Climate Risk Profile for Eastern Africa

Summary

This profile provides an **overview of projected climate parameters and related impacts** on different sectors in Eastern Africa until 2080 **under different climate change scenarios** (called Representative Concentration Pathways, RCPs). RCP2.6 represents the low emissions scenario that aims to keep global warming likely below 2 °C above pre-industrial temperatures. RCP6.0 represents a medium to high emissions scenario that is likely to exceed 2 °C. **Model projections do not account for effects of future socio-economic impacts,** unless indicated otherwise.

Depending on the scenario, the **air temperature** over Eastern Africa is projected to **rise by 1.7 to 3.9 °C** compared to preindustrial levels, with the **highest temperature increases in northern Sudan and northern Kenya**. Very hot days will also increase, especially over Somalia, eastern Ethiopia and north-eastern Kenya.

Precipitation trends are uncertain and vary across Eastern Africa, with projections indicating an increase between 15 and 136 mm per year under RCP6.0. **Precipitation amounts are expected to increase across the northern and central parts of the region and to decrease further south.** Future dry and wet periods are likely to become **more extreme**.

Under RCP6.0, **sea levels** are expected to **rise by 43 cm along the coast of Eastern Africa until 2080.** This threatens coastal communities and may cause saline intrusion in coastal waterways and groundwater reservoirs.

Water availability is driven by climatic and socio-economic factors. Projections show **general increases** in water availability, with **varying intensities**. However, per capita water availability will likely decline by 2080, mostly due to population growth.

Due to the changing climate, yields of **cassava, groundnuts, millet, sorghum and rice are projected to benefit from CO_2 fertilisation**. Maize and wheat yields show high levels of uncertainty and no clear trend. It is likely that yields will increase in some parts and decrease in other parts of the region.

Climate change is likely to cause **damage to the infrastructure sector** in Eastern Africa including major roads and urban areas. Roads are the backbone of the region's transportation network and essential in linking farmers and markets. Investments will need to be made into **building climate-resilient roads** and other infrastructure to maintain agricultural supply chains and foster economic growth.

Agro-ecological zones (AEZs) in Eastern Africa might **shift, affecting ecosystems, biodiversity** and **crop production**. Models project varying trends for species richness and tree cover, depending on the region and scenario.

The **population share affected** by at least one **heatwave** per year is projected to **rise from 1.6 % in 2000 to 10.4 %** under RCP6.0 in 2080. More frequent heatwaves will negatively affect underlying health conditions, especially those of vulnerable groups. Without adaptation, **heat-related mortality** is estimated to **increase by a factor of more than 4** by 2080.

Climate impacts are likely to **exacerbate existing vulnerabilities and increase human mobility**, thus serving as **a risk multiplier for conflict** in an already politically fragile region. Women, children as well as poor, sick and elderly people will be disproportionately affected by climate impacts.

* This climate risk profile is the product of a collaboration between Weathering Risk, the AGRICA project and the B-EPICC project at PIK. It draws on the methodology developed within the AGRICA project.

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Context

Rising temperatures, changing precipitation patterns and more extreme weather events as a result of climate change pose **existential challenges to Eastern Africa.** For millions of people across the region, the losses and damages will be felt in various sectors, including water, agriculture, infrastructure, ecosystems and human health.

Eastern Africa is an African sub-region which has access to the **Indian Ocean** through more than **13,000 km of coastline**. While there are different definitions of the countries constituting Eastern Africa, this climate risk profile follows the definition of the African Union [1], in which the region is defined as the states of the **Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Mauritius, Rwanda, Seychelles, Somalia, South Sudan, Sudan, Tanzania and Uganda** (Figure 1) . In Eastern Africa, the population amounts to **over 402 million people** [2]. Ethiopia is the most populous country, with 118 million inhabitants [2]. Different from other African sub-regions, Eastern Africa is characterised by varying population growth rates, **ranging from no or very little population growth** in the island states of Mauritius and the Seychelles to **high population growth** in some mainland countries, for example, 3.0 % in Uganda and 2.9 % in Tanzania [2]. Based on these trends, it is predicted that the population of Eastern Africa will have more than doubled by 2050 [3]. Furthermore, the population in Eastern Africa is **one of the youngest in the world**, with more than 40 % of the population aged less than 14 years [2].

The **economic growth rate varies widely** within the region and GDP per capita rates cover the spectrum from 447 US dollar in Somalia to 15,714 US dollar in the Seychelles [2]. Although Eastern Africa was the only African sub-region that has **not experienced a recession as a result of the COVID-19 pandemic**, smallholder farmers felt the impacts of the pandemic through sickness and trade restrictions. The **war in Ukraine** further strains smallholder farmers through **increased prices** for different foods and fertilisers [4]. Irrespective of these more recent crises, Eastern Africa has been long characterised by **high poverty** rates, with **large parts of the population living on less than 2.15 US dollar a day**, which is the World Bank threshold for extreme poverty. The states of Mauritius and the Seychelles present exceptions since only minimal parts of the population (0.1 and 0.5 %, respectively) live in **extreme poverty** [2]. However, in all other Eastern African countries, extreme poverty rates are high, in particular in Somalia (71 %) and Madagascar (81 %) [2]. Consequently, most countries in the region rank **among the lowest on the Human Development Index (HDI)** [5].[1]

Figure 1: Topographic map of Eastern Africa.

[1] Somalia is not included in the Human Development Index.

Although the services sector contributes the largest share to the Eastern African economy, **agriculture** continues to be the **most important sector in terms of employment**, providing livelihoods for the majority of the population [2]. In some countries like Uganda the share of employment in agriculture is as high as 72 % [2]. The majority of agricultural production in Eastern Africa is **subsistence-based and rain-fed**. Hence, especially smallholder farmers suffer from climate impacts like rising temperatures, droughts or flooding, all of which can lead to crop failures and reliance on food assistance programs [6]. Particularly **women are disproportionately affected** by climate impacts, due to a greater dependence on natural resources and disparities in climate information, mobility and gendered responsibilities for children and other family members. Additionally, climate change is impacting the **availability of fertile soils and grassland**, which are essential resources not only for farmers but also for herders. In some parts of the region, such as Somalia, herders constitute the majority of the population [7]. However, this type of livelihood has been challenged by increasingly unpredictable precipitation patterns and insufficient grasslands, leading to increasing competition for limited natural resources, violent conflicts and **forced migration** [8].

In addition to poverty and food insecurity, countries in Eastern Africa tend to be characterised by **weak governance**, which is reflected in poor provision of participatory structures, basic services and accountability mechanisms: According to the 2019 Ibrahim Index of African Governance, Somalia, South Sudan and Eritrea ranked among the lowest in terms of their governance performance [9]. Weak governance, along with **high levels of corruption** [10], result in **political instability**, which is also demonstrated in the Fragile States Index, where the majority of Eastern African countries score low [11]. For example, Somalia and South Sudan are ranked among the three most fragile countries, along with Syria. In particular **Somalia** has witnessed a combination of stressors, including ongoing **armed conflict, insecurity, drought and humanitarian crises**, causing hundreds of thousands to flee and seek refuge in other countries [12].

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Topography and environment

The topography of Eastern Africa is largely determined by the **East African Rift Valley**[2] and the **East African Highlands**, which make **the region’s landscape highly diverse**. The East African Highlands span from the Red Sea to southern Tanzania, including the Ethiopian massif to the north; the Kenyan highlands, which are fringed by Africa's highest mountains Mount Kibo (Kilimanjaro) (5,895 m) in Tanzania and Mount Kenya (5,199 m); and the Western Rift Mountains stretching from western Uganda to southern Tanzania. Between the Ethiopian and the Kenyan highlands, the Turkana Gap, a 300-km wide depression, connects the region’s two major low-lying areas: the Nile Plains to the north-west, covering most of Sudan and South Sudan, and the plains to the east, which border the Indian Ocean. The latter region is also home to the continent’s lowest depressions, including Lake Assal in Djibouti (153 m below sea level) and the Danakil Depression in Ethiopia (125 m below sea level). The region comprises **different agro-ecological zones (AEZs)** (Figure 2) with specific temperature and moisture regimes, which are largely determined by the region’s topography. Accordingly, Eastern Africa can be divided into warm arid to semi-arid tropics in the north-western and eastern plains, sub-humid to humid warm tropics in the plateau region and the island states, and cool arid to humid conditions in regions of high altitude.

Eastern Africa is home to the **African Great Lakes**, a lakes region in and around the East African Rift Valley. Important lakes include Lake Victoria, Africa's largest and the world's second largest freshwater body, and Lake Tanganyika, Africa's second largest and the world's second deepest lake [13] (Figure 2). The **Nile River**, the region’s most important and Africa’s longest river, flows northwards from Burundi through Rwanda, Uganda, South Sudan, Sudan, Ethiopia and Egypt towards the Mediterranean Sea. The **Niger river catchment area** comprises almost 3.4 million km³ (10 % of Africa’s total area), and provides the population in the Nile Valley with water and fertile soils for agriculture [14] (Figure 2). Nevertheless, most Eastern African countries are characterised by **water stress or water scarcity**, with water demand exceeding available renewable water resources. Some countries like Djibouti, Eritrea, Ethiopia, Somalia and Kenya are among the most drought-affected countries in the world [15].

