia: Progress and Policy Challenges, ed. Paul A. Dorosh and Shahidur Rashid. Chapter 3 pp. 53-83. Philadelphia, PA: University of Pennsylvania Press. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/127350

Taylor, I. H. *et al.* The impact of climate mitigation on projections of future drought. *Hydrol. Earth Syst. Sci.* **17**, 2339–2358 (2013).

Taylor, R.G., Scanlon, B., Doll, P., Rodell, M., van Beek, R., Wada, Y. et al (2013). Ground water and climate change. *Nature Climate Change*, 3, 322-329.

Taylor, S.F.W., Roberts, M.J., Milligan, B. et al. (2019) Measurement and implications of marine food security in the Western Indian Ocean: an impending crisis? Food Sec. 11, 1395–1415 (2019). https://doi.org/10.1007/s12571-019-00971-6

Tenzing, J.D. (2019). Integrating social protection and climate change adaptation: A review. Advanced Review. *WIREs Climate Change*, Vol 11, Issue 2, March/April 2020. https://doi.org/10.1002/wcc.626

Thornton, P., Cramer, L. (2012) Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR ' s mandate . CCAFS Working Paper 23. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Thornton , P. K., Jones, P.J., Alagarswamy, G., Andresen, J., Herrero, M. (2010) Adapting to climate change: agricultural system and household impacts in East Africa . Agric. Syst. 103 : 73 – 82

Trujillo, L., González, M.M., Jiménez, J.L. (2018) Efficiency Drivers in Eastern African Ports. Athens: IAME 2018.

Tucker, J., MacDonald, A., Coulter, L., & Calow, R. (2014). Household water use, poverty and seasonality in Ethiopia: quantitative findings from a highland to lowland transect. *Water Resources and Rural Development, 3*, 27-47.

UNECA (2020) Macroeconomic and Social Developments in Eastern Africa 2020. Kigali: United Nations Economic Commission for Africa

UNEP-DHI (2021) Results of Modelling of Future Scenarios of Lake Turkana and its River Basins. Technical Report. Hørsholm: UNEP-DHI Centre.

UNICEF (2014) Generation 2030 Africa: Child Demographics in Africa. New York: UNICEF Division of Data, Research and Policy.

UNGA, 2016: Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction. A/71/644, United Nations General Assembly (UNGA), 41 pp.

USAID (2018a) Climate Change Vulnerability and Adaptation in East Africa: Aquatic Ecosystems and Water. Fact Sheet. Arusha: East African Community.

USAID (2018b) Climate Risk Profile: Tanzania. ATLAS.

USAID (2019) South Sudan Climate Vulnerability Profile. https://www.climatelinks.org/sites/default/files/asset/document/USAID_The%20Cadmus%20Group_South%20Sudan%20Climate%20Vulnerability%20Profile%20to%20Improve%20Resilience.pdf

Vashisht, A., Zaitchik, B., & Gnanadesikan, A. (2021). ENSO Teleconnection to Eastern African Summer Rainfall in Global Climate Models: Role of the Tropical Easterly Jet, Journal of Climate, 34(1), 293-312.

Vellinga, M., & Milton, S. F. (2018). Drivers of interannual variability of the East African "Long Rains". *Quarterly Journal of the Royal Meteorological Society*, *144*(712), 861-876.

Vrieling, A., Meroni, M., Mude, A. G., Chantarat, S., Ummenhofer, C. C., & de Bie, K. (C. A. J. M. . (2016). Early assessment of seasonal forage availability for mitigating the impact of drought on East African pastoralists. Remote Sensing of Environment, 174, 44–55. doi:10.1016/j.rse.2015.12.003

Wainwright, C. M., Marsham, J. H., Keane, R. J., Rowell, D. P., Finney, D. L., Black, E., & Allan, R. P. (2019). "Eastern African Paradox" rainfall decline due to shorter not less intense Long Rains. *Npj Climate and Atmospheric Science*, *2*(1). https://doi.org/10.1038/s41612-019-0091-7

Wainwright, C. M., Marsham, J. H., Rowell, D. P., Finney, D. L., & Black, E. (2021). Future changes in seasonality in east africa from regional simulations with explicit and parameterized convection. *Journal of Climate*, *34*(4), 1367–1385. https://doi.org/10.1175/JCLI-D-20-0450.1

Watkiss, P., Wilby, R. and Rodgers, C.A. (2020). *Principles of Climate Risk Management for Climate Proofing Projects*. ADB Sustainable Development Working Series Papers No. 69, July 2020.

