Climate risk report for the West Africa region

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Recommended citation: Doherty, A., Amies, J., Higazi, A., Mayhew, L., Osborne, R., Griffith, H., and Buonomo, E. (2022) Climate risk report for the West Africa region. Met Office, ODI, FCDO.

Image location: Senegal

Document history

Version	Purpose	Date
0.1	Review	31/01/2022
1.0	Final delivery	07/02/2022

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February 2022

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Executive summary

This report highlights the headline risks to consider in any climate resilient development planning for the West Africa region. Key climate-related risks have been identified by considering climate change projections and climate hazards in the 2050s, and how these hazards may interact with dynamic underlying socio-economic vulnerabilities. These interactions are considered in relation to water resources, agriculture and pastoralism, urban environments and infrastructure, coastal regions, human health and mortality, and biodiversity and ecology.

The West Africa region examined in this report includes Senegal, The Gambia, Guinea-Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin, and Nigeria.

The West African climate is characterised by a north to south gradient in temperature and rainfall, with the southerly coastal regions being cooler and wetter and the northern areas being hotter and drier as they get closer to the Sahel. Observations from 1981-2010 show a moderate increasing trend in temperature compared to other regions of the world, but as the region has a narrow climatic temperature range both interannually and seasonally, the significance of this change is greater than it might be in other areas.

Rainfall trends are less clear, but recent observations show increases in annual totals in the north and east of the region and decreases in the southwest. Future projections indicate the year-to-year variability in rainfall in the region will continue to be high, while the frequency and intensity of rainfall events will increase. There is some indication that the number of consecutive dry days seen in the region will also increase, which, combined with increasing temperatures, indicates a reduction in both the quantity and quality of water resources.

Sea levels are projected to rise by an average of 0.3 m in West Africa between the 2000s and the 2050s, this will have severe implications for coastal areas and the one third of the region's population living on the coast.

This report outlines key climate risks at a regional level for West Africa, a more detailed country level analysis is required for national risk assessments. Most risks identified in this report are not new in the context of West Africa, but they are likely to be amplified as the climate changes. Our analysis identifies the following key risks as the most critical across the West Africa region as assessed in six socio-economic themes.

Water security

Water security is already a key issue in West Africa due to distribution, management and storage issues, as well as the high variability in rainfall and uneven geographical and economic distribution of water resources. Water stress will increase as changes in rainfall patterns and increased temperatures compound pressures that already exist on water supplies. Water availability and quantity are projected to decrease, impacting agriculture, human health, and biodiversity.

Water demand in West Africa is increasing due to rapidly growing populations and expected increases in irrigated agriculture. Risks to water supplies will be elevated as rising temperatures increase evapotranspiration.

Groundwater depletion will increase to offset more variable rainfall and increased demand due to population growth. However, as groundwater depletion increases the efficiency of groundwater recharge will be vital and needs to be better understood. Deforestation has already weakened the hydrological cycle at local and subregional levels, and further loss of forest cover will compound vulnerabilities over water availability.

Changes to rainfall patterns and terrestrial water storage will compound the pressures on water supplies and exacerbate the stresses of human impacts. The frequency and intensity of drought is likely to increase in West Africa, with an increase in consecutive dry days between rainfall events. This will have particular impacts on agriculture and water resources. Increased evapotranspiration will further limit availability of water. Water related migration is therefore likely to increase, as is competition for water.

Flood risk will increase as heavier rainfall events become more common, bringing increased risk of loss of life, loss of crops, contamination of water supplies, and damage to housing and infrastructure. Increased flooding and rising sea levels will also increase the risk of contamination of drinking water sources.

Agricultural production and pastoral systems

Crops are grown in all ecological zones of West Africa (outside desert areas) and farming is essential to food security across the region. Systemic vulnerabilities in agriculture and pastoralism exist across West Africa, including food insecurity and vulnerability of populations to rising food costs. Approximately 60% of West Africa's population rely on rainfed agriculture.

A warming climate increases exposure to heat stress, drought risk and harvest failure. Competition for water will increase in areas where irrigated farming is possible, exacerbated by increasing demand from growing populations.

Climate change will alter agro-ecology, favouring crops that can tolerate higher temperatures and which are less sensitive to fluctuations in rainfall. This will negatively impact some of the main crops currently grown in the region, reducing yields in those crops (such as maize).

Ecological degradation and biodiversity loss that reduces crop yields, also creates a negative feedback loop that will be exacerbated by higher temperatures.

Pastoralism and livestock are important for food security and rural economies in West Africa. These will be at risk from higher temperatures resulting in decreased biomass, reduced pasture, and increased evaporation of water sources, exacerbating existing competition for farmland and problems of grazing land being lost to cultivation. This will potentially raise farmer-herder tensions and rural insecurity. The expansion of cultivation, encroachment of livestock onto crops, and population pressure has already put pastoralists and farmers under pressure.

Water is a key issue for pastoralism in the dry season; increased water scarcity due to higher rainfall variability and higher evapotranspiration will negatively impact herders. Droughts lead to cattle and other livestock dying due to lack of pasture, or at least to decreasing reproduction, and will become an increasing feature of the climate in the region. The distribution of livestock and herders could shift towards areas with more available water and land.

Urban areas and infrastructure

Risks from extreme heat are compounded in urban centres by the Urban Heat Island (UHI) effect. This means rising temperatures will place particular pressure on urban infrastructure and expose urban populations to increased risk of heat stress. Temperature increases may be less pronounced in coastal areas, where most West African capital cities are located, but higher humidity means heat stress will still be a risk here.

Increased frequency of heavy rainfall coupled with a hardening of the urban environment and inadequate drainage to deal with high quantities of water, will place urban areas at increased risk of flooding. Most of West Africa's largest cities are coastal and low-lying and are therefore susceptible to inundation by sea water. Due to higher sea levels and shoreline retreat, the risks and exposure of coastal cities to coastal flooding will increase.

Water shortages in cities will also become more acute, as some areas experience decreases in rainfall. Even in places that see increases in aggregate rainfall this will be offset by higher evaporation and increased demand for water due to demographic growth. Access to clean water will also be threatened by contamination of water supplies from flooding and sea level rise.

Coastal regions

West Africa's most populous cities are located on the coast, with a third of the population living along the coastline. Coastal regions are significant areas in West Africa for economic activity, supporting fisheries and agriculture, as well as trading centres and extractive industries, including oil and gas.

The risk from sea level rise is acute. A projected 0.3 metres sea level rise will impact coastal settlements through loss of beaches, shoreline retreat and inundation of low-lying areas posing a considerable risk for the third of West Africa's population that live in coastal regions. Low-lying villages and settlements along the coast are vulnerable to inundation and coastal erosion, and therefore may require relocation further inland. The loss of beaches would also cause a significant loss of tourist income in the coastal states, including in The Gambia, Côte d'Ivoire, Ghana, Sierra Leone, and Liberia. Saltwater intrusion of coastal aquifers may be further exacerbated due to sea level rise.

The fishing industry is crucial to local livelihoods in most of coastal West Africa, but the region already has depleted fish stocks due to over-fishing and exploitation. Rising sea temperatures, including the risk of marine heatwaves, acidity and deoxygenation will have a further detrimental impact on marine life and threaten fisheries and fish stocks.

Human health and mortality

Heat stress is a prominent climate risk across West Africa and will increase as the number of days with temperatures above 40°C increase. This will particularly impact infants, the elderly and those with underlying health conditions. This could become especially dangerous if combined with water shortages during heat waves and droughts, with increased risk of death by dehydration.

Urban areas will be hardest hit by higher temperatures due to the urban heat island effect and large populations living in poverty without air conditioning will be most exposed. Outdoor labourers such as construction workers and farmers will be adversely impacted by heat risk. Outdoor labour during the hotter months may become impossible or at least limit the hours of outdoor work to early mornings, especially in the north of West Africa.

