




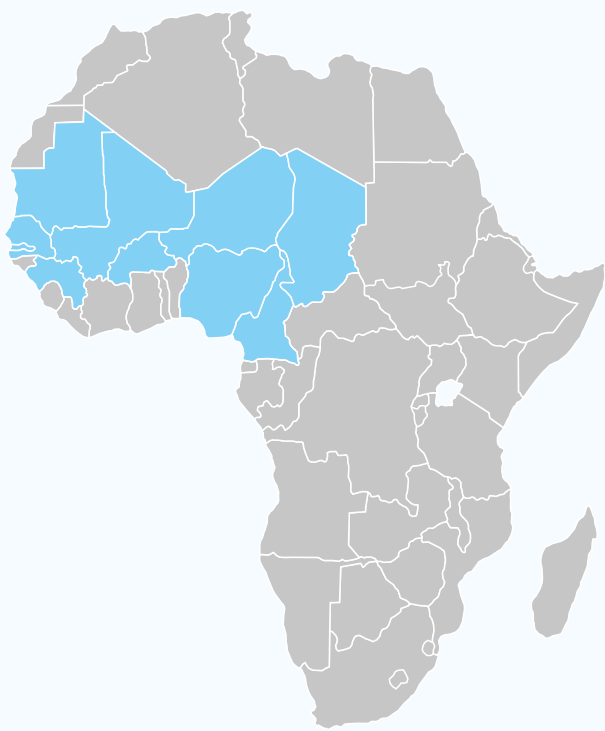





Climate Risk Profile: Sahel*

Summary

	<p>This profile provides an overview of projected climate parameters and related impacts on different sectors in the Sahel region until 2080 under different climate change scenarios (called Representative Concentration Pathways, RCPs). RCP2.6 represents the low emissions scenario in line with the Paris Agreement; RCP6.0 represents a medium to high emissions scenario. Model projections do not account for effects of future socio-economic impacts.</p>	 <p>Per capita water availability will decline by 2080 mostly due to population growth. Model projections indicate that water saving measures are expected to become more important all over the Sahel after 2050.</p>
	<p>In the Sahel, a complex picture of interacting factors of crisis in agriculture, violent conflicts and weak governance is discernible. A better understanding of emerging risk hotspots is important to identify well-targeted anticipatory action, which is key to support the implementation of the United Nations Integrated Strategy for the Sahel (UNISS), in particular its third goal to promote long-term resilience.</p>	 <p>The population share affected by at least one heatwave per year is projected to rise from 4.3 % in 2000 to 19.9 % in 2080. This is related to an average of 59 more very hot days per year over this period. As a consequence, heat-related mortality is estimated to increase by a factor of 4 by 2080.</p>
	<p>Depending on the scenario, temperature in the Sahel is projected to rise between 2.0 and 4.3 °C by 2080, compared to pre-industrial levels, with higher temperatures and more temperature extremes projected for the northern part of the region.</p>	
	<p>Precipitation trends are uncertain and vary across the Sahel, with projections indicating an overall increase in annual precipitation of up to 16 mm by 2080. Future dry and wet periods are likely to become more extreme.</p>	
	<p>Under RCP6.0 and until 2080, sea levels are expected to rise by 38 cm on the Atlantic coast and by 40 cm in the Gulf of Guinea. This threatens coastal communities and may cause saline intrusion in coastal waterways and groundwater reservoirs.</p>	
	<p>Climate change will have an impact on crop yields. Yields of maize, millet and sorghum are projected to decline, while yields of cassava, cow peas, groundnuts and rice are projected to benefit from CO₂ fertilisation. Farmers will need to adapt to these changing conditions.</p>	

* This Climate Risk Profile was developed as part of a collaboration with the Potsdam Institute for Climate Impact Research (PIK) and is based on the Climate Risk Profiles developed within the AGRICA project, funded by the German Federal Ministry for Economic Cooperation and Development (BMZ)

Context

Rising temperatures and more extreme weather conditions pose existential challenges to semi-arid regions like the Sahel. Future emissions will determine the severity of climate impacts and thereby the damages to traditional agriculture, livelihoods and the health of millions of people across the region.

The Sahel, located in Northern Africa, forms a natural border between the Sahara Desert to the north and the tropical savannas to the south. The region spans 5,900 km from the Atlantic Ocean in the west to the Red Sea in the east [1]. As summarized by Biasutti [2] “*The name Sahel refers to the semi-arid region stretching longitudinally from Senegal in West Africa to Sudan and Ethiopia in East Africa and latitudinally from just north of the tropical forests to just south of the Sahara desert (roughly between 10 ° and 20 °N).*” However, there is no universally defined list of countries of the Sahel.

For the purpose of this Climate Risk Profile the Sahel shall be defined as the states of **Burkina Faso, Cameroon, Chad, the Gambia, Guinea, Mali, Mauritania, Niger, Nigeria and Senegal**, in accordance with the **United Nations Integrated Strategy for the Sahel (UNISS)**. These countries share long-standing cultural and political linkages. Hence, the Sahelian countries’ socio-economic, political and security dynamics are intrinsically linked [3].

In the Sahel, the **population amounts to over 300 million people**, Nigeria being the most populous country with 206 million inhabitants [4]. Despite high mortality rates of children under five [5], the Sahel is home to some of the fastest growing societies in the world with **high population growth rates between 2.6 % and 3.8 %** [6]. Based on these developments, it is predicted that the population will have more than doubled by 2050 [7]. Furthermore, the population in the Sahel is one of the youngest in the world, since **64.5 % of the population are below the age of 25** [1].

The **economic growth rate varies widely** within the region and GDP per capita covers the spectrum from 2091 US dollar in Nigeria to 565 US dollar in Niger [8]. Apart from a recent general economic recession due to the COVID-19 pandemic, the region is marked by steady economic growth. The overall economic growth rate in the Sahel is higher than the continental average and is based on the export of primary goods [3]. The region offers **great potential** considering the abundant natural resources, such as oil in Chad and Nigeria, and great capacity for renewable energy [3]. Despite these potentials, people in the Sahel are affected by multiple interrelated crises. According to the World Bank Poverty Headcount Ratio, **large parts of the Sahelian populations live below 1.90 US dollar a day**. The states of the Gambia and Cameroon represent exceptions since only a relatively small proportion of the population, namely 10 % and 26 %, live in

extreme poverty [9]. However, overall, nearly 50 % of the population of the region live in extreme poverty [3] and consequentially, most countries in the Sahel rank among the lowest on the Human Development Index [10].

In the Sahel, agriculture is the most important sector and provides livelihoods for the majority of the population [3]. This so-called **primary sector employs more than 60 %** of the population and contributes to around 40 % of the Gross Domestic Product (GDP) [11]. Rain-fed agriculture, in particular, is vulnerable to climate change. Repeated cycles of droughts, desertification and floods make it increasingly harder for the local population to sustain subsistence agricultural practices. **Extreme weather events** can lead to widespread crop failure and a reliance on food assistance programs [3], [12]. Additionally, the impact of climate change is straining the relationship of herders and pastoralists and thus also ethnic relations. For centuries, pastoralists have crossed the Sahel following seasonal patterns, which allowed them to feed their herds. The scarcity of water, pasture and fertile soil force people to migrate. Such **displacement** can lead to conflicts over land and resources between herders and farmers, which in turn further fuel displacement dynamics [13]. Climate variability strongly interacts with other conflict drivers and thus can be difficult to distinguish. However, climate impacts represent a key factor with regards to displacement [13].

In addition to poverty and food insecurity, there are **high levels of corruption**, which are reflected in low scores of most Sahelian countries in the Corruption Perceptions Index by Transparency International [14]. Together, these factors render **political instability** and lack of state capacity common and, accordingly, all countries in the region score low on the Fragile States Index. Chad is especially vulnerable to conflict, followed by Mali, Niger, Cameroon, Nigeria and the Guinea [15].

Increasingly, this vacuum is filled by Jihadist groups, who represent a threat to civilians and governments and exploit the population’s despair and frustration for recruitment [13]. Jihadist groups also interfere in already existing inter-communal conflicts, for instance between the Fulani and the Dogon in Mali, exacerbating tensions and ethnic disputes. After the Libyan regime fell in 2011, armed uprisings in Mali increased armed conflicts which have spiralled into neighbouring countries [3]. This complex crisis has led to massive **internal and cross-border displacement** of more than 4 million people in the region [16]. This is particularly true for the Liptako Gourma region in the border areas between Burkina Faso, Mali and Niger due to increasing activity of jihadist groups. In Burkina Faso, the number of internally displaced people (IDPs) due to conflict increased more than ten-fold between 2018 and 2020 [13].

Topography and environment

The topography of the Sahel is mostly flat. **Altitudes** mostly range between 200 and 400 m in elevation, while most of Senegal and the coastal areas of Mauritania and Nigeria lie at sea level. Some isolated mountain areas with an elevation between 1,000 and 2,000 m can be found in northern Niger, northern and eastern Chad and northern-central Cameroon (see Figure 1).