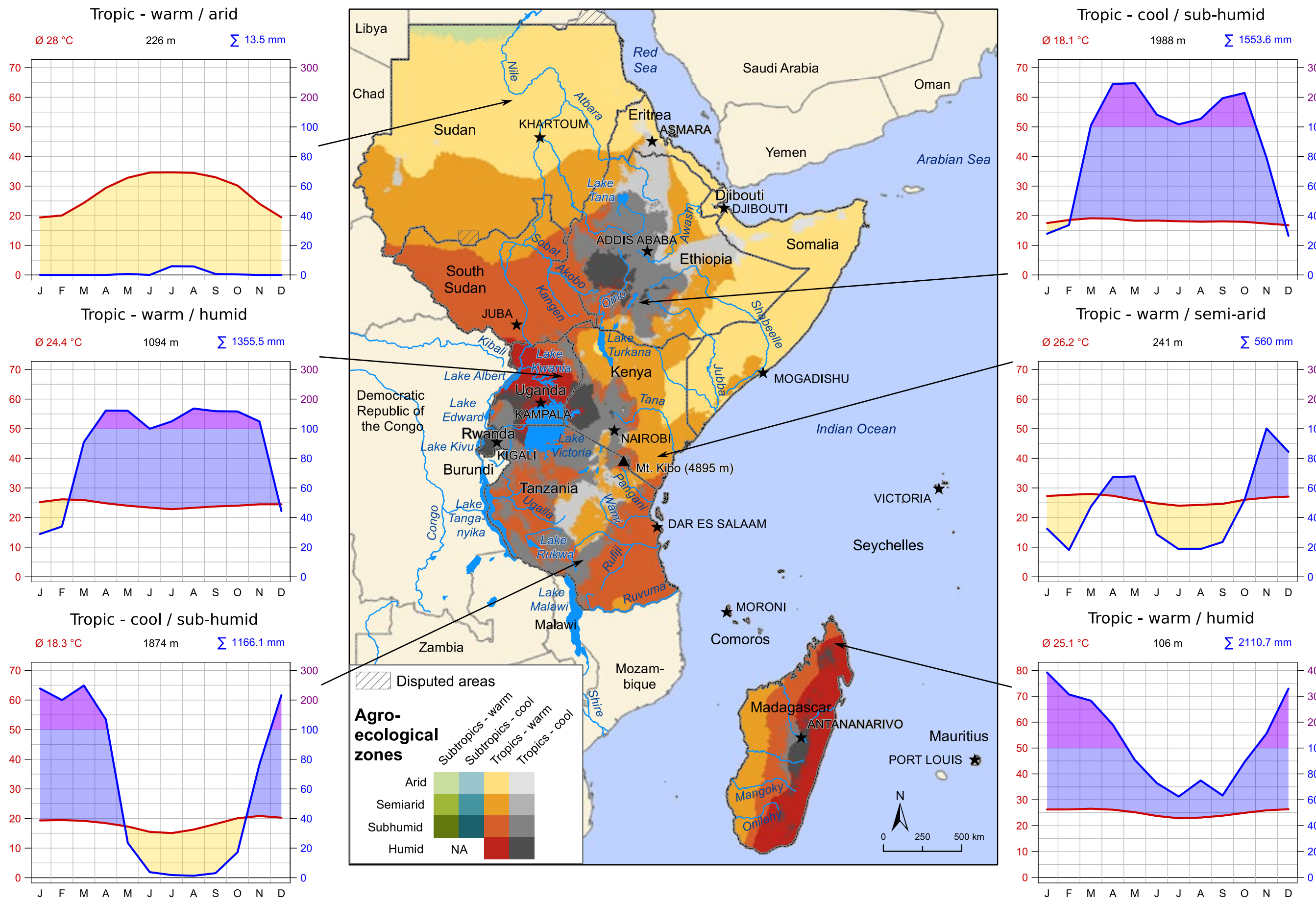

Figure 2 : Map of Eastern Africa showing agro-ecological zones and location-specific examples of annual temperature and precipitation patterns.

[2] The East African Rift Valley is part of the Great Rift Valley which spans 6,000 km from northern Syria to the south of Mozambique. Its geological activity created the highest mountains and the deepest lakes on the African continent.

Present and past climate

Currently, average annual **temperatures** in Eastern Africa **range from 11.6 to 30.7 °C**, with lower temperatures across the region's high altitudes and higher temperatures in the Sahel and the Saharan desert, as well as in southern Somalia and northern Kenya [18]. Mean annual **precipitation amounts for Eastern Africa vary**, ranging from over 2,000 mm in south-western Ethiopia to less than 250 mm in the arid regions of Djibouti, Eritrea, Ethiopia, Kenya, Somalia and Sudan [13]. The region is characterised by **two types of precipitation regimes**: Unimodal precipitation regimes with one rainy season and bimodal precipitation regimes with two rainy seasons. Unimodal precipitation regimes are predominantly found in the northern and southern parts of Eastern Africa, with one rainy season from around June to September, while the equatorial regions and most of the Indian Ocean coastal plains have two rainy seasons, with the long rains falling from around March to May and the short rains from around October to December [13] [15]. Precipitation **regimes also differ within countries**: Tanzania, for example, experiences both unimodal and bimodal precipitation.

Between **1973 and 2013**, mean annual **temperatures increased** by between 0.7 to 1 °C, depending on the season. The number of warm days and warm nights also increased [16]. Since the 1980s, **decreasing precipitation during the long rainy season** (March to May) has been observed over the Horn of Africa, although this decrease has recovered more recently. In contrast, total precipitation during the shorter rainy season (October to December) increased since the 1960s. In the northern part of the region, precipitation decreased in the 1960s and has remained relatively low since then. **Heavy precipitation events** also increased both in frequency and intensity [17].

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Projected climate changes

How to read the line plots

historical — best estimate
RCP2.6 — likely range
RCP6.0 — very likely range

Lines and shaded areas show multi-model percentiles of 31-year running mean values under RCP2.6 (blue) and RCP6.0 (red). Lines represent the best estimate (multi-model median) and shaded areas the likely range (central 66 %) and the very likely range (central 90 %) of all model projections.

How to read the map plots

Colours show multi-model medians of 31-year mean values under RCP2.6 (top row) and RCP6.0 (bottom row) for different 31-year periods (central year indicated above each column). Colours in the leftmost column show these values for a baseline period (colour bar on the left). Colours in the other columns show differences relative to this baseline period (colour bar on the right). The presence (absence) of a dot in the other columns indicates that at least (less than) 75 % of all models agree on the sign of the difference. For further guidance and background information about the figures and analyses presented in this profile please refer to the supplemental information.

Temperature changes

Air temperature

The **air temperature over Eastern Africa is projected to rise by 1.7 to 3.9 °C (very likely range) by 2080 relative to the year 1876**, depending on the future GHG emissions scenario (Figure 3). Under the low emissions scenario RCP2.6, compared to pre-industrial levels, the projected air temperature increase will very likely range between 1.6 and 2.0 °C by 2030, and between 1.7 and 2.2 °C by 2080. Median increases amount to approximately 1.7 °C in 2030, 2.0 °C in 2050 and 2.1 °C in 2080 under RCP2.6. Under RCP6.0, air temperature will increase by between 1.6 and 1.9 °C by 2030, and between 2.7 and 3.9 °C by 2080 (very likely range). Median increases amount to 1.7 °C in 2030, 2.2°C in 2050 and 3.1 °C in 2080.

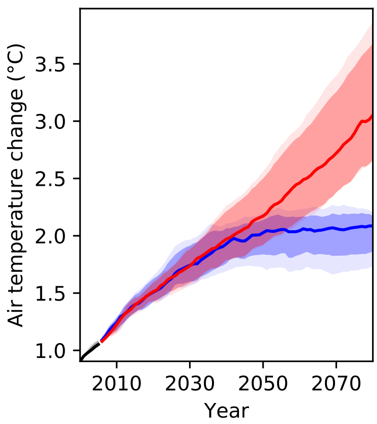
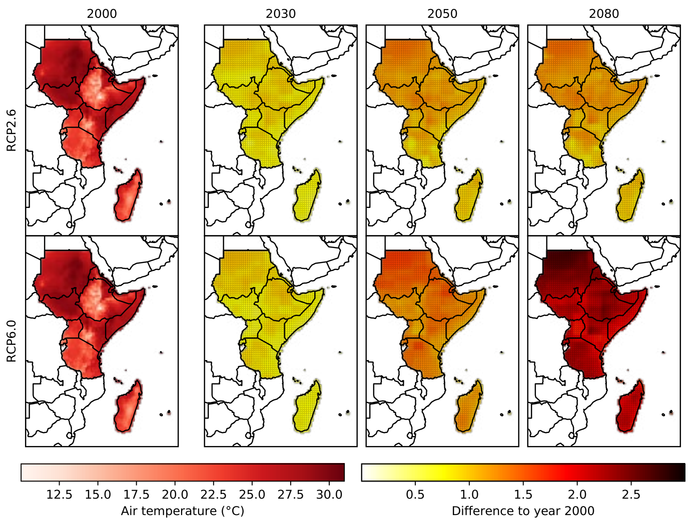


Figure 3: Air temperature projections for Eastern Africa for different GHG emissions scenarios.[3]



Air temperature increases will affect the entire region (Figure 4). However, their magnitude will vary: The highest values will be found in northern Sudan and northern Kenya, where average temperatures will increase by up to 2.7 °C by 2080 under RCP6.0. Overall, temperature increases will be comparatively lower across large parts of Uganda, southern Kenya and along the coasts of Kenya, Somalia and Tanzania. Nevertheless, in the long term, these countries will also experience temperature increases of at least 1.5 °C by 2080 under RCP6.0.

Figure 4: Regional air temperature projections for Eastern Africa for different GHG emissions scenarios.

[3] Note that the baseline for Figure 4 is the year 2000, while for Figure 3, this is the year 1876. Hence, the projected differences are lower for Figure 4 than for Figure 3.