Some vector borne diseases, particularly those transmitted by mosquitoes such as malaria and dengue fever, may be reduced as higher evaporation rates reduce areas of long-standing stagnant water. However increased flooding risks outbreaks of cholera and other water-borne diseases. Health impacts from poor air quality will be greater as drier conditions increase dust content in the atmosphere especially during the Harmattan - dry northerly winds - bringing dust from the Sahara.

Biodiversity and ecology

Future changes in both temperature and precipitation will alter the conditions of West Africa's natural habitats. This change will be at an unprecedented rate which will push the adaptive ability of ecosystems to their limits. West Africa's tropical forests and savannah forests are already threatened and much reduced from logging, cultivation, hunting, grazing, and population pressure. Many species of plants and animals are already endangered and will be vulnerable to climate change. Climate change will exacerbate these existing impacts and create new ones in changing temperature and rainfall regimes.

Changes in temperature and rainfall patterns will alter the distribution of some of West Africa's flora and fauna, with limited opportunity for species to take hold in new geographies because of existing pressure on habitats and ecosystems.

Protected areas such as national parks are crucial to West African biodiversity, but species may be pushed into new areas that are not protected or where the vegetation and land use is already degraded. National parks in West Africa span tropical rainforests and savannah regions but the resilience of these ecosystems is being undermined by current pressures, increasing their vulnerabilities to climate change. Wildlife is also susceptible to direct impacts of high temperatures and especially to drought, which reduces biomass, impacting ecosystems and food sources for animals.

Climate change impacts in the Atlantic such as sea level rise, rising ocean water temperatures and increased frequency of marine heat waves also compound threats to marine ecosystems in West Africa.

Careful management of forests, and of national parks and marine protected areas, is essential for sustaining and increasing the resilience of ecosystems and wildlife in the region. West Africa's biodiversity will further diminish if protected areas are not strengthened and maintained.

Headline climate statements for West Africa

Temperature

- West Africa has warmed by 1-1.5ºC since pre-industrial times, in line with other areas in the tropics.
- Annual mean temperatures are projected to further increase by 1.3-1.8ºC between the baseline period and 2050s, depending on the emissions scenario (IPCC, 2021).
- Intensity and frequency of extreme hot days projected to increase with maximum temperatures increasing and exceeding key thresholds for longer periods.
- West Africa has a narrow climatic temperature range, both interannually and seasonally, the projected increase will push temperatures into a range outside that currently experienced.

Precipitation

- There is a decreasing south to north precipitation gradient across West Africa. The timing and intensity of the single rainy season is controlled by the West African Monsoon and there is high inter-annual variability in the amount and timing of rainfall.
- There is some indication that 2050s average annual rainfall totals will be lower in the west and higher in the east.
- Year-to-year variability in seasonal rainfall amounts and timing will continue to be a feature of the future climate with the variability projected to increase, resulting in more frequent wetter and drier years.
- The frequency and intensity of heavy rainfall events is projected to increase with associated increases in pluvial and fluvial flooding.
- Drought and consecutive dry days in the region are projected to increase.

Oceans

- Sea levels will continue to rise by an average of 0.3 m around West Africa between the 2000s and the 2050s.
- Erosion and flooding of the coastal areas will be a major risk, with many major coastal cities affected.
- Saltwater intrusion into fresh water supplies will be a risk from sea level rise.
- Sea surface temperatures are projected to increase by 1-2˚C above pre-industrial levels by the 2050s, the frequency and intensity of marine heatwaves will increase with impacts on marine life and fisheries.

Headline risk statements for West Africa	
Water security and resources	• Water resource quality and quantity are projected to decrease. • Groundwater depletion will increase as a result of rising demand and falling supply. • The frequency and intensity of droughts will increase, with an increase in consecutive dry days between rainfall events, with impacts on agriculture and water resources. • Flood risks will increase resulting in loss of life, loss of crops, contamination of water supplies, and damage to housing and infrastructure. • Deforestation has already weakened the hydrological cycle at local and subregional levels, and further loss of forest cover will compound vulnerabilities over water availability.
Agricultural and pastoral systems	• Climate change will alter agro-ecology, favouring crops that can tolerate higher temperatures and which are less sensitive to fluctuations in rainfall and reducing yields in less flexible crops, such as maize. • Competition for water will increase in areas where irrigated farming is possible, exacerbated by increasing demand from growing populations. • Ecological degradation and biodiversity loss will reduce crop yields due to reduced pollination, and nutritious vegetation is reduced for grazing livestock. • Pastoralism and livestock are at risk from higher temperatures that cause heat stress, reduced pasture, and increased evaporation of water sources, exacerbating existing land pressures and potentially raising farmer-herder tensions.
Urban environments and infrastructure	• Urban areas will be hardest hit by higher temperatures due to the urban heat island effect and large populations living in poverty. • Increased frequency of heavy rainfall coupled with a hardening of the urban environment and inadequate drainage will place urban areas at increased risk of flooding. • Rising sea levels will expose urban areas to sea water inundation, increased risk of flooding and storm surges. • As urban populations grow, access to clean water will be threatened by a combination of growth in demand and contamination from flooding and sea level rise.

Coastal regions	• Sea level rise along the West African coast will severely impact coastal settlements where one third of the West African population lives.
	• Saltwater intrusion of coastal aquifers may be further exacerbated due to sea level rise
	• Fisheries are already under threat due to overexploitation. Climate change will further negatively impact fish stocks as ocean temperature, acidity and deoxygenation all increase.
	• Considerable socio-economic and ecological damage is possible from:
	    ◦ The erosion of sandy beaches and coastline,
	    ◦ Damage to coastal ecosystems, and
	    ◦ Coastal cities facing increased flooding with associated risks to populations and infrastructure

	• Rising temperatures will increase the risk of heat stress and heat stroke, with heatwaves becoming more dangerous when combined with water shortages.

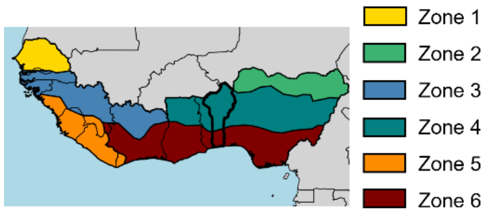
Human health and mortality	• Working outside during the day in the hotter months may become impossible, especially in the north of West Africa. • Vector borne diseases may be reduced as increased evaporation reduces areas of stagnant water, but flooding can trigger disease outbreaks such as cholera. • Health impacts from poor air quality will be a greater risk as drier conditions increase dust content in the atmosphere, especially during the Harmattan winds that blow down from the Sahara.
Biodiversity and ecology	• Future climate changes will alter the conditions of West Africa's habitats at an unprecedented rate, which is beyond the adaptive capacity of many natural systems. • Deforestation has already depleted much of West Africa's tropical and savannah forests and many plant and animal species are endangered. This makes these habitats and their endemic species more vulnerable to climate change. • Changes in rainfall and temperature will alter the distribution of some of West Africa's flora and fauna, with limited opportunity for species to take hold in new geographies because of existing pressure on habitats and ecosystems. • Careful management of forests, and of national parks and marine protected areas, is essential for sustaining and increasing the resilience of ecosystems and wildlife in West Africa.

Country summaries

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

Benin country profile

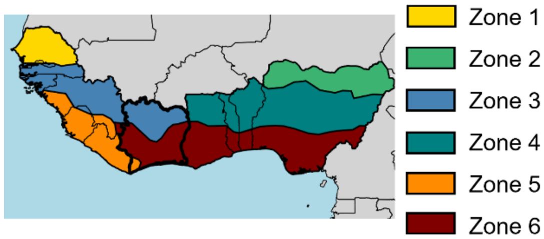
Benin is located on the West African south coast of the Atlantic Ocean in the Gulf of Guinea. It is divided between zone 4 and zone 6 in this report.