The Sahel is a semi-arid region separating the Sahara Desert to the north and tropical savannas to the south [17]. As shown in Figure 2, it comprises several, quite diverse **agro-ecological zones**, which divide the Sahel into latitudinal sections, moving from a mainly arid climate in the north to a more humid climate in the south: The northern part, covering most of Mauritania, Mali, Niger and Chad is dominated by arid-warm tropics. In addition, there are smaller areas in the north of Mauritania, Niger and Chad which are characterized by arid-warm subtropics as well as arid-cool subtropics in the north of Niger and Chad and arid-cool tropics in the north of Chad due to higher elevations between 1,000 and 2,000 m. Subsequently, most parts of Senegal, The Gambia and Burkina Faso as well as the south of Mali, Niger and Chad and the north of Nigeria are characterized by a semi-arid-warm tropical climate. Below that, sub-humid-warm tropics can be found in Guinea, the south of Burkina Faso, Nigeria (and small parts of Chad) as well as in northern Cameroon. Finally, the southern parts of Guinea, Nigeria and Cameroon have a humid-warm tropical climate.

The Sahel is irrigated by **11 main rivers** which are part of the basins of Lake Chad, Niger, Queme, Volta, Comoé, Bandama, Sassandra, Senegal and Gambia-Gorubal [18]. They flow through several hydrological regions and across national borders, which is why water resources are managed collectively by several river basin authorities [19]. The major river of the Sahel, the Niger River, is the longest and largest river in western Africa. It rises in the Guinean highlands and flows through the semi-arid and arid regions of Mali and Niger before entering the more humid region north of the Gulf of Guinea in Nigeria [20]. The major tributary of the Niger River, the Benue River, rises in northern Cameroon and flows west through the geographic centre of Nigeria where it meets the Niger River. Burkina Faso represents the main catchment area of the Volta River, which covers a total area of 400,000 km² [19]. Another large river in the region is the Senegal River which has its main source in Guinea, providing water to the semi-arid zones of Mali, Senegal and Mauritania [19]. Lake Chad is situated at the southernmost edge of the Sahara in the bordering region between Niger, Chad, Nigeria and Cameroon and constitutes an oasis in a largely arid region. Its basin covers diverse climatic zones and more than 8 % of the African continent [21].

In general, **water resources in the Sahel are distributed unequally** both over space and time. Some countries, such as Nigeria, have abundant water resources, while others, such as Burkina Faso, have to deal with water scarcity [19].

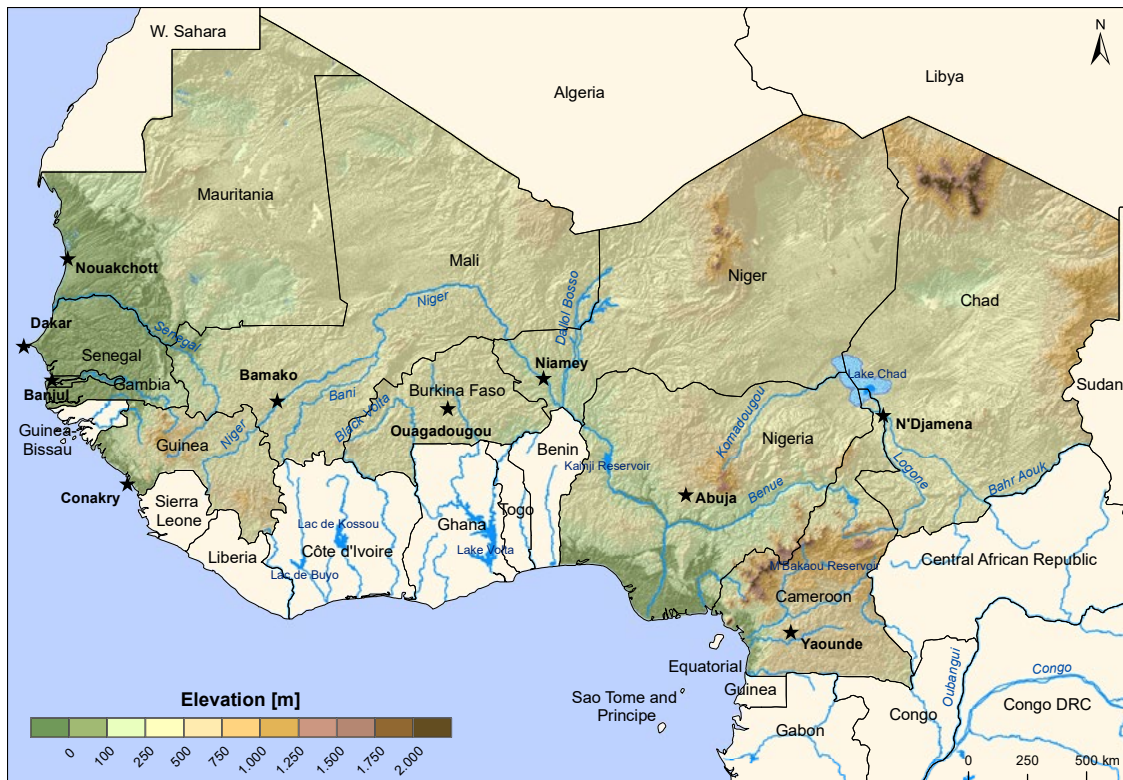


Figure 1: Topographic map of the Sahel.

The Sahel is highly exposed to climate change, yet impacts vary across different regions. The Sahel will gradually become hotter, with some areas experiencing increased, but erratic rainfall. Extreme weather events, including droughts and floods, are expected to intensify in this context. Niger and Mauritania, for instance are among the top 10 countries with the highest share of the populations affected by natural hazard-related disasters between 2000 and 2019 (standardised to population size) [22]. These developments highlight the need for adaptation measures to reduce vulnerabilities and the risk of violent conflicts in the region.

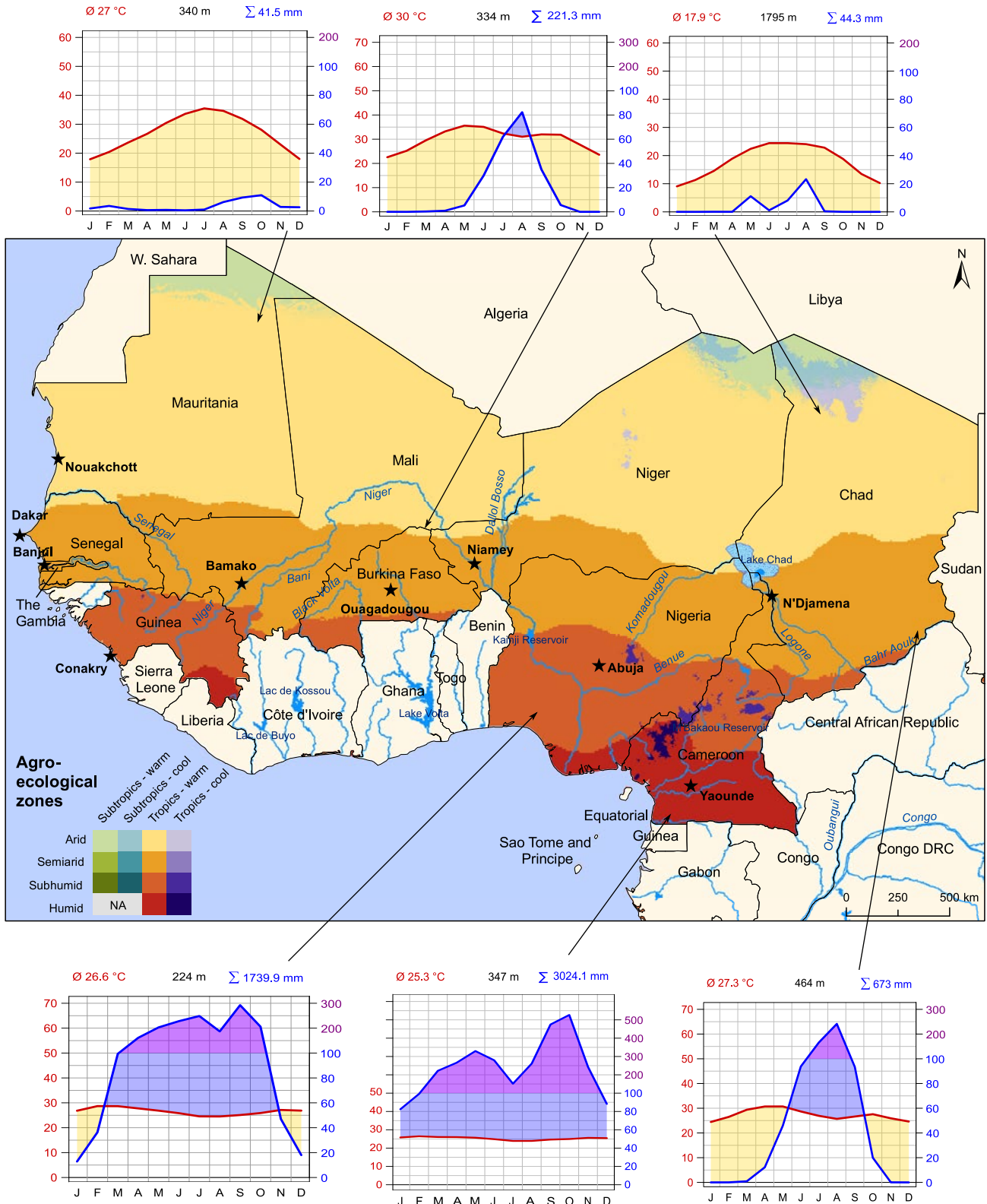


Figure 2: Map of the Sahel showing agro-ecological zones and location-specific examples of annual temperature and rainfall patterns.