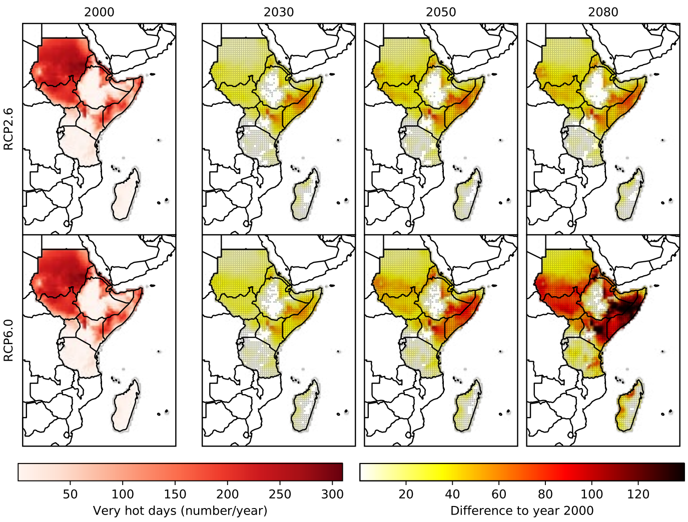


Figure 5: Regional projections of the annual number of very hot days (daily maximum temperature above 35 °C) for Eastern Africa for different GHG emissions scenarios.[4]

Very hot days

In line with rising temperatures, the **number of very hot days** (days with a daily maximum temperature above 35 °C) **will increase**, yet to **varying degrees** across the region (Figure 5). Under RCP6.0, large parts of Somalia, eastern Ethiopia and the north-east of Kenya are projected to experience up to 66 and 165 additional very hot days by 2030 and 2080, respectively. Parts of South Sudan, southern Sudan and Eritrea will also experience high long-term increases under the same scenario.

Sea level rise

Sea level rise is **not uniform across the globe** but subject to regional differences due to thermal expansion of water and ocean currents, among other factors. Averaged over the entire coastline of Eastern Africa, median **increases in sea level rise** amount to 12 cm by 2030 and 35 cm by 2080 under RCP2.6, compared to the year 2000 (Figure 6). While the median sea level rise under RCP6.0 will increase to around 11 cm by 2030, the long-term median increase will be much higher than under RCP2.6, amounting to **43 cm by 2080**. A vulnerability assessment identified **Somalia as being at particular risk** of rising sea levels, largely due to the combined effects of low-lying coastal areas, vegetation loss and low institutional and socio-economic capacity to adapt. According to the assessment, Kenya and Tanzania face similar challenges, albeit to a smaller degree [18]. Rising sea levels threaten coastal communities and may cause **saline intrusion in coastal waterways and groundwater reservoirs**, rendering water unusable for domestic use and harming biodiversity.

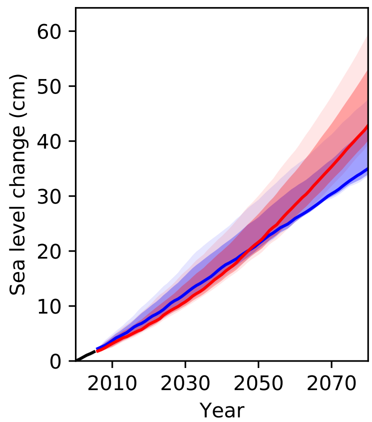


Figure 6: Projections for sea level rise, averaged over the Eastern African coastline for different GHG emissions scenarios, relative to the year 2000.

[4] Due to the high altitude in the regions which are marked as blank, there are no days when the daytime temperature exceeds 35 °C degrees.

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Uncertainties in climate change projections

Uncertainties are always part of climate change projections. They arise from various factors, including natural variability, uncertainties in GHG emissions scenarios and differences in the models which are used in the projections [19]. Consequently, no future (climate change) projection comes without some level of uncertainty. The levels of uncertainty, however, differ. We present the results of ten different global models. To indicate the uncertainty of the projections we consider model agreement. The more models agree, the higher the certainty; the more they disagree, the lower the certainty. For example, if different models project a similar result under the same scenario, the projected changes demonstrate low levels of uncertainty. However, if they project very different changes (in terms of range and even direction) under the same scenario, then projections are uncertain. Generally speaking, projections regarding temperature-related data are more certain than projections regarding precipitation-related data. Precipitation-related data is subject to higher uncertainty, as many of the atmospheric and surface processes that influence local precipitation patterns are difficult to model in their entirety. For example, while the formation of clouds is an important factor for precipitation, it takes place at a smaller scale than that which is applied in global models in order to model processes at a much larger scale, which is equally relevant for local precipitation.

Precipitation, flood and drought risks

Precipitation

Precipitation projections are less certain than temperature projections (Figure 7). **Under RCP2.6 and compared to the year 2000, precipitation will very likely increase by between 7 and 38 mm per year** (best estimate of around 17 mm) by 2030. In the long term, precipitation changes will very likely range between −11 and 60 mm while the best estimate shows a decrease by more than 3 mm by 2080. In contrast, **under RCP6.0, precipitation is projected to increase**, although uncertainty remains high, with further increases from 2030 onwards. Precipitation will very likely increase by between 7 and 29 mm per year (best estimate of 18 mm) by 2030, and between 15 and 136 mm per year (very likely range, best estimate of 31 mm) by 2080, compared to the year 2000.

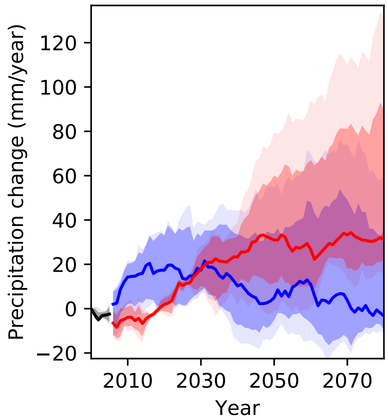

Figure 7: Annual mean precipitation projections for Eastern Africa for different GHG emissions scenarios, relative to the year 2000.

Not only do precipitation amounts vary across Eastern Africa, but also the direction and magnitude of changes vary. Overall, **precipitation amounts are projected to increase in the northern and central parts of Eastern Africa, and to decrease further south** (Figure 8). A **wetting trend is expected in the medium to long term under RCP6.0**, particularly in much of the Horn of Africa and in Kenya and Uganda. In contrast, the south of Tanzania and most of Madagascar will see decreases in precipitation under both scenarios. An **exception is the north of Sudan**, where both sharp increases and sharp decreases are projected under both scenarios. In some regions, especially under RCP2.6, projections are **uncertain.**

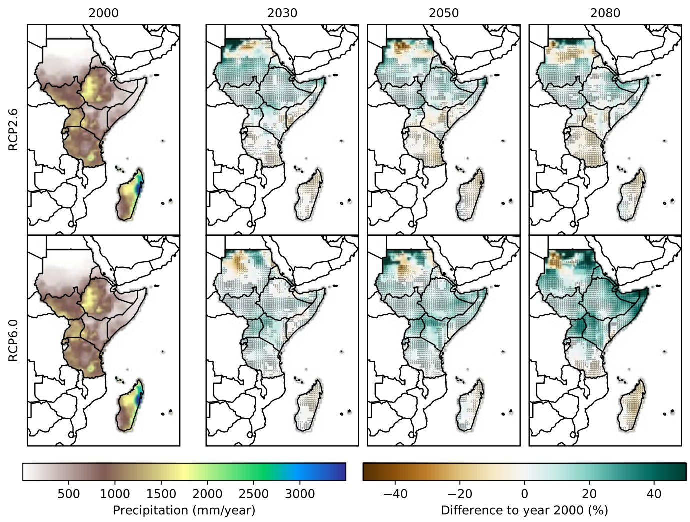

Figure 8: Regional projections of the annual mean precipitation for Eastern Africa for different GHG emissions scenarios, relative to the year 2000.

Frequency of heavy precipitation events

In response to global warming, **heavy precipitation events are expected to become more intense in many parts of the world** due to the increased water vapour holding capacity of a warmer atmosphere. At the same time, the number of days with heavy precipitation events is expected to increase. This tendency is also reflected in climate projections for Eastern Africa. Despite uncertainties, particularly under the low emissions scenario, the overall number of **days with heavy precipitation is projected to increase** (Figure 9). However, looking at different parts of the region, there are differences in the magnitude of change. For example, Uganda and southern South Sudan will see much higher increases than other parts of the region.

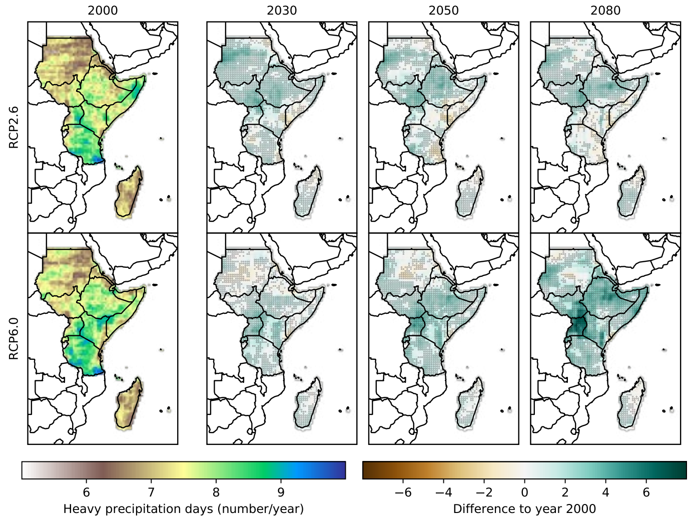

Figure 9: Regional projections of the number of days with heavy precipitation over Eastern Africa for different GHG emissions scenarios, relative to the year 2000.

Soil moisture

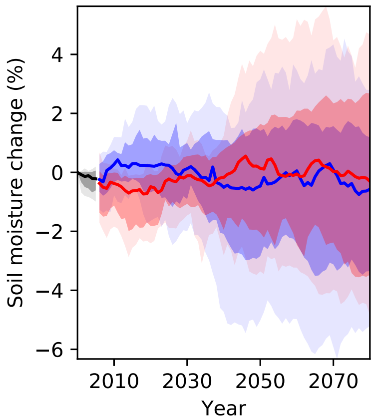

Figure 10: Soil moisture projections for Eastern Africa for different GHG emissions scenarios, relative to the year 2000.