Summary of analysis relevant to Benin	Report section
Benin (Zones 4 and 6) experiences a tropical climate. Benin has an urbanisation rate of 49%, with most people living in the country's southern cities, with the coastal city of Cotonou (29% of the population) being the most populous. This region has already experienced a significant amount of warming since pre-industrial times. In the 2050s, there is high confidence the region will be at least 1-3.5°C warmer than the current climate throughout the year. Although there is less confidence in rainfall projections, our analysis suggests a small increase in annual rainfall. Variability in seasonal rainfall amounts and timings is also expected to increase, as is the frequency and intensity of heavy rainfall events. Sea levels will continue to rise with associated risk of flooding, erosion and saltwater intrusion into water supplies. The frequency and intensity of marine heatwaves will also increase	3.3.4 and 3.3.6
Regional risks relevant to Benin	**Report section**
Risks to crop production relating to changes in rainfall patterns and temperature increases	4.2.3
The combined effect of coastal erosion and sea level rise, leading to increased risk of flooding.	4.4.3

Côte d'Ivoire country profile

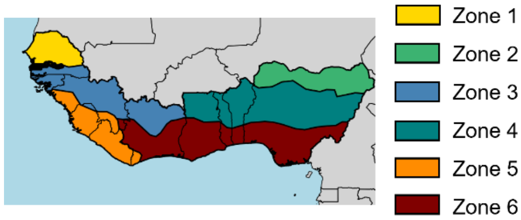
Côte d'Ivoire, or Ivory Coast, is located in the centre of the coastal region of West Africa. It is divided between zone 3, zone 5 and zone 6 in this report.



Summary of analysis relevant to Côte d'Ivoire	Report section
The north of Côte d'Ivoire is in the tropical savannah zone 3. Agriculture and pastoralism are the main economic activities in this zone. This zone has already experienced significant warming since pre-industrial times. In the 2050s there is high confidence that temperatures will increase further by between 1 and 4°C. Zone 3 shows smaller interannual variability in temperature across the baseline period than the other zones with a defined peak in temperatures in August. The rainy season (March to October) is projected to start later in the 2050s compared to the present day (medium confidence).	3.3.3
A small area in the very south-west corner of Côte d'Ivoire is in zone 5, a tropical rainforest area. Temperatures in zone 5 have seen a significant increase since pre-industrial times. In the 2050s, there is high confidence the region will be at least 1.5-3°C warmer than the baseline period throughout the year. There is less confidence around precipitation, but our analysis indicates a decrease in precipitation totals in the March-June season, at the start of the rainy season. This is supported by the literature which indicates a shift in the onset and cessation of the rainy season. Sea levels and sea surface temperature will continue to rise with associated risk of flooding and erosion and increases in the frequency and intensity of marine heatwaves.	3.3.5
Most of the southern area of Côte d'Ivoire is in zone 6. Côte d'Ivoire has an urbanisation rate of 49%, with most cities concentrated in the south of the country, with the coastal city of Abidjan (41% of the population) in zone 6 being the most populous. This zone is important for national and regional food security and for cash crops for export such as cocoa, of which Côte d'Ivoire is the largest producer worldwide. Along the coasts, there are fish-based livelihoods. The south of Côte d'Ivoire has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be at least 1.5-3°C warmer than the current climate throughout the year. Although there is less confidence in rainfall projections, our analysis suggests the existing high interannual variability will continue and the complex rainy season distribution could change. In October-November a majority of models indicate an increase in precipitation of up to 100 mm/season. Sea levels will continue to rise with associated risk of flooding and erosion and the frequency and intensity of marine heatwaves will also increase.	3.3.6
Sea-level rise, coastal erosion and salt-water intrusion.	4.4.3
The potential impact of changes in river flow to the Kossou dam.	4.1.3

The Gambia country profile

Gambia is located on the west Atlantic coast of West Africa; it is surrounded by Senegal and is divided between zone 1 and zone 3 in this report.

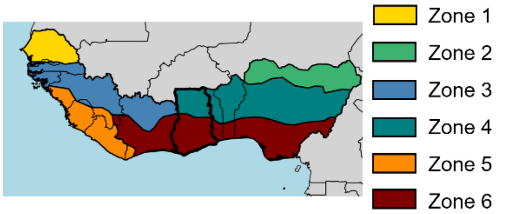


Summary of analysis relevant to The Gambia	Report section
The north of The Gambia is included in Zone 1 and experiences a semi-arid climate. This zone has a high dependence on rain-fed agriculture which is vulnerable to changes in the characteristics of the rainy season. Irrigated farming occurs mainly along the River Gambia This region has already experienced a significant amount of warming since pre-industrial times. In the 2050s there is high confidence that the region will be at least 1.5-4°C warmer than the baseline period (1980-2010). There is some indication that the onset of the rains may be delayed on average. There is already a high interannual variability in rainfall in zone 1 and this will continue into the 2050s with medium confidence that the number of consecutive dry days will increase in the region and the frequency and intensity of rainfall events will also increase.	3.3.1
The south of The Gambia is included in zone 3 which is a tropical savannah climate. Agriculture and pastoralism are the main economic activities in this zone. With the main crops in The Gambia being millet and ground nuts. The Gambia has an urbanisation rate of 56%, with most of the population living on the cost, with the coastal city of Serrekunda (70%) being the most populous. This region has already experienced a significant amount of warming since pre-industrial times. In the 2050s there is high confidence that temperatures will increase further by between 1 and 4°C. Zone 3 shows smaller interannual variability in temperature across the baseline period than the other zones with a defined peak in temperatures in August. The rainy season (March to October) is projected to start later in the 2050s compared to the present day (medium confidence). Sea levels will continue to rise with associated risk of flooding and erosion. up to the present-day.	3.3.3

Regional risks relevant to The Gambia	Report section
Increased risk of fatalities linked to heat stroke heightened by water shortages in the Senegambia region (Zone 1).	4.5.1
The negative impact to the productivity of fisheries, linked to those changes in the Canary current and seasonal upwelling.	4.4.2

Ghana country profile

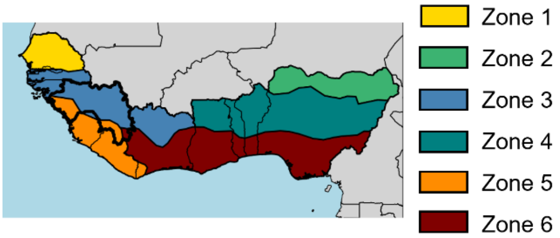
Ghana is located on the West African south coast. It is divided into zone 4 and zone 6 in this report.



Summary of analysis relevant to Ghana	**Report section**
The north of Ghana is included in zone 4 which is tropical savannah climate. There are many cities in zone 4 with populations well over a million people, including Tamale in Ghana. Major rivers and water bodies in zone 4 include part of Lake Volta in Ghana, and the Black and White Volta Rivers, which flow through northern Ghana southwards. The Volta Basin is a vital water source for Ghana. Zone 4 has already experienced a significant amount of warming since pre-industrial times. Models project increases of 1-3.5°C between the baseline (1981-2010) and the 2050s using the SSP5-8.5. Precipitation patterns in zone 4 show high interannual variability and this will continue into the 2050s with medium confidence in a small magnitude increase most likely to be seen in the rainy season (July-September).	3.3.4
The south of Ghana is included in Zone 6 which is a more humid coastal zone, and important for national and regional food security and for cash crops for export such as cocoa, of which Ghana is the second largest producer in the world. Most people live in this part of Ghana and are concentrated in coastal cities such as Accra, where 31% of the population live. This region has already experienced a significant amount of warming since pre-industrial times. Models project increases of 1.5-3°C (using worst case scenario SSP5-8.5) between baseline (1981-2010) and the 2050s throughout the year with potential for a greater increase up to 4°C in the dry period (December-February). There is less confidence around rainfall; however, our analysis suggests the existing high interannual variability will continue and the complex rainy season distribution could change. In October-November a majority of models indicate an increase in precipitation of up to 100 mm/season. Sea levels will continue to rise with associated risk of flooding and erosion and the frequency and intensity of marine heatwaves will also increase.	3.3.6
Regional risks relevant to Ghana	**Report section**
Health risks related to high temperatures and increased risk of heat stress, particularly in urban areas compounded by Urban Heat Island effects in Zone 4.	4.5.1
The impacts of sea level rise on tourism and salt water intrusion within coastal aquifers impacting coastal agricultural production.	4.4.1

Guinea country profile

Guinea is located on the Atlantic coastline and is divided between two zones in this report: Zone 3 and Zone 5.