Present climate

- The Sahel has a very diverse climate largely influenced by latitude. Mean annual temperatures range from 21 °C to 31 °C with lower values in southern Cameroon and higher values in south-western Mauritania.
- Annual precipitation sums range from 10 mm in northern Niger, which has an arid desert climate, to 3,800 mm in western Cameroon, which is characterised by a tropical coastal climate.
- Most parts of the Sahel have one rainy season in the summer months of the northern hemisphere. Here, too, the length is influenced by latitude, with regions closer to the Saharan desert receiving very little rain around the month of August. In regions further south, however, the rainy season is much longer, pausing only around the months of December and January. Such is, for example, the case in southern Nigeria.

Past climate

- Rainfall in the Sahel, controlled by the West African monsoon, has experienced substantial multi-decadal swings and an overall reduction during the course of the 20th century [23].
- Near surface temperatures have increased with cold days and cold nights decreasing and warm days and warm nights increasing [24].
- During the second half of the 20th century, the Sahel experienced a major shift in climate – from a relatively wetter period in the 1950s and 1960s to a dryer climate in the 1970s and 1980s leading to severe droughts, which caused humanitarian crises with millions of deaths and hampered development [25].
- Higher rainfall rates returned to the Sahel in the 1990s, which is still below the levels of the pre-drought period of the 1940s and 1950s [26].



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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). In particular, 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 kindly refer to the supplemental information on how to read the climate risk profile.

Temperature change and heat risk indicators

Temperature

In response to increasing greenhouse gas (GHG) concentrations, **air temperature over the Sahel is projected to rise by 2.0 to 4.3 °C (very likely range) by 2080** relative to the year 1876, depending on the future GHG emissions scenario (Figure 3). Compared to pre-industrial levels, median climate model temperature increases over the Sahel amount to approximately 2.0 °C in 2030, 2.4 °C in 2050 and 2.5 °C in 2080 under the low emissions scenario RCP2.6. Under the medium/high emissions scenario RCP6.0, median climate model temperature increases amount to 2.0 °C in 2030, 2.6 °C in 2050 and 3.6 °C in 2080. The highest increases are projected for north-eastern Mauritania and north-western Mali, with temperature increases of up to 3.0 °C in the period 2000–2080 and under RCP6.0.¹ The lowest temperature increases are projected for western Senegal, which will see a 1.6 °C increase (Figure 4).

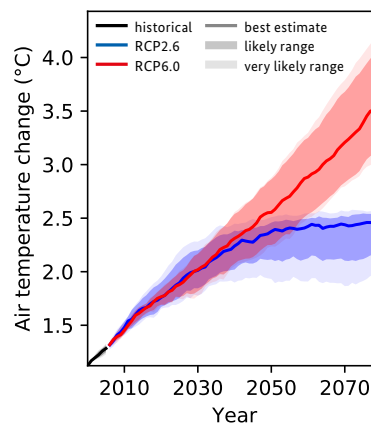


Figure 3: Air temperature projections for the Sahel for different GHG emissions scenarios.¹

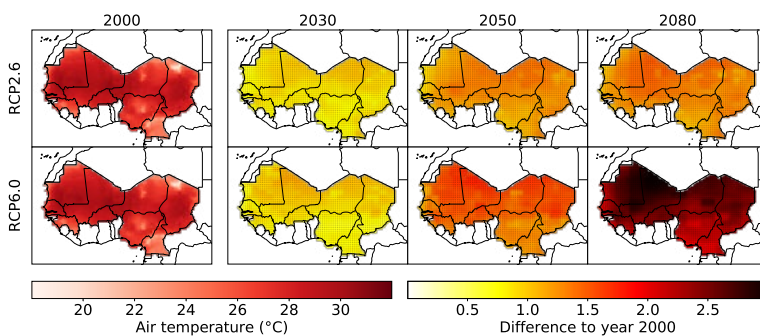


Figure 4: Regional projections of air temperature for the Sahel for different GHG emissions scenarios, relative to the year 2000.

¹ 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.

Sea level rise

In response to globally increasing temperatures, sea levels off the Atlantic coast of the Sahel and in the Gulf of Guinea are projected to rise (see red boxes in Figure 6). Until 2050 and for each of the coastal regions, very similar sea levels are projected under both emissions scenarios. Afterwards, however, the different emissions scenarios see diverging trends. For example, off the **Atlantic coast**, the median climate model projects a **sea level rise of 32 cm (RCP2.6) and 38 cm (RCP6.0) in 2080** (left line plot in Figure 5). Sea levels in the **Gulf of Guinea** are projected to rise even more with **34 cm (RCP2.6) and 40 cm (RCP6.0)** projected for 2080 (right line plot in Figure 6). Sea level rise is not uniform around the globe but subject to regional differences due to thermal expansion of water and ocean currents, among other factors. Coastal and ocean systems are important for the economies and livelihoods of the countries located off the Atlantic coast and the Gulf of Guinea. Climate change will increase challenges from existing stressors, such as overexploitation of resources, habitat degradation, loss of biodiversity, salinization, pollution and coastal erosion [27].

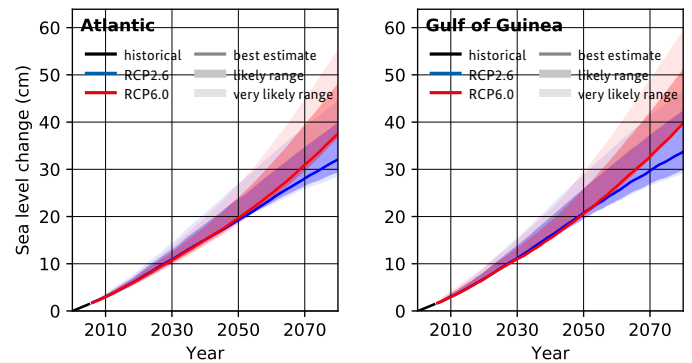


Figure 5: Projections for sea level rise off the Atlantic coast and in the Gulf of Guinea for different GHG emissions scenarios, relative to the year 2000.

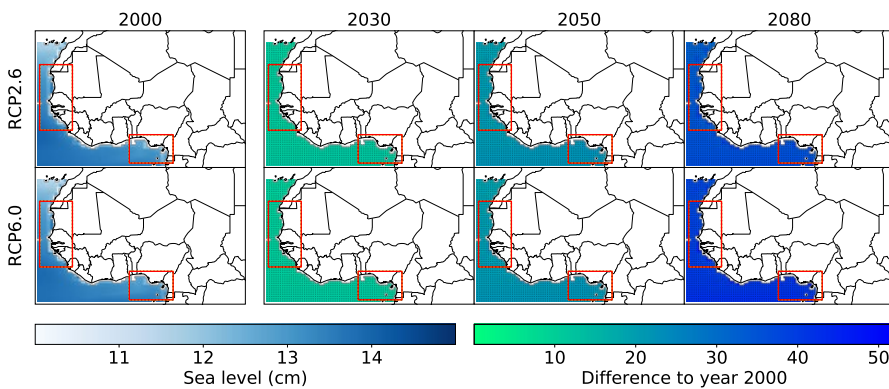


Figure 6: Regional projections for sea level rise off the Atlantic coast and in the Gulf of Guinea for different GHG emissions scenarios, relative to the year 2000.

Very hot days

In line with rising mean annual temperatures, the annual number of very hot days (days with a daily **maximum temperature above 35 °C**) is projected to rise substantially and with high certainty, in particular over north-eastern Guinea and south-western Mali (Figure 7). Under the medium/high emissions scenario RCP6.0, these regions are projected to see **125 more very hot days per year in 2080**. While the smaller difference in the northern half of the Sahel may be counterintuitive, in fact, it highlights the amount of very hot days in the present: Some parts of central Niger, for example, already experience 306 very hot days per year. Hence, in these regions, further temperature increases could amount to a **total of 339 very hot days per year in 2080** under RCP6.0. Temperatures above the threshold of 35 °C present a clear threat to human health, as well as to animal health and productivity and crop production [28], [29]

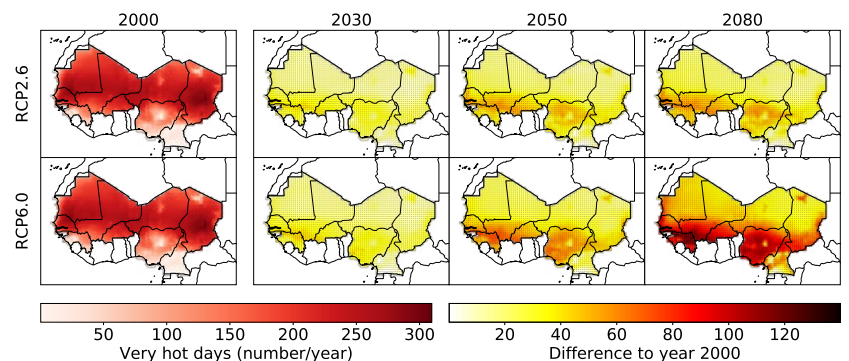


Figure 7: Projections of the annual number of very hot days (daily maximum temperature above 35 °C) for the Sahel for different GHG emissions scenarios.