Soil moisture is an **important indicator for drought conditions**. In addition to soil properties and management, it depends on both precipitation and temperature, as higher temperatures translate to higher potential evapotranspiration. Projections for annual mean soil moisture for a soil depth of up to 1 metre show a **decrease of 0.6 % under RCP2.6 and 0.3 % under RCP6.0** by 2080, compared to the year 2000 (Figure 10). Similar values can be observed throughout the century. However, among the different models underlying this analysis, there is **large year-to-year variability and modelling uncertainty**, with two models projecting an increase, one a decrease and one no change in soil moisture. The degree of uncertainty is reflected in the very likely range, which widens towards the end of the century, including decreases of up to 4.9 % and increases of up to 4.7 % under RCP6.0. In a similar way, the very likely range under RCP2.6 spans from a decrease of 5.2 % to an increase of 2.8 % by the year 2080.

Potential evapotranspiration

Potential evapotranspiration is the amount of water that would be evaporated and transpired if sufficient water was available at and below land surface. Since warmer air can hold more water vapour, it is expected that **global warming will increase potential evapotranspiration in most regions of the world**. In line with this expectation, hydrological projections for Eastern Africa indicate a stronger and more continuous rise of potential evapotranspiration under RCP6.0 than under RCP2.6 (Figure 11). Under RCP6.0, **potential evapotranspiration is projected to increase by 2.3 % in 2030 and by 5.7 % in 2080,** compared to the year 2000. Under RCP2.6, projections show an increase by 2.4 % in 2030 and a preliminary peak of 3.3 % around the year 2042, after which the increases settle around this rate until 2080.

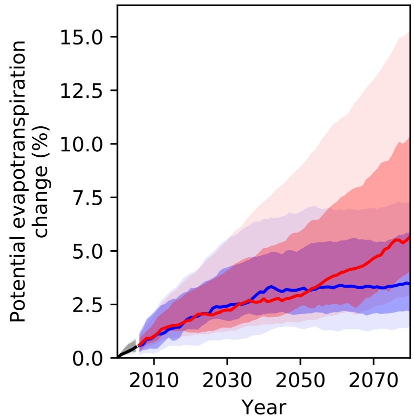

Figure 11: Potential evapotranspiration projections for Eastern Africa for different GHG emissions scenarios, relative to the year 2000.

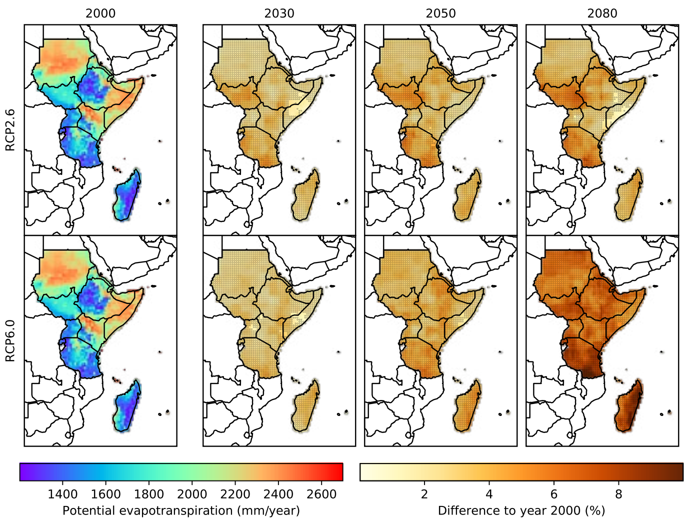

Figure 12: Regional projections of potential evapotranspiration for Eastern Africa for different GHG emissions scenarios, relative to the year 2000.

An **increasing trend** in potential evapotranspiration can be observed **all over Eastern Africa** and with high certainty (Figure 12). Countries which already experience high rates of potential evapotranspiration, such as Somalia and Sudan, will see the lowest percentage increases, however, they will arrive at the highest absolute rates by the end of the century. The **highest percentage increases will take place in Madagascar and southern Tanzania**. Higher evapotranspiration affects the water supply and the amount of surface water available for agriculture. It can reduce the fraction of precipitation that flows over land and into streams and rivers. Long-term shifts in recharge patterns can change groundwater levels and subsequently groundwater surface water interactions and soil moisture.

Sector-specific climate change risk assessment

a. Water resources

Climate models for Eastern Africa **project a wetter future** under climate change, while the current **reality is marked by decreasing precipitation** levels during the long rains [20]. This disjunction is also referred to as the **East Africa climate paradox** [21]. The models in our analysis display high uncertainty of water availability in Eastern Africa under both emissions scenarios.

Assuming a constant population level, multi-model median projections suggest a change of per capita water availability from 5,616 m³ in the year 2000 to 5,909 m³ in the year 2080 under RCP2.6 and 6,154 m³ under RCP6.0 (Figure 13A). Yet, when accounting for population growth according to SSP2 projections[5], **per capita water availability for Eastern Africa is projected to decline** dramatically, i.e. from 5,852 m³ in the year 2000 to 1,766 m³ in the year 2080 under RCP2.6 and 1,840 m³ under RCP6.0 (Figure 13B). This decline is not primarily driven by climate change, but rather by socio-economic factors. These factors include population growth, along with increased agricultural production, leading to increased water abstraction for irrigation, drinking water, domestic use and hydropower generation [22]. The decline in water availability highlights the **urgency to invest in water saving measures and technologies** for future water consumption, particularly after 2050, when median decreases start approaching the threshold for water stress (1,700 m³).

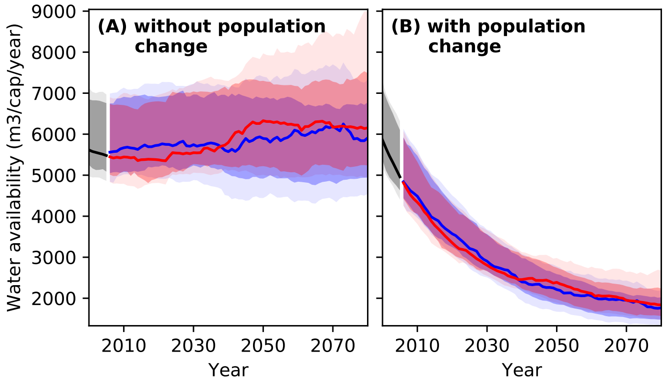

Figure 13: Projections of water availability from precipitation per capita and year with (A) national population held constant at year 2000 level and (B) changing population in line with SSP2 projections for different GHG emissions scenarios, relative to the year 2000.

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[5] Shared Socio-economic Pathways (SSPs) outline a narrative of potential global futures, including estimates of broad characteristics such as country level population, GDP or rate of urbanisation. Five different SSPs outline future realities according to a combination of high and low future socio-economic challenges for mitigation and adaptation. SSP2 represents the "middle of the road"-pathway.

Median projections of water availability from precipitation indicate a decrease of 4.7 % under RCP2.6 and an increase of 2.6 % under RCP6.0 by the year 2080 (Figure 14). However, there is **high modelling uncertainty**, which is illustrated by the large shaded area in Figure 14. Under RCP2.6, the very likely range will widen to between −3.2 and +7.0 % in 2030, −10.6 and +14.0 % in 2050, and −11.3 and +15.7 % in 2080, compared to the year 2000. Under RCP6.0, the very likely range is even more pronounced, widening to between −2.0 and +4.3 % in 2030, −7.4 and +21.6 % in 2050, and −5.5 and +37.1 % in 2080. Hence, **no clear trend in water availability from precipitation** can be identified.

Eastern Africa is home to some of the **largest transboundary water resources in the world**, including Lake Tanganyika, Lake Victoria and the river Nile. While these sources deliver much-needed water to millions of people, large parts of Eastern Africa have **poor access to water resources**. For example, total renewable water resources per capita range from 308 m^3 / year in Djibouti to 12,496 m^3 / year in Madagascar [23]. In many countries, total renewable water resources heavily **depend on external sources**. In Eritrea, for instance, 62 % of total renewable water resources come from outside the country [23]. The transboundary nature of water sources complicates an equal distribution of water resources, along with **poorly developed infrastructures** for the transportation of water. Where surface water is seasonal, drought-affected or not available, **people depend on groundwater reserves** [24]. This is an issue in the entire region, but particularly the case in northern Sudan, which receives almost no precipitation; and large parts of Somalia, Djibouti, Eritrea, eastern Ethiopia and north-eastern Kenya, where annual precipitation sums are extremely low. **Reduced precipitation, temperature increases and more frequent droughts** negatively impact surface and groundwater availability with declining trends [25].

Overall, water demand is going to increase due to **population growth**, along with rapid and uncontrolled **urbanisation, agricultural and hydropower expansion, deforestation and mining**, among other socio-economic drivers [22]. These drivers are putting pressure on Eastern Africa's water resources, leading to their **degradation and depletion**. The combined effects of climate change and socio-economic drivers can be observed in **decreasing water levels in Lake Victoria**, which receives 80 % of its freshwater from direct precipitation [26]. In the period from 2004 to 2005, water levels in Lake Victoria dropped by 1.1 m to a height of 10.69 m, reaching the lowest level since 1951 [27]. This drop was attributed to drought, in addition to unsustainable dam operations [27]. Water levels recovered recently, reaching a reversed record of 13.42 m in May 2020 [28]. This rise was attributed to continued precipitation, which started in late 2019 and resulted in the displacement of more than 480,000 people across the region [28].

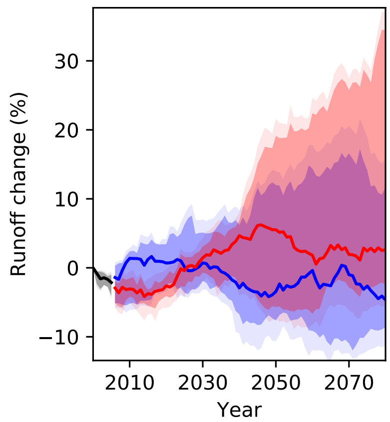

Figure 14: Water availability from precipitation (runoff) projections for Eastern Africa for different GHG emissions scenarios.