Wildlife Conservation Society (2020) "East African fish in need of recovery: Coastal fish stocks declining in Kenya, Tanzania, and Mozambique." ScienceDaily. ScienceDaily, 6 February 2020. <www.sciencedaily.com/releases/2020/02/200206184326.htm>.

Wisner, B., Blaikie, P., Cannon, T. and Davis, I. (2003) At Risk: natural hazards, people's vulnerability and disasters (2nd Ed.) New York, NY, Routledge, 464 pp.

WFP (2021) WFP's plan to support 42 million people on the brink of famine. Press Release. https://www.wfp.org/stories/wfps-plan-support-42-million-people-brink-famine.

Wheeler, K.G., Jeuland, M., Hall, J.W., Zagona, E. and Whittington, D. (2020). Understanding and managing new risks on the Nile with the Grand Ethiopian Renaissance Dam. *Nature Communications* 11:5222. https://doi.org/10.1038/s41467-020-19089-x

WHO/UNICEF (2021). Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs. Geneva: World Health Organisation (WHO) and the United Nations Children's Fund (UNICEF).

Wolff, C., G. H. Haug, A. Timmermann, J. S. S. Damste, A. Brauer, D. M. Sigman, M. A. Cane, and D. Verschuren (2011). Reduced interannual rainfall variability in East Africa during the last Ice Age. *Science*, 333, 743–747,

Woodhouse and Ganho (2011). Is Water the Hidden Agenda of Agricultural Land Acquisition in sub-Saharan Africa? In: International Conference on Land Grabbing 6 April 2011, University of Sussex.

World Bank (2010). World Development Report 2010: Development and Climate Change. Washington DC: World Bank.

World Bank (2017). Reducing Inequalities in Water Supply, Sanitation and Hygiene in the Era of the Sustainable Development Goals: Synthesis Report of the WASH Poverty Diagnostic Initiative. World Bank, Washington D.C.

World Bank WDI (2020). World Development Indicators. The World Bank Group. Data for 2020, database accessed November 2021.

World Bank (2020a) Rural Population (% of total population) - Rwanda. World Development Indicators [data file]. https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=RW

World Bank (2020b) Rural Population (% of total population) - Burundi. World Development Indicators [data file]. https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=BI

World Bank (2020c) Urban Population (% of total population) - Djibouti. World Development Indicators [data file]. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=DJ

World Bank Group (2021a) Climate Risk Profile: Djibouti. Washington, D.C.: The World Bank Group.

World Bank Group (2021b) Climate Risk Profile: Kenya. Washington, D.C.: The World Bank Group.

WSUP (2020). At the epicentre of the crisis: battling to provide clean water in Kenya. Blog by Antony Njaramba, Managing Director of the Mombasa Water Supply and Sanitation Company,10 September 2020.

Yumba, J., de Vaate, M. D. B., Kiambi, D. and Rao, K.P.C. (2014). Geographic Information Systems for Assessment of Climate Change Effects on Teff in Ethiopia, African *Crop Science Journal,* 22 (4): 847–858.

Zerboni, A., Filippo Brandolini, Guido S. Mariani, Alessandro Perego, Sandro Salvatori, Donatella Usai, Manuela Pelfini & Martin A.J. Williams (2020) The Khartoum-Omdurman conurbation: a growing megacity at the confluence of the Blue and White Nile Rivers, Journal of Maps, DOI: 10.1080/17445647.2020.1758810