Precipitation, flood and drought risk indicators

Precipitation

Future projections of precipitation are less certain than projections of temperature change due to high natural year-to-year variability (Figure 7). Out of the four climate models underlying this analysis, two models project a decrease in mean annual precipitation over the Sahel and two models project an increase. Median model projections show a **precipitation increase of 16 mm per year by 2080** under RCP6.0, while median model projections for RCP2.6 show an even stronger increase at the beginning of the century, which steadily decreases towards the end of the century, falling below RCP6.0 and reaching **8 mm by 2080** compared to year 2000. Changes in precipitation have direct impact on water availability and quality, on crop production and thus on food security.

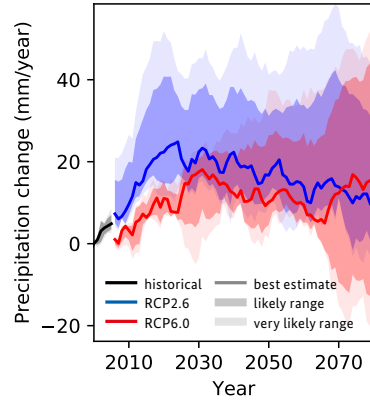


Figure 8: Annual mean precipitation projections for the Sahel for different GHG emissions scenarios, relative to the year 2000.

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 reflected in climate projections for the Sahel, with an **overall increase in the number of days with heavy precipitation** (Figure 8). However, looking at individual regions, there are differences in the direction of change as well as in the magnitude of change.

For example, northern Chad is projected to experience 7.6 more days with heavy precipitation in 2080. Also, other parts of the eastern Sahel are projected to experience increases, such as most of Niger, Nigeria and Cameroon. In the western Sahel, the picture is different: Especially **Mauritania and Senegal, but also north-eastern Mali** are projected to see **decreases in the number of heavy precipitation events**. For example, in north-western Mauritania, the number of days with heavy precipitation is projected to decrease from 7 days in the year 2000 to 5 days in 2080.

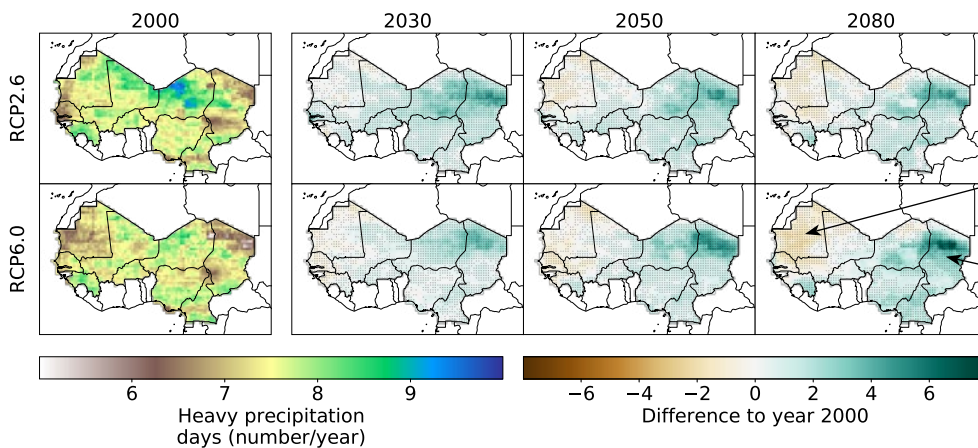
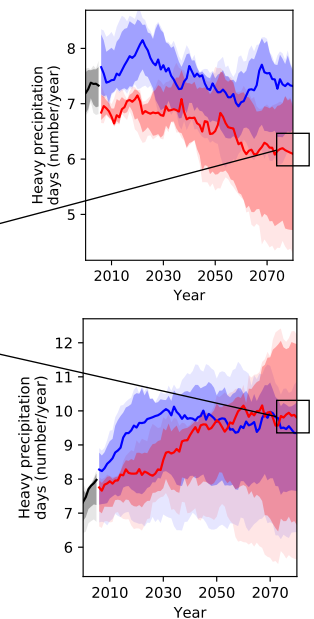


Figure 9: Regional projections of the number of days with heavy precipitation over the Sahel for different GHG emissions scenarios, relative to the year 2000, with nationally aggregated projections for Mauritania and Chad.



Soil moisture

Soil moisture is an important indicator for drought conditions. In addition to soil parameters 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 0.8 % under RCP2.6 and a slightly stronger **decrease of 1.2 % under RCP6.0** by 2080, compared to the year 2000 (Figure 10). However, looking at the different models underlying this analysis, there is large year-to-year variability and modelling uncertainty, with one model projecting a much stronger decrease and two models projecting increases in soil moisture.

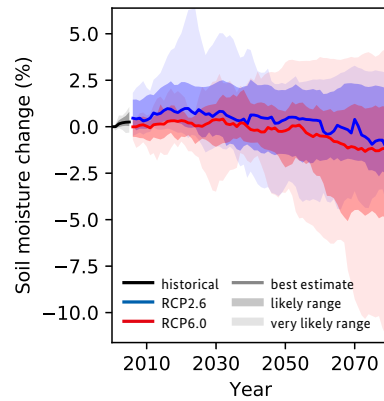


Figure 10: Soil moisture projections for the Sahel for different GHG emissions scenarios, relative to the year 2000.

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.** Higher evapotranspiration affects the water supply and the amount of surface water available for agriculture. It can shift 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.

In line with this expectation, hydrological projections for the Sahel indicate a stronger rise of potential evapotranspiration under RCP6.0 than under RCP2.6 (Figure 11). Under RCP6.0, **potential evapotranspiration is projected to increase by 2.4 % in 2030, 3.5 % in 2050 and 6.4 % in 2080**, compared to year 2000 levels. A look at Figure 12 reveals that this trend can be observed all over the

Sahel and with high certainty. Countries, which already experience high rates of potential evapotranspiration, such as Mali, Niger and Chad, will see the lowest percentage increases, however, arrive at the highest absolute rates by the end of the century.

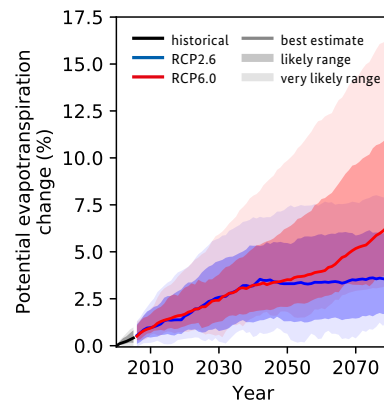


Figure 11: Potential evapotranspiration projections for the Sahel for different GHG emissions scenarios, relative to the year 2000.

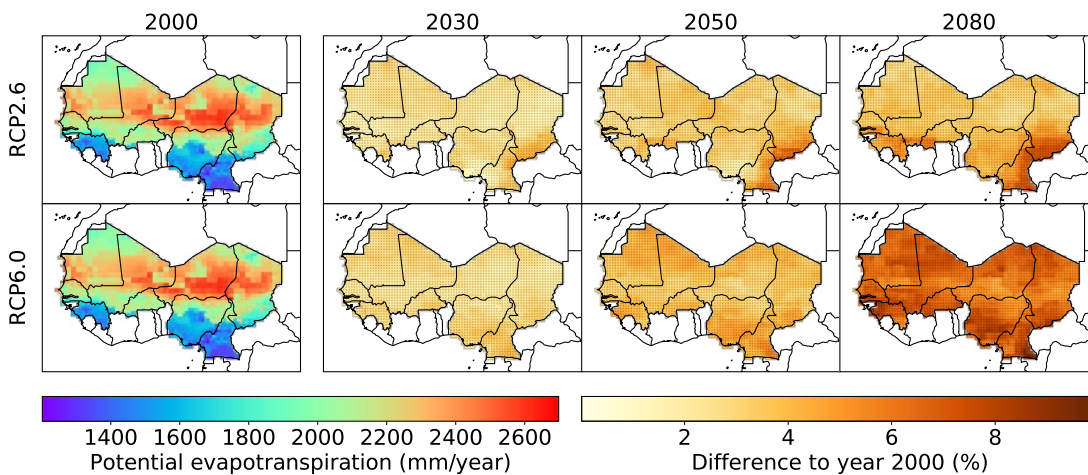


Figure 12: Regional projections of potential evapotranspiration for the Sahel for different GHG emissions scenarios, relative to the year 2000.