In many parts of Eastern Africa, **dams** are constructed to **store water** for shortages during the dry season and to **generate hydropower**, thereby reducing a reliance on fossil fuels and fuelwood [29]. However, these benefits often come **at the cost of downstream water shortages**, caused by changes in the flow regime. For example, in recent years, the construction of the Grand Ethiopian Renaissance Dam has caused **tensions among the riparian states** of the river Nile, in particular the downstream riparian states Sudan and Egypt, who both compete for water from the Nile, as well as with the upstream riparian state Ethiopia, which controls much of the river flow [30]. Similar tensions can be observed across the region. In combination with recurrent droughts, changes in river flow can negatively impact ecosystems and human livelihoods and lead to **conflicts over the use of and access to water resources**.

b. Agriculture

The **main economic activity** in Eastern Africa is agriculture, engaging up to 80 % of the population in some countries [2]. Crop production is **primarily subsistence-based and rain-fed**, with limited use of irrigation. Accordingly, the choice of livelihood is strongly influenced by climatic and topographic factors: The north of Eastern Africa, which includes parts of the Sahara, is characterised by a **desert climate**, resulting in extremely **low amounts of precipitation**. Similarly, the **eastern mainland** of the region receives very little precipitation. Here as well as in other drier parts of Eastern Africa, people turn **primarily to pastoral activities**, sometimes in addition to growing **drought-resistant crops like sorghum and millet** [31]. This type of livelihood is typically pursued in areas with annual precipitation amounts of **700 mm and less**, while farming constitutes the main source of income in wetter areas.

Agricultural livelihoods in **other parts of Eastern Africa** are more diversified. Farming activities are typically dominated by growing subsistence crops like **sorghum, maize, groundnut, millet, rice, cassava and wheat**, while major cash crops include **coffee** and **tea** [33]. Ethiopia, Uganda and Kenya are the main coffee growing countries [34]. Since growing coffee requires warmth and humidity, the highlands in these countries present a particularly conducive environment for this cash crop. The growing conditions of tea are similar, however, this crop is primarily produced in Kenya, which is the major tea-producing country in Africa. Furthermore, Kenya is known for its horticultural products and the export thereof. In 2020, **cut flowers** contributed 9.1 % of Kenya's total export volume [35]. While this sector is important for the country's economy, it is also **water-intensive** and comes at the cost of smallholder farmers and urban populations, who **compete over this scarce resource** [36].

Not only in Kenya but also in other countries in Eastern Africa, agriculture has experienced an increasing **market orientation** and **industrialisation** of the sector. This trend, along with a **growing population**, has led to a rapid and often uncontrolled **expansion of cropland** to keep pace with demand [31]. Often, this expansion is only possible **at the expense of large areas of forests**, which are cleared and converted to cropland. These changes put pressure on land and soils, increasing **soil degradation and desertification**, which in turn **reduces the productive capacity of soils** and strongly affects subsistence farmers [37]. For both farmers and pastoralists, these trends have led to an increasing fragmentation of farming and grazing land and, in turn, to overfarming and overgrazing of land, putting additional strain on people and the environment.

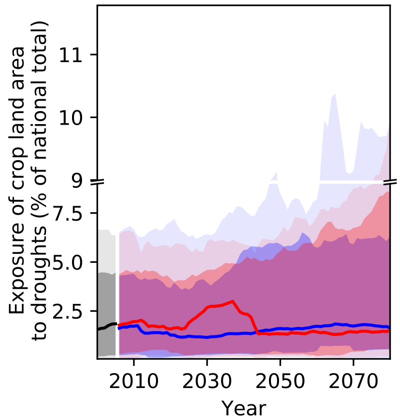

Figure 15: Projections of crop land area exposed to drought at least once a year for Eastern Africa for different GHG emissions scenarios.

Currently, the high uncertainty of precipitation projections (Figure 7) translates into high uncertainty of drought projections (Figure 15). According to the median and compared to the year 2000, **the national crop land area exposed to at least one drought per year will remain stable at around 1.5–1.6 % under both scenarios by 2080.** While median changes are marginal, the range of projected changes shows a different picture: The likely range of drought exposure of the national crop land area per year widens from 0.2–4.4 % in 2000 to 0.5–6.3 % under RCP2.6 and 0.6–8.6 % under RCP6.0 in 2080. The very likely range widens from 0.1–6.7 % in 2000 to around 0.2–10.0 % under both scenarios in 2080. **Some models project a doubling of drought exposure over this time period.**

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In terms of **yield projections**, median projections for RCP6.0 indicate a **positive trend** for **cassava** (20 %), **groundnuts** (13 %), **millet** and **sorghum** (26 %), and **rice** (7 %) by 2080 and compared to the year 2000 (Figure 16). At the beginning of the century, these crops see a similar trend under both scenarios. However, after the year 2030, the increases under RCP2.6 stagnate (e.g. millet and sorghum) or even turn into decreases towards the end of the century, for example, in the case of cassava, groundnuts or rice. Different from the above crops, median projections of **maize and wheat yields show high levels of uncertainty** and no clear trend towards the end of the century, with the exception of a 4 % decrease for maize under RCP2.6.

Although some yield changes may appear small at the regional level, they will likely increase more strongly in some countries and, conversely, decrease more strongly in other countries as a result of climate change. For example, the median changes of maize yields in Eastern Africa appear marginal, compared to other crops. However, Figure 17 shows that by 2080 and under RCP6.0, south-eastern Sudan will see decreases of up to 32 %, while in eastern Ethiopia, there will be increases of up to 77 %. These different changes point to a **shift in crop suitability**, with some regions becoming unsuitable and others becoming suitable for growing different crops. Farmers will have to adapt to these changing conditions. Overall, **crop growth and failure depend on a variety of factors** which are projected to change in the future. While higher frequency and intensity of extreme weather events, such as flooding, droughts or heat stress, can have negative effects, other climate-related changes can have positive effects, including increasing levels of water availability, higher temperatures in highland areas or greater concentrations of carbon dioxide, which can facilitate photosynthesis in some crops and spur growth.

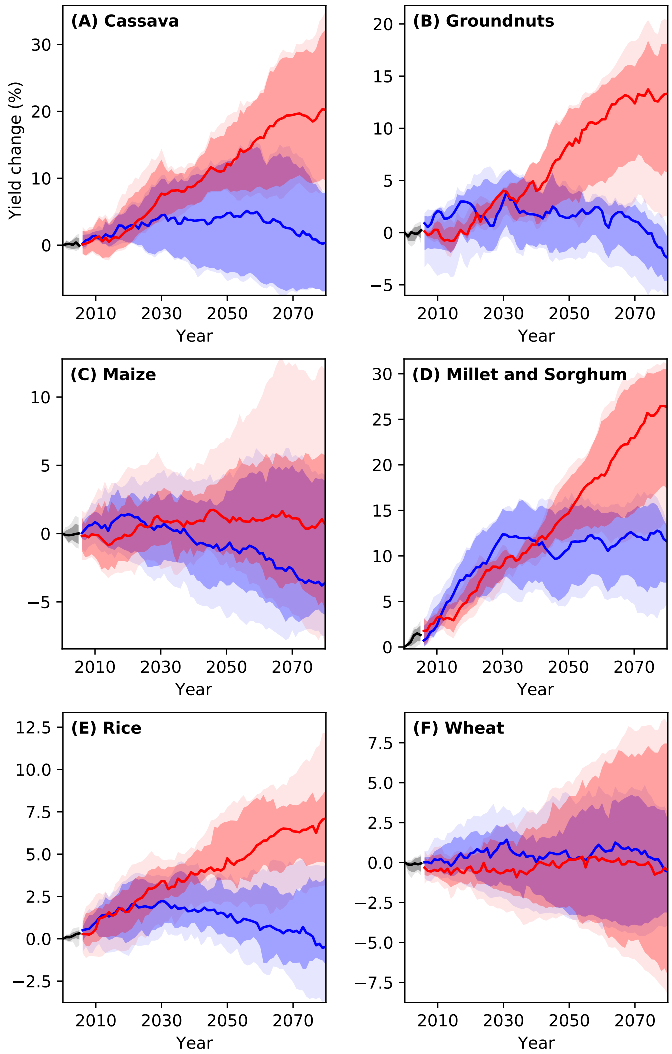

Figure 16: Projections of crop yield changes for major staple crops in Eastern Africa for different GHG emissions scenarios assuming constant land use and agricultural management, relative to the year 2000.

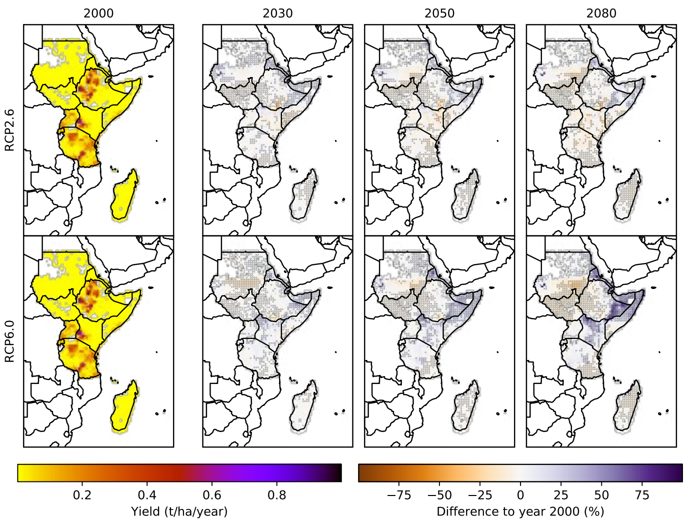

Figure 17: Regional projections of maize yields for Eastern Africa for different GHG emissions scenarios assuming constant land use and agricultural management, relative to the year 2000.