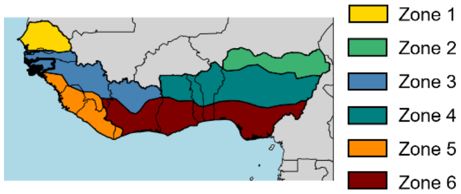


Summary of analysis relevant to Guinea	**Report section**
The northern and eastern inland parts of Guinea are included in Zone 3 and experience a tropical savannah climate. The natural vegetation of this zone is predominantly savannah woodland and grasses but verging into tropical forest in the more southerly areas of the zone in south-east Guinea. Pastoralism and agriculture are the main economic activities with extractive industries, notably mining also important. Guinea is a large miner of bauxite. This region has already experienced a significant amount of warming since pre-industrial times. In the 2050s there is high confidence that temperatures will increase further by between 1 and 4°C. Zone 3 shows smaller interannual variability in temperature across the baseline period than the other zones with a defined peak in temperatures in August. The rainy season (March to October) is projected to start later in the 2050s compared to the present day (medium confidence).	3.3.3
The western coastal and south eastern parts of Guinea are included in Zone 5. The natural ecology of this zone is mainly tropical rainforest, merging into savannah woodland in the northerly areas. Agriculture consists of a combination of cereals and root crops, fruits and vegetables. Fishing is also very important for coastal communities. The coastal areas are populated with major towns and villages including the capital Conakry. The coastal ecology is of considerable ecological importance. This region has already experienced a significant amount of warming since pre-industrial times. In the 2050s, there is high confidence the region will be at least 1.5-3°C warmer than the baseline period throughout the year. There is less confidence around precipitation projections, but our analysis indicates a decrease in precipitation in the March-June season, at the start of the rainy season. This is supported by the literature which indicates a later shift in the onset and cessation of the rainy season. Sea levels will continue to rise with associated risk of flooding and erosion and the frequency and intensity of marine heatwaves will also increase.	3.3.5

Regional risks relevant to Guinea	**Report section**
The impact of increased rainfall variability on biodiversity and ecology on the Guinea-savannah and Guinea Moist Forest.	4.6.2
Water storage and hydropower linked to Souapiti hydropower development	4.1.1

Guinea-Bissau country profile

Guinea-Bissau is located in the Atlantic coast of West Africa and is included in zone 3 of this report.

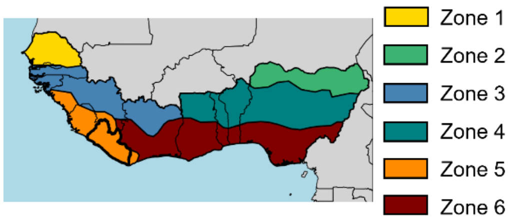


Summary of analysis relevant to Guinea-Bissau	Report section
Guinea-Bissau (Zone 3) experiences a tropical climate. It has an urbanisation rate of 34%, however this is concentrated in the coastal capital city of Bissau (78% of the population), outside of which the urbanisation rate is only 10%. Agriculture and pastoralism are the main economic activities. Extractive industries, notably mining (e.g. for minerals such as Bauxite in Guinea-Bissau), are also important. This region has already experienced a significant amount of warming since pre-industrial times. In the 2050s there is high confidence that temperatures will increase further by between 1 and 4°C. Zone 3 shows smaller interannual variability in temperature across the baseline period than the other zones with a defined peak in temperatures in August. The rainy season (March to October) is projected to start later in the 2050s compared to the present day (medium confidence). Sea levels will continue to rise with associated risk of flooding and erosion and marine heat waves with associated impact on fish stocks will become more common.	3.3.3

Regional risks relevant to Guinea-Bissau	Report section
Increase risk of heat stress linked to maximum temperatures regularly exceeding 40°C	4.5.1
The threat of sea level rise to the economically and culturally important Bijago Archipelago	4.4.1

Liberia country profile

Liberia is located in the south-west of West Africa on the coast of the Atlantic Ocean and is included in Zone 5 of this report.

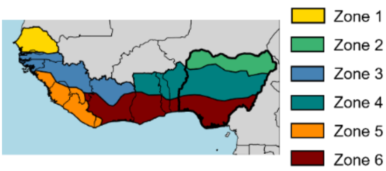


Summary of analysis relevant to Liberia	Report section
Liberia (Zone 5) experiences a tropical climate. Liberia has an urbanisation rate of 42%, with the coastal capital city of Monrovia being the most populous. The natural ecology of this zone is mainly tropical rainforest. Agriculture consists of a combination of cereals and root crops, fruits and vegetables. Fishing is also very important for coastal communities. The coastal areas are populated with major towns and villages and the capital cities of each of the countries including Monrovia. Sapo National Park is the largest protected area in that country and is reportedly the second largest area of remaining primary tropical rainforest in West Africa. The coastal ecology of zone 5 is also of considerable ecological importance. This region has already experienced a significant amount of warming since pre-industrial times. In the 2050s there is high confidence the region will be at least 1.5-3°C warmer than the baseline period. There is less confidence around precipitation projections, but they show a decrease in precipitation in the March-June season, at the start of the rainy season which is supported by the literature indicating high confidence of a delayed onset of the West African Monsoon (by on average 5-10 days) and medium confidence of its delayed retreat (IPCC, 2021; Dunning et al, 2018; Biasutti, 2013). Sea levels will continue to rise with associated risk of flooding and erosion and the frequency and intensity of marine heatwaves will also increase.	3.3.5

Regional risks relevant to Liberia	Report section
Water storage and hydropower linked to the Mount Coffee hydropower plant	4.1.1
Fisheries impacted by marine heat waves	4.4.2
The threat of sea level rise to coastal tourism	4.4.1

Nigeria country profile

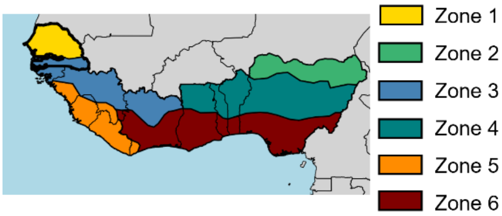
Nigeria or the Federal Republic of Nigeria is included in three zones in this report: zone 2, zone 4 and zone 6.



Summary of analysis relevant to Nigeria	Report section
North Nigeria in zone 2 has a tropical savannah climate. This area is mostly savannah land used for arable rainfed agriculture, dry season irrigated farming, and pastoralism (cattle and sheep). The largest city is Kano. Population growth is the highest in Nigeria, as are poverty levels. Civil insecurity is a major problem, with banditry in the north-west and a decade long jihadist insurgency in the north-east. This region has experienced a significant amount of warming since pre-industrial times. In the 2050s there is high confidence that temperatures will increase by 1-4°C across all seasons. There is less confidence around rainfall with year-to-year variability projected to remain high, the literature supports an increase in annual precipitation with increases in intense rainfall events during the rainy season, July to September.	3.3.2
Central Nigeria is included in zone 4 with a tropical savannah climate. More than half the population are rural and dependent on farming and pastoralism. Historically this zone had a lower population density than the rest of Nigeria, but the population has increased greatly over the past 50 years. Cities with populations well over a million people, include Abuja, Kaduna and Jos. The two largest rivers are the River Niger and River Benue; other important rivers include tributaries of the Niger and Benue, such as the river Gongola, and smaller rivers such as the Dilimi on the Jos Plateau. This area has experienced significant warming since pre-industrial times. Models project increases of 1-3.5°C between the baseline period and the 2050s using SSP5-8.5. Precipitation shows high interannual variability and this will continue to the 2050s with medium confidence in a small increase most likely in the rainy July-September.	3.3.4
Southern Nigeria is included in zone 6 and has a tropical coastal climate. This is the zone with the highest GDP in West Africa. It includes Lagos, the largest city in sub-Saharan Africa and the economic capital of Nigeria. It also includes the Niger Delta, important for Nigeria's oil and gas production. Agriculture is important, for domestic food security and for export e.g., cocoa. The biodiversity ranges from coastal mangroves and marine ecosystems to tropical and savannah forests. Protected areas include: Cross River National Park in south-east Nigeria near the Cameroon border with the endemic Cross River gorilla and other rare primates, as well as one of the few remaining areas of protected tropical rainforest in Nigeria; the southern section of Gashaka Gumti National park; and the Mambilla Plateau to the south, an upland area with some patches of protected forest, notably Ngel Nyaki, and a significant area for livestock production. This region has experienced a significant amount of warming since pre-industrial times. Models project increases of 1.5-3°C (using SSP5-8.5) between the baseline and the 2050s, with potential for a greater increase up to 4°C in the dry period (December-February). There is less confidence around rainfall; our analysis suggests the high interannual variability will continue. In October-November models indicate increased rainfall of 0-100 mm/season. Sea levels will continue to rise with risk of flooding and erosion and the occurence of marine heatwaves will increase.	3.3.6
Regional risks relevant to Nigeria	**Report section**
Health risks associated with higher temperatures in the north.	4.3.1
Health risks linked to poor air equality in areas such as Lagos and the Niger Delta.	4.5.3
Continuing shift in livestock migratory patterns to find pasture and the potential for conflict with other resource users.	4.2.2