Sector-specific climate change risk assessment

a. Water resources

Water is the medium through which climate change most directly affects the lives of people and ecosystems. Current projections of water availability in the Sahel display high uncertainty under both GHG emissions scenarios. Assuming a constant population level, multi-model median projections suggest a decrease of 2 % (RCP2.6) and 5 % (RCP6.0) in per capita water availability by the end of the century (Figure 13A). Yet, when accounting for population growth according to SSP2 projections², **per capita water availability for the Sahel is projected to decline** more dramatically, i.e. by 76 % under RCP2.6 and 77 % under RCP6.0 by 2080 relative to the year 2000 (Figure 13B). This decline is not primarily driven by climate change, but rather by socioeconomic factors. These include population growth, together with increased agricultural production, leading to increased water abstraction for irrigation, drinking water supply, domestic use and hydropower generation through dams [20]. The decline in water availability highlights the urgency to invest in water saving measures and technologies for future water consumption after 2030.

Median projections of water availability from precipitation indicate a decrease of 1.9 % under RCP2.6 and no change under RCP6.0 (Figure 14). However, there is **high modelling uncertainty**: Two models project increases, one of which projects much higher increases than the other, while two models project decreases, one of which also projects much higher decreases than the other. Hence, **no clear trend in water availability from precipitation can be identified**.

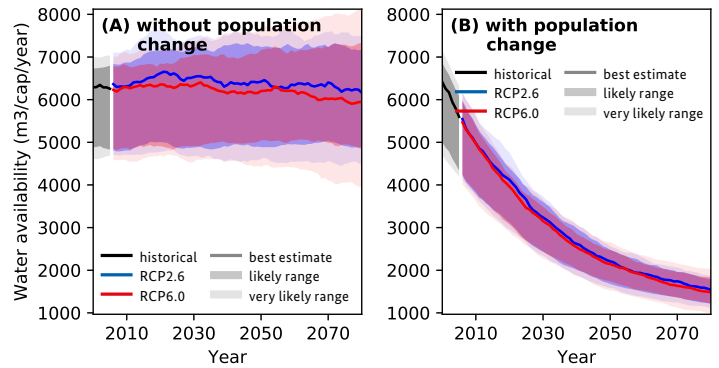


Figure 13: Projections of water availability from precipitation per capita and year with (A) national population held constant at year 2000 level and (B) changing population in line with SSP2 projections for different GHG emissions scenarios, relative to the year 2000.

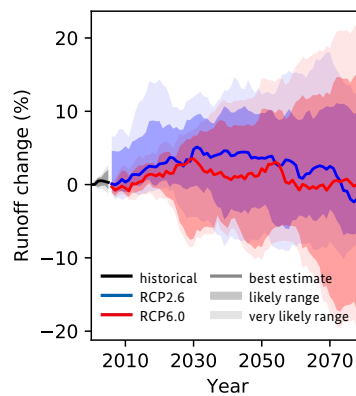


Figure 14: Projections of water availability from precipitation (runoff) for the Sahel for different GHG emissions scenarios.

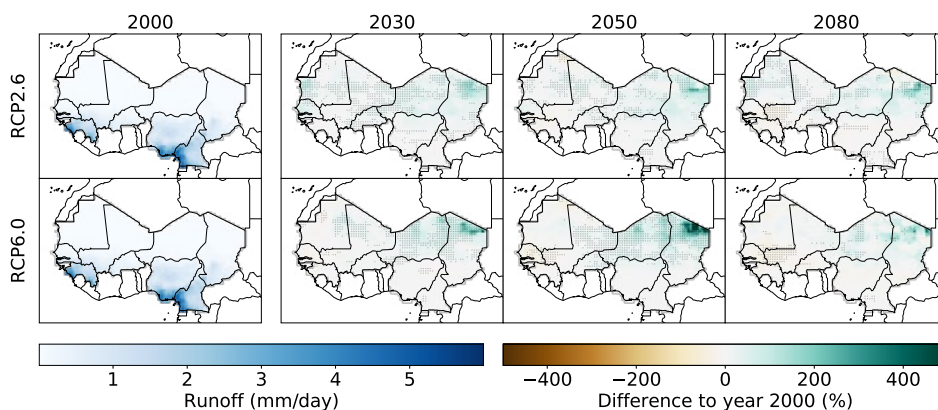


Figure 15: Regional projections of water availability from precipitation (runoff) for the Sahel for different GHG emissions scenarios.

² 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.

In general, the Sahel has abundant renewable water resources, of which less than 1 % is being extracted [18]. However, at present, the Sahel's **water supply is unevenly distributed**, difficult to access due to poor hydraulic supply systems and challenging to manage due to the transboundary nature of water resources. For instance, total renewable water resources per capita range from 745,600 m³/year in Burkina Faso to 6,818,000 m³/year in Mali and over 40 % of water supply in Mali and Chad and 90 % in Mauritania and Niger is sourced from outside national borders [30]. As surface water is limited and mostly seasonal, **many people in the region depend on groundwater reserves** [30]. However, both surface and groundwater availability and accessibility show declining trends as a result of **reduced rainfall, temperature increases and more frequent droughts** [23], [30]. In addition, there is a lack of infrastructure, which would be needed to access water supplies in the dry season or in dry years [30]. It is projected that in future years, areas with 200–500 mm of annual precipitation, including the Sahel, may face a further decline in groundwater recharge due to climate change [31]. This may lead to prolonged drought and other precipitation irregularities [31]. **Population growth with associated urbanization**, increased irrigation and land use change put further pressures on this development. Over the last thirty years, increasing demand for water supply has resulted in 25–60 % reductions in flows,

causing increasingly low water levels [30]. Similarly, Lake Chad has lost 95 % of its surface since the 1960s due to increased water use, changing rainfall patterns and rising temperatures which result in increasing disputes over access to water, fishery and land ownership [30]. Dams are often constructed for water storage during dry seasons in order to reduce uncertainties and water shortages and to produce hydroelectric power, thereby reducing reliance on fossil fuels and fuelwood [30]. Yet, these benefits come at the cost of downstream water shortages, nutrient contamination and, **in some cases conflict over the use of and access to water resources** [18].

The predicted temperature increases, extreme weather events and changes in water availability will also have an **impact on water quality** [20]. The global temperature increase stimulates the growth of algae and bacteria in the water, while the oxygen solubility of the water decreases. Reduced water levels also reduce the dilution capacity of water with regard to pollutants. Taken together, this has **negative consequences for the ecological integrity of aquatic systems** and thus also for the communities that depend on them. Water quality is also negatively affected by extreme weather events such as floods and landslides. Furthermore, climate change has a variety of indirect negative effects on water quality, for example through increased irrigation as a result of droughts.



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b. Agriculture

Agriculture represents the main economic activity in the Sahel, engaging between 80–90 % of the population [32]. Agricultural production is **primarily subsistence-based and rainfed**. Accordingly, crop production and agropastoralism dominate the areas with rainfall around 600 mm and above, whereas rearing of livestock prevails in areas with rainfall around 400 mm and below [32]. Land pressures due to rapid population growth, agricultural extensification and intensification, overcultivation, overgrazing and deforestation result in land degradation and desertification which in turn reduce the productive capacity of soils and strongly affect subsistence farmers [32].

Agriculture in the Sahel is characterised by limited water availability, with **soil moisture from precipitation often being the only available source of water** [32]–[34]. Agriculture is further restricted by up to 50 % of rainfall evaporating before crops can make use of it [33]. **Dry spells and droughts are the primary reason for crop failures**, especially when they occur during essential phases of crop growth [33]. Use of irrigation facilities to bridge these gaps is rare due to insufficient surface run-off and thus insufficient water for extraction from wells or rivers, making irrigation impractical in large areas of the Sahel [32], [33]. This makes agricultural production and subsequently food security in the Sahel highly dependent on rainfall patterns and thus vulnerable to climate change [35]. The **northern Sahel is drier** than its southern counterpart due to its proximity to the Saharan biomes,

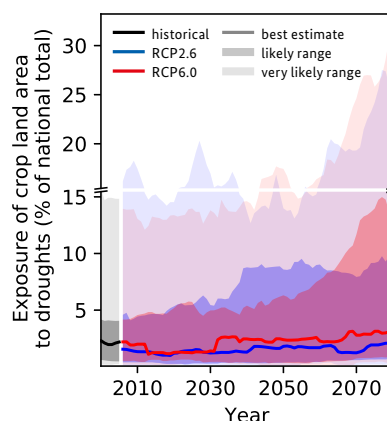


Figure 16: Projections of crop land area exposed to drought at least once a year for the Sahel for different GHG emissions scenarios.

consisting mostly of marginal lands [33]. It is thus **dominated by transhumant pastoralism** and some farming of drought-resistant sorghum and millet crops [32]. Overgrazing and land clearing to promote growth of more palatable grasses caused by high livestock densities and the expansive needs of a rapidly growing population are common issues leading to land and soil degradation, as a quarter of the population in the northern Sahel is engaged in animal husbandry and livestock herds are an integral part of local cultural practices, determining social status and livelihoods [32]. Potential for agricultural expansion and intensification is low [34]. **Agriculture in the southern Sahel is more diversified**, including **subsistence crops such as groundnuts, cassava, cow peas and cash crops such as cotton, maize and sugar cane** as well as