Climate impacts on agricultural production can have **differential impacts on men and women**, whose tasks in agricultural activities and rural households are often gendered. For example, women tend to be responsible for growing crops for household food consumption, while men tend to be responsible for cash and export crops [38]. In many parts of Eastern Africa, women are also responsible for water collection, which can present an **additional burden** where water is becoming scarce and where the travelling time to wells is increasing [39]. This is particularly true for the dry season, when many men migrate for work, **making women the de-facto managers of households and agricultural production**.

c. Infrastructure

Climate change is expected to affect the infrastructure of Eastern Africa. High precipitation amounts can lead to the **flooding of transport networks**, while high temperatures can cause **roads, bridges and infrastructures to develop cracks and degrade more quickly**. The Rural Access Index, which is defined as the proportion of the rural population living within 2 km of an all-season road, lies between 19–96 % in Eastern Africa, depending on the country. While South Sudan, Sudan and Somalia achieve the lowest scores with 19–20 %, island states and smaller countries like Mauritius (96 %), the Seychelles (92 %) and Rwanda (80 %) achieve the highest scores [40]. Although road access tends to be highest in coastal areas, the case of Somalia shows that political instability and violent conflict can serve to impede infrastructural development. Especially during the rainy season, many inland **rural roads are inaccessible**, cutting off villages and communities. Investments will have to be made to build climate-resilient infrastructure, such as roads and railway networks.

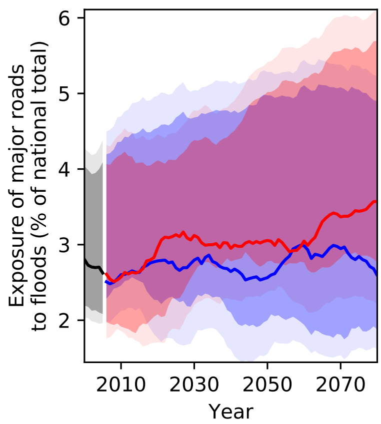

Figure 18: Projections of major roads exposed to river floods at least once a year for Eastern Africa for different GHG emissions scenarios.

Extreme weather events also have **devastating effects on human settlements and economic production sites**, especially in cities like Nairobi, Dar es Salaam or Addis Ababa, characterised by large populations and high population density. **Informal settlements are particularly vulnerable to extreme weather events**: Makeshift homes are often built at unstable geographical locations including steep slopes or river banks, where strong winds and flooding can lead to landslides, contamination of water, loss of housing, injury or death. Dwellers usually have a low adaptive capacity to respond to such events due to high levels of poverty and lack of risk-reducing infrastructures. For example, after heavy precipitation in 2020, the **northern part of Eastern Africa**, in particular Ethiopia, Sudan and South Sudan, **experienced heavy flooding**, which **affected more than 3.6 million** in the entire region [41]. The flooding caused damage and destruction of houses, crops and livestock, as well as infrastructures, including roads and bridges [41]. It coincided with other challenges including the COVID-19 pandemic, the desert locust outbreak and violent conflicts, forcing people to cope with back-to-back shocks.

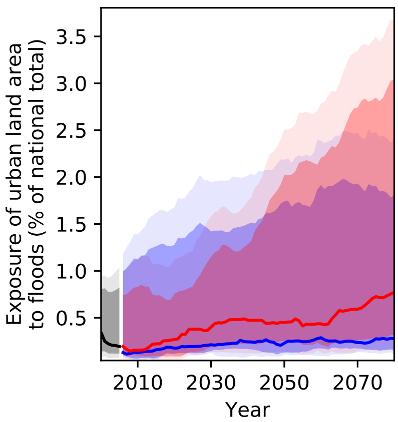

Figure 19: Projections of urban land area exposed to river floods at least once a year for Eastern Africa for different GHG emissions scenarios.

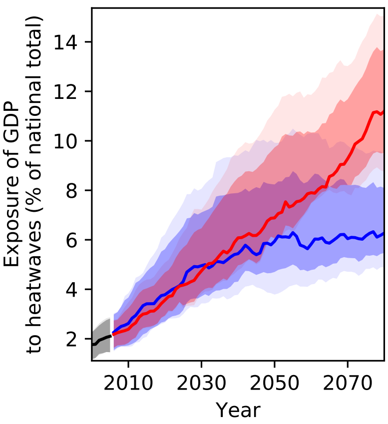

Figure 20: Exposure of GDP in Eastern Africa to heatwaves for different GHG emissions scenarios.

Climate change is likely to cause damages to infrastructure, yet a precise projection of the location and extent of these impacts is difficult to make. Local vulnerability assessments of critical infrastructure are needed. For example, projections of river flood events are subject to high modelling uncertainty, largely due to the uncertainty of future projections of precipitation amounts and their spatial distribution, which affects flood occurrence (see also Figure 7). In the case of Eastern Africa, median projections show **an increase in national road exposure to river floods** under RCP6.0 (Figure 18). In 2000, 2.8 % of major roads were exposed to river floods at least once a year. By 2080, this value is projected to increase to 3.6 % under RCP6.0 and to decrease to 2.6 % under RCP2.6. While the median change appears small, a look at the range of changes shows a different picture. For example, under RCP6.0, the very likely range will widen from 2.03–4.3 % in 2000 to 2.2–6.1 % in 2080, indicating much higher possible increases.

In a similar way, the median **exposure of urban land area to river floods** shows little change: Under RCP2.6, it is projected to fluctuate around 0.3 % throughout the century, while under RCP6.0, it is projected to increase from 0.34 % in 2000 to 0.77 % by 2080 (Figure 19). However, the very likely range shows the possible magnitude of changes also in this case: Under RCP6.0, the very likely range will widen from 0.1–0.9 % in 2000 to 0.2–3.7 % in 2080.

The **exposure of the GDP to heatwaves is projected to increase** from around 4.1 % in 2000 to 14.2 % (RCP2.6) and 19.1 % (RCP6.0) by 2080 (Figure 20). It is thus recommended that policy planners start identifying heat-sensitive economic activities and production sites, providing shading of public spaces and integrating climate adaptation strategies such as improved solar-powered cooling systems, "cool roof" isolation materials or switching the operating hours from day to night [41].

d. Ecosystems

Eastern Africa is known for its **rich biodiversity**, being home to some of the world's 36 biodiversity hotspots.[6] These hotspots include the mountains of the Eastern Afromontane which stretch from Saudi Arabia to Mozambique, the arid Horn of Africa, the Coastal Forests of Eastern Africa, as well as Madagascar and its neighbouring island groups. Similar to the region's terrestrial ecosystems, its aquatic ecosystems are also rich in biodiversity, as they are home to high numbers of endemic fish species, such as in Lake Tanganyika [42] [43].

Climate change contributes to **land degradation and desertification**, posing a serious threat to farming and pastoral communities. In addition, it is expected to affect the ecology and distribution of tropical ecosystems, although the magnitude and direction of these impacts are uncertain [44]. Climatic changes can also impact the succession in forest systems, while concurrently increasing the risk of invasive species, all of which affects ecosystems. In addition to these climatic drivers, low agricultural productivity and population growth might motivate unsustainable agricultural practices, resulting in increased deforestation, fires and land degradation.

Furthermore, climate change impacts **freshwater and marine ecosystems**. Reduced precipitation and increased droughts have already increased the water temperature of Eastern African lakes and rivers, thereby negatively impacting the habitat for freshwater species [43]. In addition, the region's coral reefs, which host a great variety of rare marine species and serve as a natural barrier against storm waves and coastal erosion, will be affected by rising sea surface temperatures and ocean acidification: At 2°C of global warming, it is projected that over 90 % of Eastern African coral reefs will very likely be destroyed [18].

Shifts in **species distribution** in relation to climate change are also evident. For example, over the last four decades, tropical bird species in the Usambara Mountains of Tanzania, a global biodiversity hotspot, have shifted uphill in response to global warming [45].

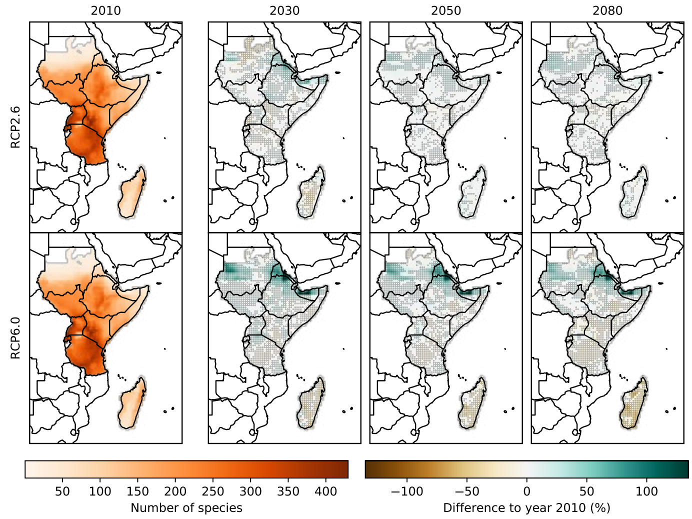

Figure 21: Regional projections of the aggregate number of amphibian, bird and mammal species for Eastern Africa for different GHG emissions scenarios.[7]

Model projections of species richness, including amphibians, birds and mammals, and tree cover for Eastern Africa are shown in Figure 21 and 22, respectively. Trends in species richness **differ depending on the region and scenario**. Projections under RCP2.6 are characterised by high modelling uncertainty, with small changes where models agree on projected impacts. RCP6.0, however, shows a different picture: Under this scenario, a much **higher increase** in species richness is projected in **western and eastern Sudan, Eritrea, Djibouti, northern Ethiopia and the north of Somalia**. This increase will amount to 211 % and 139 % by 2030 and 2080, respectively, compared to the year 2010. In contrast, species richness will **decrease further south**, with the highest decreases in **Madagascar**. Here, species richness will decrease by up to 54 % and 60 % by 2030 and 2080.

[6] Biodiversity hotspots are "geographic areas with an exceptionally high richness of species, including rare and endemic species" [42].
[7] Due to limited data availability, no tree cover projections could be derived for northern Sudan.

With regard to **tree cover changes**, projections strongly depend on the scenario (Figure 22). Under RCP2.6, model results are uncertain and do not allow for an identification of trends. Modelling certainty is higher under RCP6.0: **Projections show either no change or an increase, e.g. for most of the highland regions of Ethiopia, Kenya and Tanzania**, with the highest increases in the long term. This increase in tree cover could be partially explained by increasing precipitation amounts in those regions, as well as by rising temperatures in higher altitudes (see also Figures 4 and 7).