Senegal country profile

Senegal is located in the north-west part of the West Africa region and is divided between two zones in this report: Zone 1 and Zone 3.

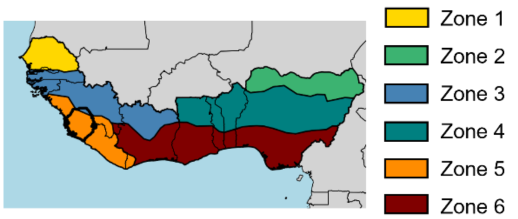


Summary of analysis relevant to Senegal	Report section
The northern part of Senegal is included in Zone 1 and experiences an arid/semi-arid climate. Senegal has an urbanisation rate of 51%, with the majority taking place within the "city region" of Dakar-Mbour-Touba, with the coastal city of Dakar (43% of the population) being the most populous. This zone has a high dependence on rain-fed agriculture. Irrigated farming occurs mainly in the Senegal River Valley in northern Senegal (bordering Mauritania) and along the River Gambia - the two main river systems in the region. Groundnut (peanut) production in Senegal is a major commercial crop for the country and occupies a large area of cultivation. The largest city is Dakar, which is a major commercial, political and diplomatic hub in West Africa. This region has already experienced a significant amount of warming since pre-industrial times. In the 2050s there is high confidence that the region will be at least 1.5-4°C warmer than the baseline period (1980-2010). There will be no major change to the rainy season although there is some indication that the onset of the rains may be delayed on average. There is already a high interannual variability in rainfall in zone 1 and this will continue into the 2050s with a strong chance that the number of consecutive dry days will increase in the region and the frequency and intensity of rainfall events will also increase. Sea levels will continue to rise with associated risk of flooding and erosion and the frequency and intensity of marine heatwaves will also increase.	3.3.1
The southern part of Senegal is included in zone 3 and experiences a tropical savannah climate. The natural vegetation of this zone is predominantly savannah woodland and grasses. Agriculture and pastoralism are the main economic activities in this zone. Extractive industries, notably mining, are also important. This region has already experienced a significant amount of warming since pre-industrial times. In the 2050s there is high confidence that temperatures will increase further by between 1 and 4°C. Zone 3 shows smaller interannual variability in temperature across the baseline period than the other zones, with a defined peak in temperatures in August. The rainy season (March to October) is projected to start later in the 2050s compared to the present day (medium confidence). Sea levels will continue to rise with associated risk of flooding and erosion.	3.3.3

Regional risks relevant to Senegal	Report section
Impact of drought on agriculture and pastoralism particularly cash crops, and food security.	4.2.1
Impact of projected reductions of reduced rainfall groundwater reserves (Zone 1).	4.1.2
Changes to run off and stream flow along both the Senegal and Gambia river basins impact on the efficiency of the Felou Hydroelectric plant.	4.1.1

Sierra Leone country profile

Sierra Leone is located in the south-west of the West Africa region on the Atlantic Ocean Gulf of Guinea coastline and is divided between two zones in this report: Zone 3 and Zone 5.

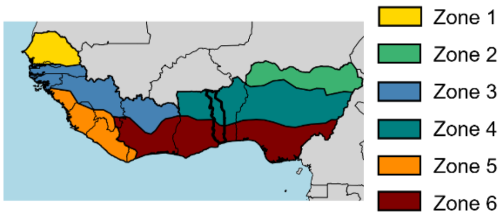


Summary of analysis relevant to Sierra Leone	**Report section**
The northerly tip of Sierra Leone is included in zone 3 and experience a tropical savannah climate. The natural vegetation of this zone is predominantly savannah woodland and grasses. Agriculture and pastoralism are the main economic activities in this zone. This region has already experienced a significant amount of warming since pre-industrial times. There is high confidence that temperatures will increase further by between 1 and 4°C by the 2050s. Zone 3 shows smaller interannual variability in temperature across the baseline period than the other zones with a defined peak in August. There is no model consensus on changes to the rains in zone 3 although there is some indication in our analysis that the rainy season (March to October) may be delayed in the 2050s compared to the present day and this is supported by the literature.	3.3.3
The majority of Sierra Leone is included in Zone 5 and experiences a humid tropical climate. The natural ecology of this zone is mainly tropical rainforest, merging into savannah woodland in the northerly areas. Agriculture consists of a combination of cereals and root crops, fruits and vegetables. Fishing is also very important for coastal communities. The coastal areas are populated with major towns and villages including Freetown in Sierra Leone. Sierra Leone has several protected areas, including three national parks, all of which have high biodiversity and contain endangered species. Temperatures in zone 5 have seen a significant increase since pre-industrial times. In the 2050s, there is high confidence the region will be at least 1.5-3°C warmer than the baseline period in all seasons. There is less confidence around precipitation, but our analysis indicates a decrease in precipitation totals in the March-June season, at the start of the rainy season. This is supported by the literature which suggests a shift in the onset and cessation of the rainy season. Sea levels will continue to rise with associated risk of flooding, erosion and salt water intrusion and the frequency and intensity of marine heatwaves will also increase impacting fisheries.	3.3.5

Regional risks relevant to Sierra Leone	**Report section**
The impact of MHW to the productivity of fisheries	4.4.2
The threat to coastal tourism as a result of sea level rise and coastal agriculture	4.4.1

Togo country profile

Togo is located in the centre of the West African region with a coast on the Gulf of Guinea, it is included in zone 4 and zone 6 of this report.



Summary of analysis relevant to Togo	**Report section**
Northern Togo is included in zone 4 of this report which has a tropical climate. There are a number of large inland market towns in this region which have a rising population. Much of this zone is productive agriculturally and more than half the population are in rural areas and dependent on farming. Pastoralism is also important in much of zone 4. The Mono and Oti rivers flow through Togo and Benin. This region has already experienced a significant amount of warming since pre-industrial times. Models project increases of 1-3.5°C between the baseline (1981-2010) and the 2050s using the SSP5-8.5. Precipitation patterns in zone 4 show high interannual variability and this will continue into the 2050s with medium confidence in a small magnitude increase most likely to be seen in the rainy season (July-September).	3.3.4
Southern Togo is included in zone 6. This area is agriculturally important and productive, for national and regional food security and for cash crops for export. This region has already experienced a significant amount of warming since pre-industrial times. Models project increases of 1.5-3°C (using SSP5-8.5) between baseline (1981-2010) and the 2050s throughout the year, with potential for a greater increase up to 4°C in the dry period (December-February). There is less confidence around rainfall; however, our analysis suggests the existing high interannual variability will continue and the complex rainy season distribution could change. In October-November most models indicate an increase in precipitation of 0-100 mm/season. Sea levels will continue to rise with associated risk of flooding and erosion and the frequency and intensity of marine heatwaves will also increase.	3.3.6