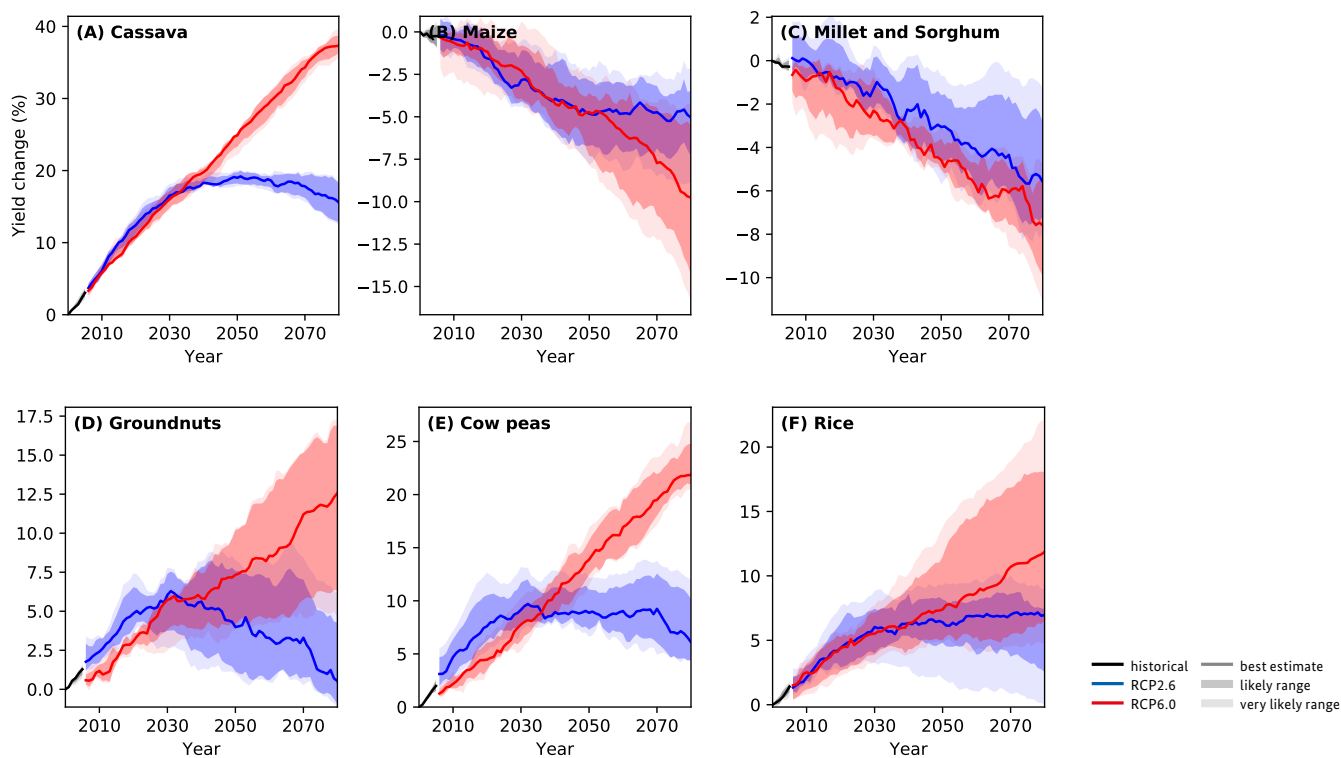


Figure 17: Projections of crop yield changes for major staple crops in the Sahel for different GHG emissions scenarios assuming constant land use and agricultural management, relative to the year 2000.

extensively used forest and parkland areas comprised of natural vegetation [32], [34]. As rainfall amounts are higher in the southern Sahel, **soil quality is a prominent yield-limiting factor** here due to low availability of Nitrogen and Phosphorous and poor water-holding capacity [32]. As yields have stagnated in the past 30 years with only momentary periods of growth [36], the needs of a rapidly growing urban population and an increased market orientation of agriculture have necessitated **rapid expansion of croplands to keep pace with demand**, leading to more marginal areas being put under production and unsustainable agricultural practices such as shortening of fallow periods, further degrading soils via soil-mining caused by over-cultivation [32], [35]. As a result, **more than 40 % of the Sahelian population are food insecure** [35] with **low potential for agricultural intensification or adoption of adaptation strategies** due to low incomes, low education levels and a lack of market infrastructures [35], [36].

Currently, the high uncertainty of projections regarding water availability (Figure 14) translates into high uncertainty of drought projections (Figure 15). According to the median over all models employed for this analysis, **the national crop land area exposed to at least one drought per year will decrease from 2.3 % in 2000 to 2.0 % and increase to 3.2 % in 2080 under RCP2.6 and RCP6.0, respectively**. Under RCP6.0, the likely range of drought exposure of the national crop land area per year widens from 0.6–4.2 % in 2000 to 0.9–14.0 % in 2080. The very likely range widens from 0.2–15.7 % in 2000 to 0.3–32.1 % in 2080. This means that **some models project a doubling of drought exposure over this time period**.

In terms of **yield projections**, model results indicate a negative trend for maize, millet and sorghum under both RCPs (Figure 17). By 2080 and compared to the year 2000, **yields of maize (-9.8 %), millet and sorghum (-7.6 %) are projected to decrease under RCP6.0. Yields of cassava (37.3 %), groundnuts (12.6 %), cow peas (21.9 %) and rice (11.9 %), on the other hand, are projected to increase** under the same scenario. At the beginning of the century, these crops follow a similar trend under RCP2.6 as under RCP6.0, however, after the year 2030, the increase stagnates or even turns into a decrease towards the end of the century, for example, in the case of groundnuts. A possible explanation for the more positive results under RCP6.0 is that cassava, groundnuts, cow peas and rice are so-called C3 plants, which follow a different metabolic pathway than, for example, maize (a C4 plant), and benefit more from the CO₂ fertilisation effect under higher concentration pathways. Although some yield changes may appear rather 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 decreases of millet and sorghum are smaller than that of other declining crops, however, Figure 18 shows that south-western Mali will see decreases of up to 17 %, while the eastern part of the country as well as parts of southern Niger will see increases of up to 55 %.

Overall, adaptation strategies such as switching to improved varieties in climate change-sensitive crops need to be considered, yet should be carefully weighed against adverse outcomes, such as a resulting decline of agro-biodiversity and loss of local crop types.

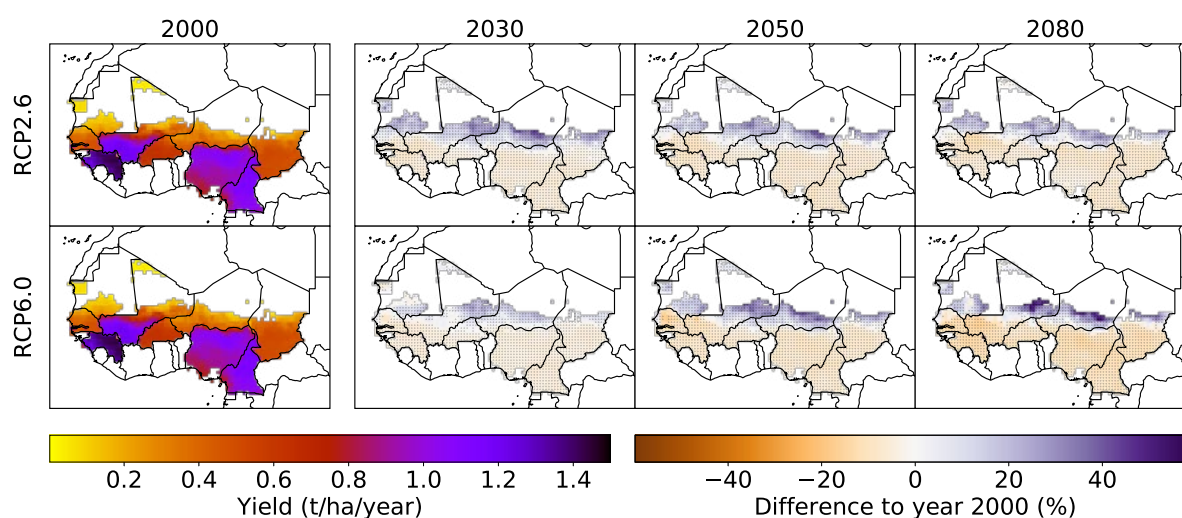


Figure 18: Regional projections of millet and sorghum yields for the Sahel for different GHG emissions scenarios assuming constant land use and agricultural management, relative to the year 2000.

c. Infrastructure

Climate change is expected to affect the infrastructure of the Sahel through extreme weather events. High precipitation amounts can lead to the **flooding of roads**, while high temperatures can cause **roads, bridges and coastal infrastructures to develop cracks and degrade more quickly**. The Rural Access Index lies between 25–50 % in most of the Sahel, with 49 % in Senegal. While Chad achieves the lowest score with 24 %, Guinea with 52 %, Nigeria with 64 % and Cameroon with 57 % achieve the highest scores [37]. This demonstrates that the road access is highest in coastal regions of the Sahel which corresponds to the locations of most main cities in the coastal regions [38].