It is important to keep in mind that the **model projections exclude any impacts on biodiversity loss from human activities**, such as land use or poaching, which have been responsible for losses of global biodiversity in the past and are **expected to remain its main driver in the future** [46]. High population growth favours cropland expansion and increases the pressure on forests and natural land areas [47]. For example, in the vegetated slopes of Mount Kilimanjaro a combination of demographic, socio-economic and governance-related factors have led to an expansion of cultivated land from 54 % in 1973 to 63 % in 2000, at the expense of natural vegetation [48]. **Deforestation** rates, associated with a growing demand **for fuelwood and agricultural land** due to increasing population pressures, are particularly high in Madagascar: Between 2001 and 2021, Madagascar lost 4.36 million ha of tree cover, which equals a 25 % decrease in tree cover since 2000 [49]. High deforestation rates have a **particular impact on women**, who are often the **managers of natural resources** like forests, with their livelihoods relying on forest products including for fuel, food and medicine.

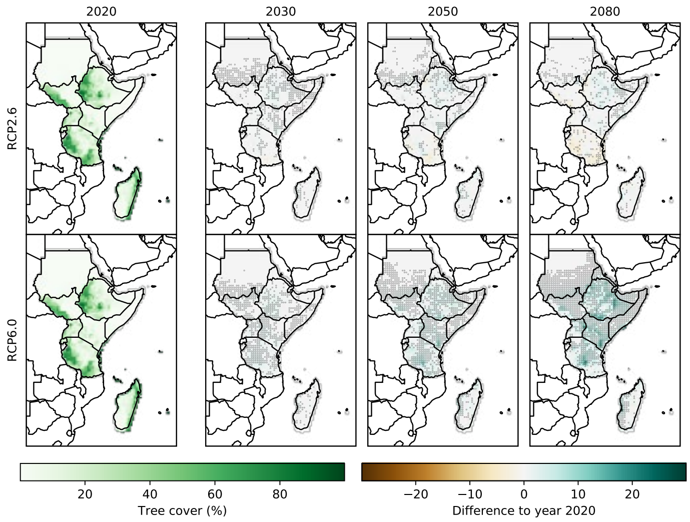

Figure 22: Regional projections for tree cover for Eastern Africa for different GHG emissions scenarios.[7]

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[8] Due to limited data availability, no tree cover projections could be derived for northern Sudan.

e. Human health

Climate change threatens the health and sanitation sector through more frequent incidences of heatwaves, floods, droughts and storms, with **particular impacts on vulnerable groups** like children, elderly people, women, chronically ill people and at-risk occupational groups like outdoor workers. Climate impacts on human health and well-being can thus exacerbate existing inequalities [18].

Rising temperatures and shifting precipitation patterns are likely to **impact food and water supply**, thereby increasing the **risk of malnutrition, hunger and death by famine**. In Somalia, 60 % of the population were undernourished in 2019 [1] and almost 28 % of children under the age of five suffered from stunting [50]. Across Eastern Africa, the **failure of four consecutive rainy seasons with well below average precipitation** has left up to 90 million people food insecure as of July 2022 [51]. Food insecurity has increased through the COVID-19 pandemic and as a result of the war in Ukraine, which is driving the costs for food and fertilisers to record highs [51]. Furthermore, high temperatures and extreme precipitation events favour the **spread of waterborne diseases, such as bacterial diarrhoea and cholera**. Research found that cholera outbreaks across Eastern Africa have been more frequent during El Niño periods: For example, during the 2015–2016 El Niño, multiple cholera epidemics occurred in Eastern Africa, including one of the largest cholera outbreaks in Tanzania, compared to previous outbreaks in the country [52] [53].[8]

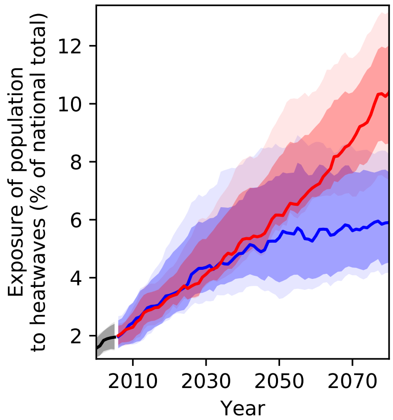
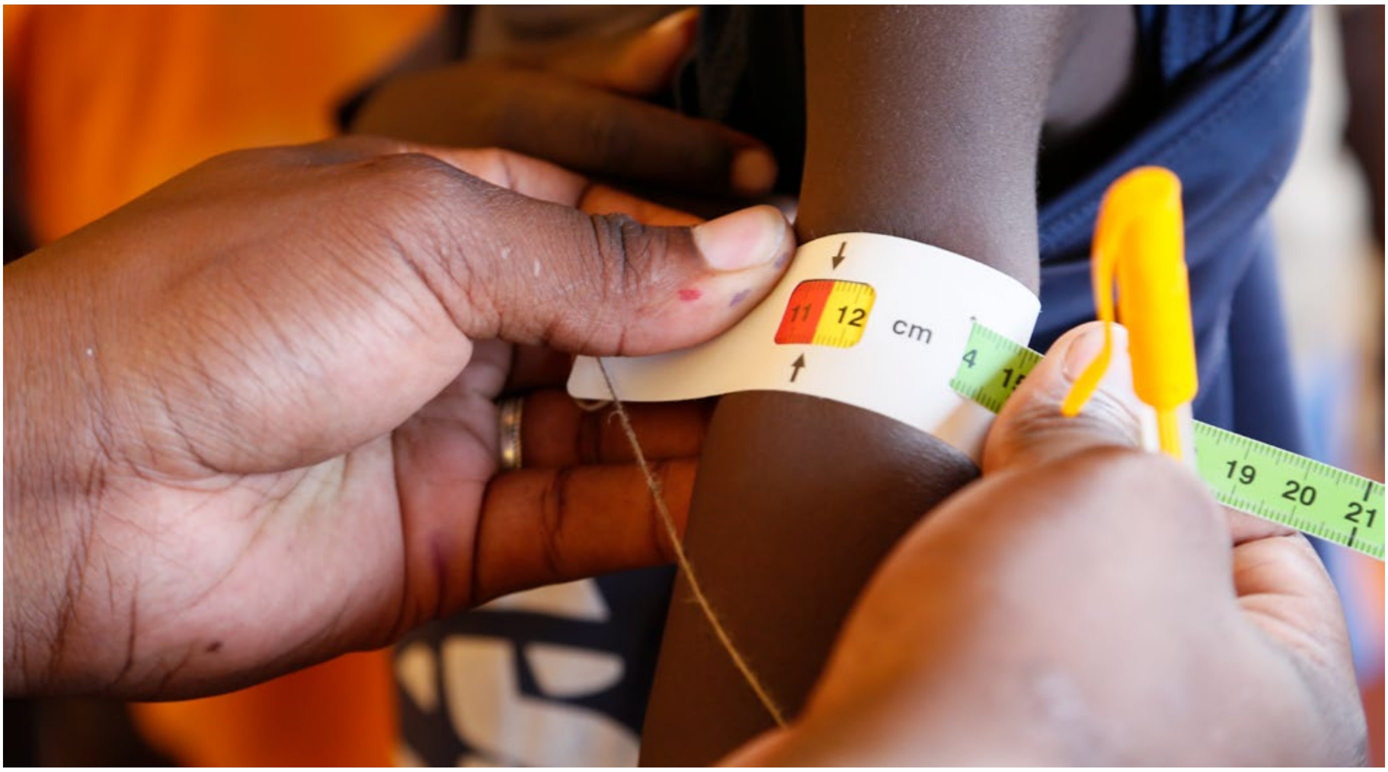


Figure 23: Projections of population exposure to heatwaves at least once a year for Eastern Africa for different GHG emissions scenarios.

Climate change can **alter the geographic range and transmission periods of vector-borne diseases**. For example, novel outbreaks have been observed in higher altitudes of Eastern Africa, which have been previously free of malaria [18]. Rising temperatures could also change the length of the transmission period of malaria, which could turn malaria from a seasonal to an endemic, i.e. year-round, disease in some places. Under RCP8.5[9], an additional 73.4 million people are projected to be at a year-round risk of contracting malaria in Eastern Africa by 2080.[10] Central Uganda, the Lake Victoria region and the East African Highlands will be particularly affected [54].



[9] The outbreak affected over 23,000 people across 23 of 25 regions of Tanzania [52].
[10] RCP8.5 is a high emissions scenario which does not consider any climate mitigation efforts, assuming ‚business as usual‘. The modelling work in this climate risk profile does not include projections for this scenario.
[11] This study accounts for increasing temperatures only and does not include changing precipitation patterns [54].