Regional risks relevant to Togo	**Report section**
Impacts of coastal erosion and sea level rise	4.4.1
Health risks due to more intense flooding and higher temperatures	4.1.4 and 4.5.1
Increased risk of drought (zone 6)	4.5.4

Image location: Dakar, Senegal

Glossary

Acronyms

AMO	Atlantic Multidecadal Oscillation
AR5	IPCC 5th Assessment Report
AR6	IPCC 6th Assessment Report
CHIRPS	Climate Hazards group InfraRed Precipitation with Station data
CORDEX	CoOrdinated Regional climate modelling Downscaling EXperiment
CMIP	Climate Model Intercomparison Project
ENSO	El Niño Southern Oscillation
FCDO	Foreign, Commonwealth & Development Office (UK Government)
GBV	Gender Based Violence
GCM	Global Climate Model
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
IUU	Illegal, Unreported and Unregulated fishing
MHW	Marine Heat Waves
MPA	Marine Protected Area
ODI	Overseas Development Institute
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SLR	Sea Level Rise

SST	Sea Surface Temperature
UHI	Urban Heat Island
UNFCCC	United Nations Framework Convention on Climate Change
WAM	West African Monsoon
WATCH	WATer and global CHange
WFDEI	WATCH Forcing Data ERA-Interim

Technical terms

These definitions have been taken from the IPCC reports from 2001, 2013, 2014, 2018 and 2019; the Met Office website (www.metoffice.gov.uk/weather/learn-about; https://www.metoffice.gov.uk/hadobs/monitoring/climate_modes.html); Wikipedia, the World Atlas (https://www.worldatlas.com) and the Cambridge dictionary (https://dictionary.cambridge.org/).

Term	Definition
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.
Aerosols	A suspension of airborne solid or liquid particles, with a typical size between a few nanometres and 10 μm that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in several ways: through both interactions that scatter and/or absorb radiation and through interactions with cloud microphysics and other cloud properties, or upon deposition on snow- or ice-covered surfaces thereby altering their albedo and contributing to climate feedback.
Agropastoral [livelihood]	Mixed crop-livestock farming found in semi-arid (medium rainfall) areas of Africa, typically with low access to services. It includes the dryland mixed farming system of North Africa, often depending on wheat, barley and sheep. In SSA the main food crops are sorghum and millet, and livestock are cattle, sheep and goats. In both cases, livelihoods include pulses, sesame, poultry and off-farm work.
Anthropogenic	Resulting from or produced by human activities.
Atlantic Multidecadal	The Atlantic Multidecadal Oscillation/Variation (AMO/AMV) has two phases, a positive phase where sea-surface waters in the North Atlantic are warmer than average and a negative phase when they are colder than average.

Oscillation/Variation (AMO/AMV)	There are a number of ways of calculating an AMO "index" which depend on the way that the longer-term trend seen in the observed record is dealt with. It is not entirely clear what causes changes in the AMO. Long records of the AMO from non-instrumental sources suggest that it is a long-lived natural fluctuation generated spontaneously within the ocean-atmosphere system. However, there is also evidence that switches in phase can be driven by changes in the output of manmade pollution. The different phases of the AMO have been associated with a variety of impacts. The positive phase has been associated with reduced Arctic sea ice, melting of the Greenland ice sheet, increased hurricane activity in the North Atlantic and increased rainfall over the Sahel region of sub-Saharan Africa. The cold negative phase has the opposite impacts: cooling at high latitudes, reduced hurricane activity and a drier Sahel.
Atmosphere	The gaseous envelope surrounding the earth, divided into five layers – the *troposphere* which contains half of the Earth's atmosphere, the *stratosphere*, the mesosphere, the thermosphere, and the exosphere, which is the outer limit of the atmosphere.
Baseline	The state against which change is measured. It might be a 'current baseline,' in which case it represents observable, present-day conditions. It might also be a 'future baseline,' which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.
Biodiversity	The part of the Earth System comprising all ecosystems and living organisms, in the atmosphere, on land (terrestrial biosphere) or in the oceans (marine biosphere), including derived dead organic matter, such as litter, soil organic matter and oceanic detritus.
Carbon Dioxide (CO2)	A naturally occurring gas, CO2 is also a by-product of burning fossil fuels (such as oil, gas and coal), of burning biomass, of land-use changes and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas (GHG) that affects the Earth's radiative balance.

CHIRPS rainfall dataset	The Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a quasi-global rainfall data set. As its title suggests it combines data from real-time observing meteorological stations with infra-red data to estimate precipitation. The data set runs from 1981 to the near present.
Climate	In a narrow sense, climate is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization.
Climate Change	A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.
Climate Feedback	An interaction in which a perturbation in one climate quantity causes a change in a second and the change in the second quantity ultimately leads to an additional change in the first. A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced.
Climate Information	Information about the past, current state, or future of the climate system that is relevant for mitigation, adaptation and risk management. It may be tailored or "co-produced" for specific contexts, taking into account users' needs and values.
Climate Impacts	Impacts describe the consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability.
Climate Indicator	Measures of the climate system including large-scale variables and climate proxies.
Climate Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Climate Model	A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties.
Climate Projection	The simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHG) and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized.
Climate Risk	The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.
Climate System	The highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere and the interactions between them.
Climate Variability	Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events.
Confidence	The robustness of a finding based on the type, amount, quality and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement across multiple lines of evidence

Crop Water Deficit	A water deficit occurs whenever water loss exceeds absorption. The use of total water potential as the best single indicator of plant water status has its limitations while attempting to understand the effect of water deficits on the various physiological processes involved in plant growth. Water deficits reduce photosynthesis by closing stomata, decreasing the efficiency of the carbon fixation process, suppressing leaf formation and expansion, and inducing shedding of leaves.
Disaster	A 'serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts' (UNGA, 2016).
Downscaling	A method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses.
El Niño Southern Oscillation (ENSO)	The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere–ocean phenomenon, with preferred time scales of two to about seven years, is known as the El Niño-Southern Oscillation (ENSO). The cold phase of ENSO is called La Niña.
Emissions Scenario	A plausible representation of the future development of emissions of substances that are radiatively active (e.g., greenhouse gases (GHGs), aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change, energy and land use) and their key relationships.
Evapotranspiration	The process in which water moves from the earth to the air from evaporation (= water changing to a gas) and from transpiration (= water lost from plants).

Exposure	Exposure describes the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.
Extreme/heavy precipitation event	An extreme/heavy precipitation event is an event that is of very high magnitude with a very rare occurrence at a particular place. Types of extreme precipitation may vary depending on its duration, hourly, daily or multi-days (e.g., 5 days), though all of them qualitatively represent high magnitude. The intensity of such events may be defined with block maxima approach such as annual maxima or with peak over threshold approach, such as rainfall above 95th or 99th percentile at a particular space.
Fifth Assessment Report (AR5)	A series of IPCC reports published in 2013-2014, reports are divided into publications by three working groups.
Global Warming	The estimated increase in global mean surface temperature averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue.
Greenhouse Effect	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect.
Greenhouse Gas (GHG) Concentrations	Lead to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect.
Greenhouse Gases (GHGs)	The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the

	atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapour (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and ozone (O3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO2, N2O and CH4, the Kyoto Protocol deals with the GHGs sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). [IPCC, 2018]
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
Heat Stress	A range of conditions in, e.g., terrestrial or aquatic organisms when the body absorbs heat during overexposure to high air or water temperatures or thermal radiation. In aquatic water breathing animals, hypoxia and acidification can exacerbate vulnerability to heat. Heat stress in mammals (including humans) and birds, both in air, is exacerbated by a detrimental combination of ambient heat, high humidity and low wind-speeds, causing regulation of body temperature to fail.
Heatwave	A period of abnormally hot weather often defined with reference to a relative temperature threshold, lasting from two days to months. Heatwaves and warm spells have various and, in some cases, overlapping definitions
Ice sheet	An ice body originating on land that covers an area of continental size, generally defined as covering >50,000 km^2, and that has formed over thousands of years through accumulation and compaction of snow. [IPCC, 2019]
Impacts	Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system.