Despite the risk of infrastructure damage being likely to increase due to climate change, precise predictions of the location and the extent of exposure are difficult to make. For example, projections of river flood events are subject to substantial modelling uncertainty, largely due to the uncertainty of future projections of precipitation amounts and their spatial distribution, affecting flood occurrence (see also Figure 8). In the case of the Sahel, median projections show **little change in national road exposure to river floods** (Figure 19). In the year 2000, 0.85 % of major roads were exposed to river floods at least once a year. By 2080, this value is projected to increase to 1.18 % under RCP2.6 and to 1.02 % under RCP6.0. The **exposure of urban land area to river floods** is projected to also **change only slightly** from 0.08 % in 2000 to 0.17 % under RCP2.6 and 0.15 % under RCP6.0 by the year 2080 (Figure 20).

Extreme weather events also have **devastating effects on human settlements and economic production sites**, especially in urban areas with high population densities located mostly in southern parts of the region, which hold some of Africa’s largest cities, such as Lagos and Dakar. For example, after heavy rainfalls in 2020, the Niger River overflowed, which led to a shut down of the capital city Niamey and affected more than 240,000 people through damage and destruction of more than 700 wells and the potential risk of cholera and other water-borne diseases [39].

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 loss of housing, contamination of water, 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. Refugees and IDPs are often residing in overcrowded camps and sites or among host communities, living in already precarious conditions in underserved areas, putting them at risk of secondary displacement or multiple vulnerabilities. Extreme weather events can also lead to conflicts between displaced people and their host communities due to competition over natural resources, food, water and land rights. The Sahel faces one of the world’s fast-

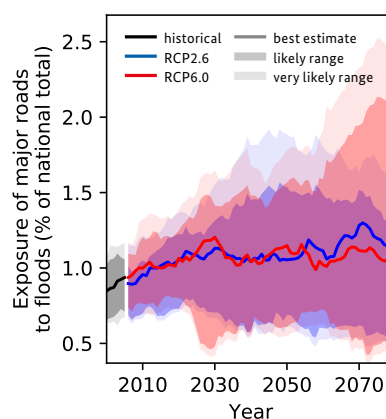


Figure 19: Projections of major roads exposed to river floods at least once a year for the Sahel for different GHG emissions scenarios.

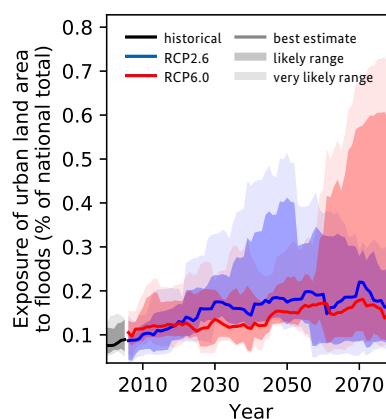


Figure 20: Projections of urban land area exposed to river floods at least once a year for the Sahel for different GHG emissions scenarios.

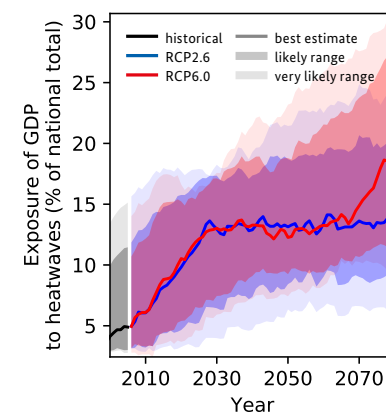


Figure 21: Exposure of GDP in the Sahel to heatwaves for different GHG emissions scenarios.

est growing displacement crises, along with cascading climate impacts on agricultural production, natural resource availability and intercommunal conflicts [40].

With the **exposure of the GDP to heatwaves projected to increase** from around 4.1 % in 2000 to 14.2 % (RCP2.6) and 19.1 % (RCP6.0) by 2080 (Figure 21), it is recommended that policy planners start identifying heat-sensitive economic production sites and activities, 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

The Sahel is one of the ecosystems that is the most sensitive to climate change and climate variability. Severe drought periods since the 1970s have led to a degradation of natural resources and ecosystems with negative impacts on the development of affected countries [18]. Climate change contributes to land degradation and desertification, posing a serious threat to agriculture and livestock-dependent communities. In addition, climate change is expected to have a significant **influence on the ecology and distribution of tropical ecosystems**, though the magnitude, rate and direction of these changes are uncertain [42]. With rising temperatures and increased frequency and intensity of droughts, wetlands and riverine systems are increasingly at risk of being disrupted and altered, with **structural changes in plant and animal populations**. Increased temperatures and droughts can also impact succession in forest systems while concurrently increasing the risk of invasive species, all of which affect ecosystems. In addition to these climate drivers, low agricultural productivity and population growth might motivate unsustainable agricultural practices, resulting in increased deforestation, fires and land degradation.

Model projections of species richness (including amphibians, birds and mammals) and tree cover for the Sahel are shown in Figure 22 and 23, respectively. The models applied for this analysis show particularly strong agreement on the development of species richness: Under RCP6.0, **species richness is expected to decrease in most parts of the Sahel**, in some parts, such as in south-eastern Mauritania, by up to 31 % (Figure 22). **Increases** are projected **only for parts of the Sahel**, mostly the north-western and north-eastern fringes, with up to 77 % in western Mauritania

or 57 % in eastern Chad. Increases are also projected for parts of the south-eastern Sahel, such as southern Cameroon, however, these are more moderate at 25 %.

With regard to **tree cover**, projections depend on both the scenario and the region within the Sahel (Figure 23). Under RCP2.6, tree cover is primarily projected to not change or to decrease, which is particularly visible in southern Guinea (3.3 %) and northern Cameroon (7.2 %), but also in other smaller patches in the southern Sahel. Under RCP6.0, projections show either no change or an increase, e.g. for most of Burkina Faso and southern Chad. However, **model results are very uncertain** under both scenarios, which is why **no clear trend** in tree cover can be identified.

It is important to keep in mind that **the model projections exclude any impacts on biodiversity loss from human activities**, such as land use, which have been responsible for significant losses of global biodiversity in the past, and are expected to remain its main driver in the future [43]. The high rate of population growth in the Sahel puts pressure on natural resources and makes the environment vulnerable to land degradation, in particular vegetation cover. At the same time, recent earth observations show a positive trend in rainfall and vegetation index over the last decades, known as **the re-greening of the Sahel**. However, it remains unclear if the observed positive trends provide an environmental improvement with positive effects on peoples' livelihoods [44]. However, in parallel, there are on-going efforts in the region to combat those negative ecosystem changes, such as the Great Green Wall, an African-led initiative aiming to restore 100 million hectares of currently degraded land in the Sahel.

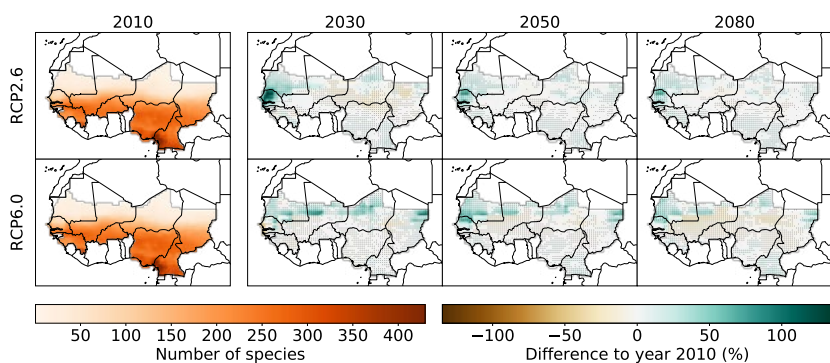


Figure 22: Projections of the aggregate number of amphibian, bird and mammal species for the Sahel for different GHG emissions scenarios.

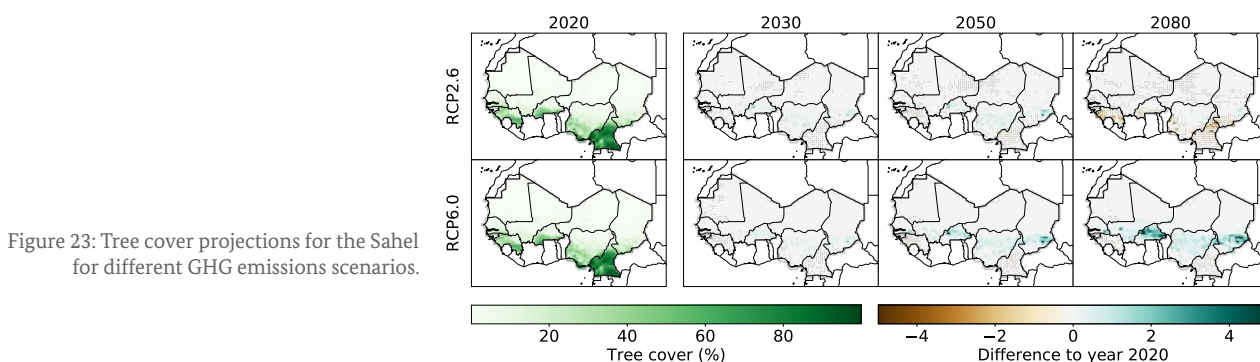


Figure 23: Tree cover projections for the Sahel for different GHG emissions scenarios.

e. Human health

Climate change threatens the health and sanitation sector

through more frequent incidences of heatwaves, floods, droughts and storms. Studies have indicated that the climate change and health nexus is becoming increasingly relevant in the Sahel [45]. Rising temperatures will result in **more frequent heatwaves**, leading to **increased heat-related mortality**. Under RCP6.0, the **population affected by at least one heatwave per year is projected to increase from 4.3 % in 2000 to 19.9 % in 2080** (Figure 24). Furthermore, under RCP6.0, **heat-related mortality will likely increase from 2.4 to 9.6 deaths per 100,000 people per year by 2080**, which translates to an increase by a factor of 4 towards the end of the century compared to year 2000 levels, provided that no adaptation to hotter conditions will take place. However, this increase is averaged over the whole Sahel, which means that some parts of the region, such as northern Mali, will see even higher increases from 2.5 to 11.9 deaths, while, for example, Senegal will see below-average increases from 1.9 to 5.7 deaths (Figure 25).