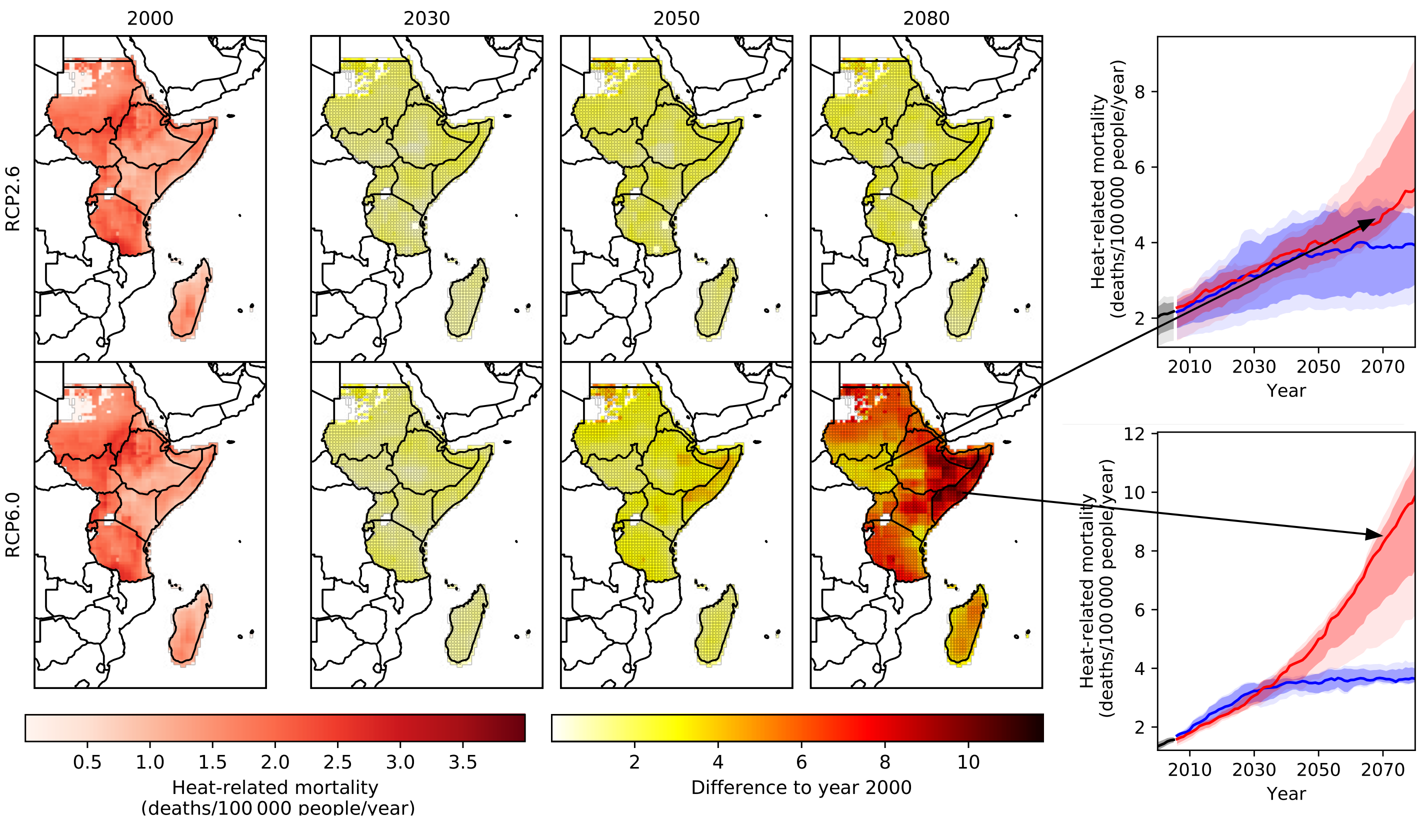


Figure 24: Regional projections of heat-related mortality for Eastern Africa and nationally aggregated data for South Sudan and Somalia for different GHG emissions scenarios assuming no adaptation to increased heat.

The African continent is also projected to see a **geographical shift in dengue fever**: While more favourable temperatures and increased precipitation amounts might increase the dengue suitability in southern and western Africa, dengue is projected to decline across some areas in central Eastern Africa, as these areas become hotter and drier [55]. Climatic changes can also **harm the mental health and well-being** of people. It has been observed that high temperatures can lead to a range of neurotic disorders including anxiety, depression and acute stress, and can increase suicide rates [56]. Studies also show an increase in depression and post-traumatic stress disorder following extreme weather events such as floods and storms [57].

Rising temperatures will very likely result in a **more frequent and higher exposure to heatwaves**, which will also increase heat-related mortality. Under RCP2.6, the population affected by at least one heatwave per year will rise from 1.6 % in 2000 to 4.4 % until 2030, and 5.9 % until 2080 (Figure 23). Under RCP6.0, exposure to heatwaves will develop in a similar way as under RCP2.6 until around 2040. From then on, it will increase more sharply, with around 6.2 and 10.4 % of the population being affected by heatwaves by 2050 and 2080, respectively.

Furthermore, under RCP2.6, **heat-related mortality is projected to increase** from 1.8 deaths per 100,000 people per year in 2000 to 2.9 and 3.4 deaths by 2030 and 2080, respectively (Figure 24). Under RCP6.0, heat-related mortality will increase to around 6.7 deaths per 100,000 people by 2080, which is more than a fourfold increase, compared to the year 2000, provided that no adaptation to hotter conditions will take place.

However, this increase is aggregated for the entire Eastern African region. **Some countries will see even higher increases in heat-related mortality**: In Somalia, heat-related mortality is projected to amount to 3.6 deaths per 100,000 people per year until 2080 under RCP2.6, and to around 10 deaths per 100,000 people per year under RCP6.0 until 2080 (Figure 24). In South Sudan, on the other hand, heat-related mortality is likely to increase to about 4 deaths per 100,000 people per year by 2080 under RCP2.6 and 5 deaths under RCP6.0. While heat-related mortality is more prevalent in Eastern Africa, people in higher altitude regions such as the Ethiopian highlands are also at risk of cold-related mortality. However, as temperatures increase, **cold-related mortality is expected to decrease** [18].

f. Migration and displacement

Climate change, along with other risks such as the COVID-19 pandemic and violent conflicts affect human mobility in Eastern Africa, highlighting its multi-causal character [58] [59]. Droughts, heatwaves and related impacts have made the availability of water and grassland less reliable, forcing farmers and pastoralists to adjust their activities, for example, changing grazing routes, or to migrate more permanently as a result of these impacts [18] [60]. In 2021, **2.5 million people in sub-Saharan Africa were displaced due to weather-related events** [61]. World Bank projections for the Eastern African region[11] suggest that by 2050 more than 10 million people will have to leave their homes due to gradually occurring climatic changes, if economic development remains unequal and GHG emissions remain high.[12] Sharp emissions reductions[13], appropriate adaptation strategies and adequate support of adaptation planning could reduce this number to 6.9 million, suggesting that there is room for action.

Out-migration hotspots in Eastern Africa will most likely be located where water availability and crop productivity are projected to decrease such as in the northern parts of the Ethiopian highlands, parts of western Uganda, southern Rwanda and in coastal zones of Kenya and Tanzania. **In-migration hotspots,** on the contrary, will be regions with more favourable climatic conditions on existing rural-urban mobility routes. These routes include cities like Kampala and Nairobi as well as the south-eastern highlands of Ethiopia and the Lake Victoria Basin [62]. Migration as an adaptation strategy requires economic and physical resources and is dependent on sociocultural norms. Since women in Eastern Africa have higher constraints in their access to these resources and livelihood opportunities as compared to men, they tend to face more difficulties in migrating [63]. Therefore, when male household members migrate, **women are often left behind**, having to reallocate roles and **navigate multiple responsibilities** in the household.

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[12] The World Bank analysis includes Malawi, which is not part of Eastern Africa, according to the African Union definition, and is therefore not included in this climate risk profile.
[13] The World Bank projections were made for the high-emissions scenario RCP8.5, which predicts a temperature increase between 2.6 and 4.8 °C by 2100.
[14] Sharp emissions reductions are represented by the low-emissions scenario RCP2.6 which predicts a temperature increase between 0.3 and 1.7 °C by 2100.

g. Conflict and governance

Conflicts and tensions in sub-Saharan Africa result from a combination of factors including **weak state capacities, corruption, poor delivery of basic services and persistent inequality**. In 2021, sub-Saharan Africa hosted 22 multilateral peace operations, which is the highest number compared to any other region in the world. Still, the region experienced four successful and three failed military coups. Among others, conflicts in Somalia, South Sudan and Sudan experienced particular escalations. Despite the presence of an African Union-led peace operation, **the jihadist group al-Shabab** has remained a threat in Somalia. In South Sudan, progress in terms of the implementation of the 2018 peace agreement has been made, although violence still affects major parts of the population. In Sudan, the security situation has deteriorated with a military coup in October 2021 and a doubling of conflict-related deaths in 2021 [64]. **Climate change can exacerbate violent conflicts and serve as a risk multiplier**, although this link is highly **dependent on socio-economic and political conditions** [65]. This holds true, for example, for sub-Sahara Africa, where rising temperatures have increased the risk of conflict by 11 % since 1980 [66]. There is also evidence that over the last 50 years, **severe droughts** have contributed to an increase of **refugees crossing international borders in Eastern Africa** [67].

Several mechanisms explain the climate-conflict nexus in this region. Livelihood conditions lie at the core of this nexus, as a large part of the population depends on rain-fed agriculture and pastoralism. Hence, the loss of income from these activities due to climate change is a prominent mechanism. The sensitivity of these resources to climate change, combined with other drivers such as poverty, weak governance, population growth and socio-cultural factors, exacerbate the already **asymmetric impacts of climate change, particularly on women** in Eastern Africa [63] [68].

The **Tigray conflict in Ethiopia** is a prominent example of how the effects of climate change exacerbate existing conflicts: Prior to the outbreak of the civil war in 2020, the Tigray region had already been fragile with just under a third of its population in need of food assistance and hosting over 100,000 internally displaced people and 96,000 refugees [69]. The combination of a desert locust outbreak, political instability, the COVID-19 pandemic and climate-related shocks contributed to greater food insecurity and further displacement and migration, adding tensions to the existing conflict. As a result, between November and December 2020, more than 55,000 people sought refuge in Sudan [69].

Climate change, along with socio-economic drivers, has a particular **impact on pastoralists** [60]. Traditional **coping strategies of pastoralists** to climate variability, such as searching for pasture and water, have been compromised by **land fragmentation** and **governmental bans on grazing areas**, leaving pastoralists more susceptible to climate impacts and in need of adjusting their mobility patterns [70]. Adjustments in mobility patterns can create conflicts between farmers and pastoralists, but also between different pastoralist groups [70]. To **settle the disputes and conflicts** between these groups, several agreements have come into place in recent years like, for example, the Birao Agreement between farmers from the Central African Republic and pastoralists from Sudan in June 2019 [81][82]. Effective **national policies and international agreements** like the Birao Peace Agreement are key to mitigating climate-related conflicts.

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