Intergovernmental Panel on Climate Change (IPCC)	The leading international body for the assessment of climate change. Scientists come together approximately every six years, to assess peer-reviewed research in working groups to generate three reports including the Physical Science Basis, impact adaptation and vulnerability, and Mitigation of Climate Change.
Intertropical Convergence Zone (ITCZ)	The Intertropical Convergence Zone (ITCZ) is a band of low pressure around the Earth which generally lies near to the equator. The trade winds of the northern and southern hemispheres come together here, which leads to the development of frequent thunderstorms and heavy rain.
Irrigated [livelihood]	Large-scale irrigation schemes associated with large rivers across Africa, e.g. Nile. Often located in semi-arid and arid areas but with medium-high access to services. Includes the associated surrounding rainfed lands. Diversified cropping includes irrigated rice, cotton, wheat, fava, vegetables and berseem augmented by cattle, fish and poultry.
Marine heatwave	A period during which water temperature is abnormally warm for the time of the year relative to historical temperatures with that extreme warmth persisting for days to months. The phenomenon can manifest in any place in the ocean and at scales of up to thousands of kilometres.
Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Ocean acidification	A reduction in the pH of the ocean, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO2) from the atmosphere, but can also be 38 caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity.

Paris Agreement	The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted on December 2015 in Paris, France, at the 21st session of the Conference of the Parties (COP) to the UNFCCC. The agreement, adopted by 196 Parties to the UNFCCC, entered into force on 4 November 2016 and as of May 2018 had 195 Signatories and was ratified by 177 Parties. One of the goals of the Paris Agreement is 'Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels', recognising that this would significantly reduce the risks and impacts of climate change. Additionally, the Agreement aims to strengthen the ability of countries to deal with the impacts of climate change.
Pastoralism [livelihood]	Pastoralism is a mode of subsistence that involves the raising of animal livestock in grassland environments on an extensive, mobile basis.
Projection/projected	A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised.
Radiative Forcing	The change in the net, downward minus upward, radiative flux (expressed in W m2) at the tropopause or top of atmosphere due to a change in a driver of climate change, such as a change in the concentration of carbon dioxide (CO2) or the output of the sun.
Reanalysis	Atmospheric and oceanic analyses of temperature, wind, current and other meteorological and oceanographic quantities, created by processing past meteorological and oceanographic data using fixed state-of-the-art weather forecasting models and data assimilation techniques.
Representative Concentration Pathways (RCPs)	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover.
Resilience	The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways

	that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation
Resolution	In climate models, this term refers to the physical distance (metres or degrees) between each point on the grid used to compute the equations. Temporal resolution refers to the time step or time elapsed between each model computation of the equations.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure and hazard.
Runoff	The flow of water over the surface or through the subsurface, which typically originates from the part of liquid precipitation and/or snow/ice melt that does not evaporate or refreeze and is not transpired.
Scenario	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g. rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions.
Signal	Climate signals are long-term trends and projections that carry the fingerprint of climate change.
Sixth Assessment Report (AR6)	The latest series of IPCC reports published in 2021-2022, reports are divided into publications by three working groups. At the time of writing this report only the Working Group I contribution to the Sixth Assessment Report published in 2021 was available to use.
Soil moisture	Water stored in the soil in liquid or frozen form. Root-zone soil moisture is of most relevance for plant activity.
Storm surge	The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or

	strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. [IPCC, 2019]
Stream Flow	Water flow within a river channel, for example, expressed in m^3s^{-1} 25 . A synonym for river discharge.
Teleconnection	Association between climate variables at widely separated, geographically fixed locations related to each other through physical processes and oceanic and/or atmospheric dynamical pathways. Teleconnections can be caused by several climate phenomena, such as Rossby wave-trains, mid-latitude jet and storm track displacements, fluctuations of the Atlantic Meridional Overturning Circulation, fluctuations of the Walker circulation, etc. They can be initiated by modes of climate variability thus providing the development of remote climate anomalies at various temporal lags.
Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. In climate change analysis, it may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes, or uncertain projections of human behaviour.
United Nations Framework Convention on Climate Change (UNFCCC)	The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in May 1992 and opened for signature at the 1992 Earth Summit in Rio de Janeiro. It entered into force in March 1994 and as of May 2018 had 197 Parties (196 States and the European Union). The Convention's ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.' The provisions of the Convention are pursued and implemented by two treaties: the Kyoto Protocol and the Paris Agreement. [IPCC, 2018]

Urban Heat Island	The relative warmth of a city compared with surrounding rural areas, associated with changes in runoff, effects on heat retention, and changes in surface albedo
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm, and lack of capacity to cope and adapt.
Weather	The conditions in the air above the earth such as wind, rain, or temperature, especially at a particular time over a particular area.