Malnutrition can be another indirect effect of crop failure due to drought and extreme precipitation events within a region that exhibits extraordinary population growth. Many of these challenges are expected to become more severe under climate change. This has dramatic consequences for the population, and in particular children. **Burkina Faso already has a stunting rate (low height in regards to age) of 25 % for children under the age of five.** Moreover, **9 % of children under five suffer from severe malnourishment or are wasted** (exhibit low weight to height ratio) [46].

The vector-borne disease **malaria is widely spread across the West African region.** Unlike neighbouring countries in other regions of Africa, Sahelian countries exhibit a **strong seasonality**

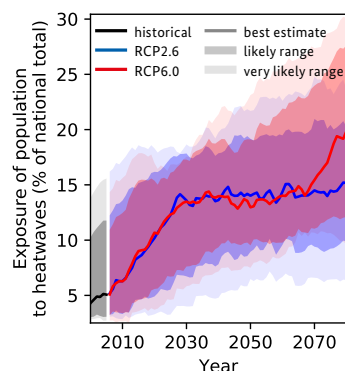


Figure 24: Projections of population exposure to heatwaves at least once a year for the Sahel for different GHG emissions scenarios.

with respect to malaria incidence. As of 2018, six Sahelian countries employed seasonal malaria chemoprevention (SMC), which benefited 17 million children [47]. A study within the Nigerian context assessing the prevalence of malaria and meningitis under climate change found that increases in **malaria cases strongly correlated with increases in precipitation**. Considering the unequal distribution in rainfall between Northern countries of the Sahel and the South of the region, it is no surprise that the **south is, in general, more affected by malaria**. Indeed, the **southern Sahel is one of the two regions, along with East Africa, that is projected to not see a decrease in malaria cases**. While other regions within sub-Saharan Africa are expected to witness an increase in temperatures but a decrease in rainfall, precipitation in the Sahel may in fact increase while becoming more erratic. This would favour the spread of malaria [45]. At the same time, for the Sahelian region, **meningitis demonstrated a strong correlation with temperatures and aerosols** [48]. Considering climate projections for the region, **higher temperatures and increased variability in regards to precipitation patterns could exacerbate government's struggles to keep malaria and meningitis at bay in the region.**

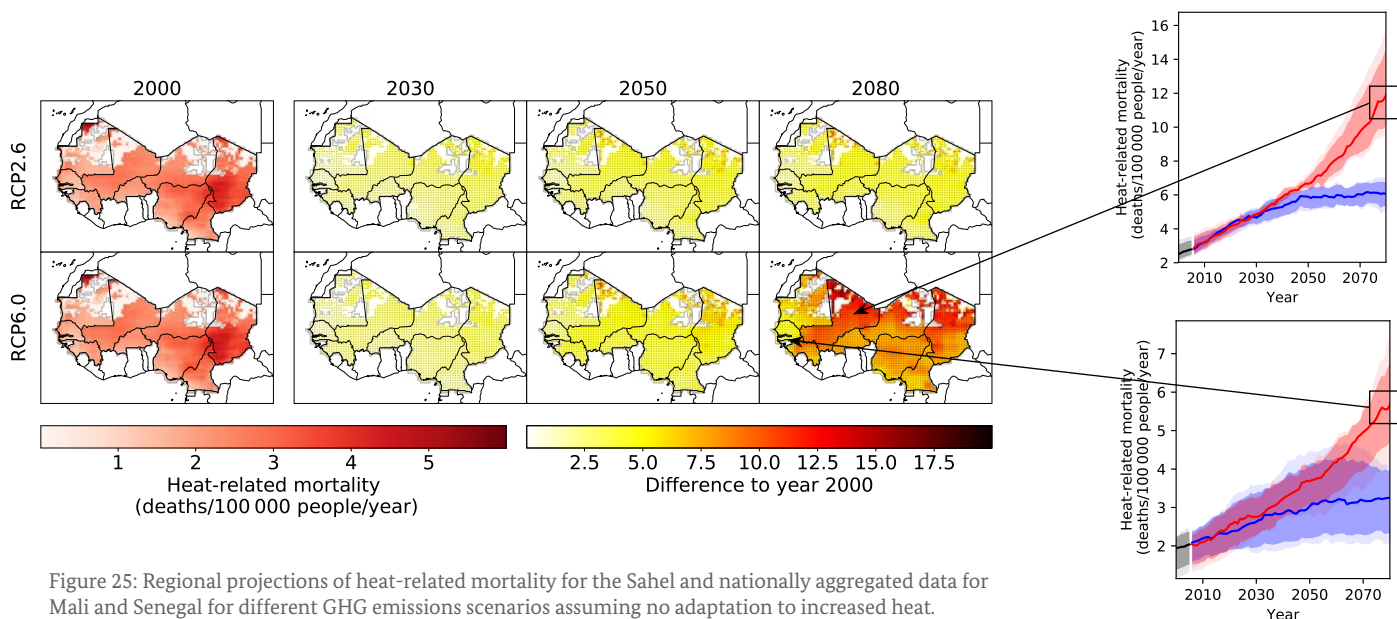


Figure 25: Regional projections of heat-related mortality for the Sahel and nationally aggregated data for Mali and Senegal for different GHG emissions scenarios assuming no adaptation to increased heat.

f. Displacement

The climatic changes projected above can lead to widespread food insecurity and significant displacement within the region (Biasutti, 2019; Mertz et al., 2012). Additionally, a majority of the population relies on subsistence farming and herding and high levels of population growth, together with a depleting resource base, **contribute to turning migration from choice to necessity** [50]–[53].

In a pessimistic scenario, more than 85 million people could have to move internally in sub-Saharan Africa because of climate change (Clement et al. 2021). **Within the Sahel, Chad hosts the highest number of refugees and asylum seekers (half a million) followed by Niger with a quarter million.** In Burkina Faso, more than 1 million people have been internally displaced due to both ongoing violence and prevailing droughts [55]. In fact, **the displacement situation in Burkina Faso is one of the fastest growing ones.** In 2018 around 72,000 people were registered as internally displaced. That number grew to 600,000 persons of concern in 2019 and doubled again in 2020, leaving about 1 Million people as refugees, internally displaced and asylum seeking [55]. In regions grappling with the influx of displaced people, these humanitarian crises add to pre-existing pressures such as fragile state institutions, ethnic tensions, competition over natural resources such as land, pasture and water, and recurring attacks by non-state armed groups [56]. The Liptako Gourma Region bordering Burkina Faso, Mali, and Niger, is a hotspot for this complex interplay of factors and is thus considered a high-risk region for climate impacts on human security.

Vulnerabilities

Marginalized groups such as ethnic minorities, especially those living a nomadic or semi-nomadic life, are considered particularly vulnerable in the face of climatic extremes and therefore most at risk of displacement [57]. Furthermore, displacement is particularly problematic for these groups, as they are often **unable to integrate into the urban population and the local labor market.** Discrimination against ethnic minorities is prevalent and language barriers further complicate efforts to seek employment. With no formal education or marketable skillset, many IDPs end up **unemployed and in poverty** on the outskirts of urban centers. Women and children are most at-risk within these populations, with widespread experiences of **sexual and gender-based violence** [58]. A recent study based on stakeholder interviews with seasonal migrant laborers and their wives in Burkina Faso has shown that **migration can be a last resort strategy of climate adaptation,** leading at times to adverse migration outcomes, such as a lower socioeconomic status for migrants and their families. For a lack of better options, migration in these cases is a means of survival rather than an effective climate adaptation strategy [59].

Governance Structures

In the absence of institutions and effective policies to mitigate adverse conditions, vulnerable parts of the population are at-risk of being targeted for **recruitment by extremist groups** [60]. Qualitative research based on stakeholder interviews with nomadic groups and ethnic minorities in the region has shown that the combination of climate impacts, **weak governance,** socio-economic and political marginalization, and out-group emigration provide a fertile ground for the **exacerbation of underlying ethnic tensions** as well as recruitment by armed non-state actors [61].



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