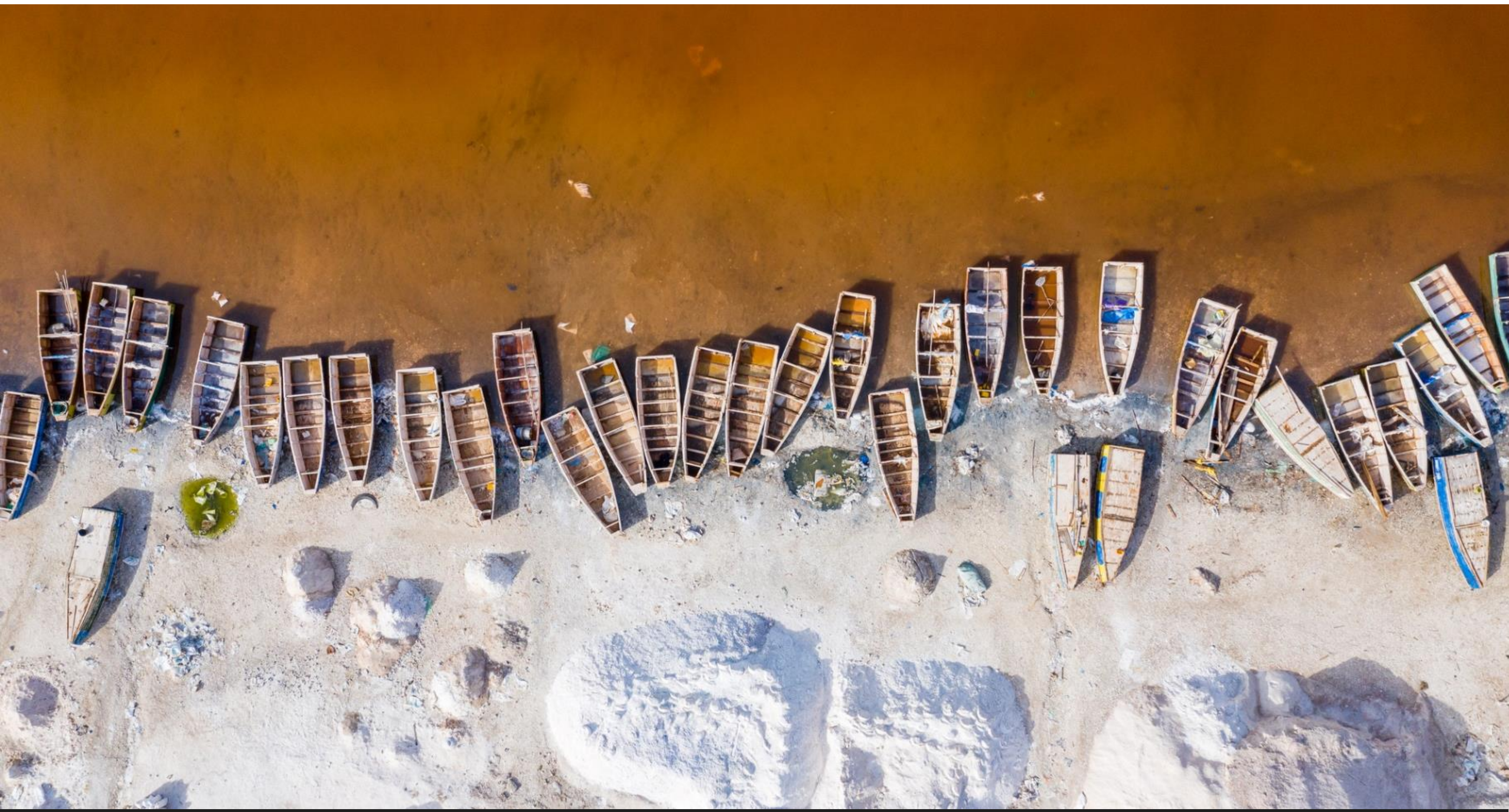


Image location: Lac Rose, Senegal

1. Introduction

1.1 Purpose of this report

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

This report is part of a series of climate risk reports for the UK Government's Foreign, Commonwealth & Development Office (FCDO). In this series we are standardising how we process and interpret climate information to support FCDO offices and climate assured development planning in different regions. This provides consistency both within the specified region and across regions. It also ensures we are consistent with other climate information such as the Sahel Climate Risk Report (Holmes et al., 2022), briefing notes and monthly outlooks that the Met Office, the UK's meteorological service, provides to FCDO country offices.

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

The region considered in this report (hereafter "West Africa") covers the coastal countries of West Africa. These are all situated along the Atlantic, from Senegal, The Gambia, Guinea-Bissau, Guinea, Sierra Leone and Liberia, through to Côte d'Ivoire, Ghana, Togo, Benin, and Nigeria in the Gulf of Guinea (Figure 1, top panel). Key aspects of the region included in the

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

analysis, such as the geography and population densities, are also shown in Figure 1 (middle and bottom panels). When West Africa is considered in the literature it often includes a larger area encompassing the Sahel, but other than northern Senegal and northern Nigeria this area is not covered in this report. For climate risks relevant to the Sahel see Holmes et al. (2022).

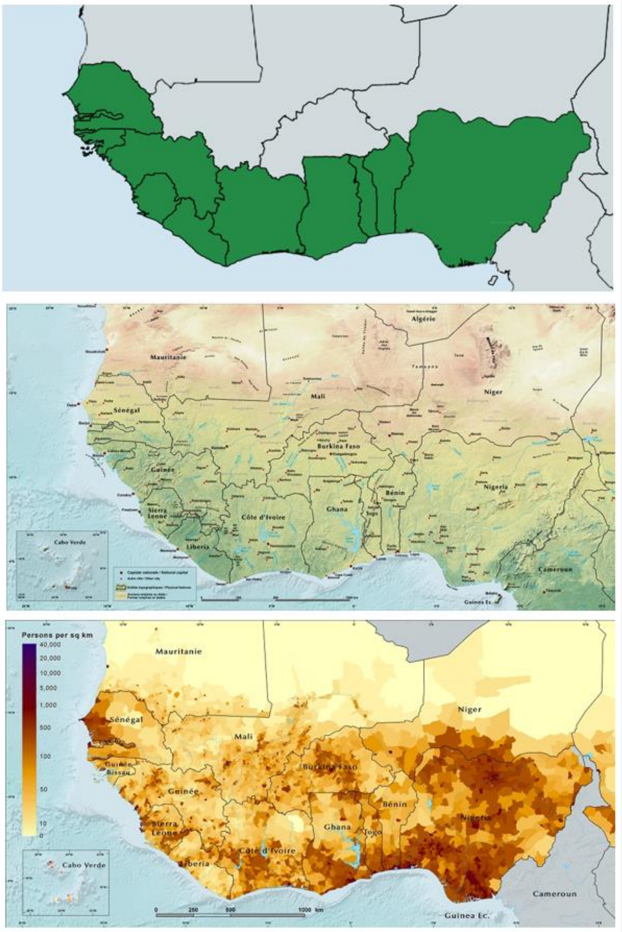


Figure 1: The West Africa region considered in this report. Top panel: countries included in the analysis, middle panel: geography of the region, bottom panel: population density by administrative unit in 2015. Source: U.S. Geological Survey (https://eros.usgs.gov/westafrica/)

1.2 Methodological approach

1.2.1 Methods and data

1.2.1.1 Socio-economics Data and Methods

The socio-economic contributions to this report draw on a review of the relevant literature and key informant interviews with experts working on both climate and agronomy within the West Africa region. We use this to identify appropriate livelihood groupings and key socio-economic variables, as well as suitable climate indicators to support the climate data analysis.

1.2.1.2 Climate data and methods

This report draws on bespoke climate data analysis in the selected zones (see Section 3.2) and relevant scientific literature.

The analysis processes gridded observation data to characterise the current climate over the 1981-2010 baseline period, and climate model projections to assess the projected trends in average temperature and precipitation for the 2050s (using the 2041-2070 future time period compared to the baseline period). The analysis focuses on quantifying projected changes in annual, seasonal, and monthly means in the spatial analysis zones. We draw information on the projected changes in other climate variables and indicators included in the analysis - such as Sea Surface Temperatures (SSTs), Sea Level Rise (SLR) and relevant climate extremes - from relevant scientific literature, noting where baseline and future time periods differ from the bespoke analysis.

To characterise the baseline climate, we processed temperature from WFDEI-CRU (Weedon et al., 2014) and precipitation data from CHIRPS[2] over the 1981-2010 baseline period. Using these datasets and this time-period keeps this report consistent with FCDO climatology briefing notes provided to FCDO offices for many of the countries in the West Africa region.

[2] https://www.watres.com/CHIRPS/

We used global and regional climate model simulations to assess the projected change in temperature and precipitation for the 2050s under the RCP8.5[3] (van Vuuren et al., 2011) or SSP5-8.5[4] (O'Neill et al., 2016) scenarios. This future time-period and scenario combination represents an increase in global average temperature of around 2.5˚C compared to pre-industrial levels. This is higher than the goal of limiting warming to well below 2˚C set by the United Nations Framework Convention on Climate Change Paris Agreement[5].

We used the following model simulations in this analysis:

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

See Appendix A for more details on the specific model simulations included.

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

[4] With an additional radiative forcing of 8.5 W/m² by the year 2100, this scenario represents the upper boundary of the range of scenarios described in the literature. It can be understood as an update of the CMIP5 scenario RCP8.5, now combined with socio-economic reasons. https://www.dkrz.de/en/communication/climate-simulations/cmip6-en/the-ssp-scenarios

[5] https://unfccc.int/

1.3 How to use this report

This report presents climate information in the context of the socio-economic challenges of the West Africa region, framed in terms of the key climate risks. The aim is to help development planners focus in on areas that may need attention and to identify the questions they need to ask when considering climate risks in their development plans. This report does not include every climate risk, rather, it brings West Africa's most prominent regional climate risks to the fore. Bear in mind that climate risks are not isolated threats: how they interact with, and compound other sources of risk is very important and can be hard to disentangle. The climate analysis and subsequent discussion outline the needs of a development pathway between the present day and the 2050s, so they have been designed to highlight the key risks to consider in future development plans. The country summaries provided in the executive summary outline prominent climate risks for each country within the regional context. However, neither these summaries, or the report itself, provide a national level analysis; additional climate risks may apply at a national scale, and these should also be considered in a national or subnational development plan. This report offers a starting point for better understanding some of the key regional risks relevant to development programming within FCDO. For individual programmes where relevant risks are identified, or where national or sub-national scale risk information is required, additional climate and socio-economic analysis is recommended.

Section 2 sets the scene by providing an overview of the current vulnerability and climate resilience in the West Africa region. The current climate already includes large areas where some aspects of human and ecological systems are at their limits, or are not well adapted to the harsh environment they are in. This section justifies the need for an intersectional approach when it comes to interpreting compound risks associated with, or exacerbated by, climate change.

Section 3 focuses on the current and future climate projections for the West Africa region and takes a geographical approach. It includes a summary of the region's climate and explains how this study divides the region into six spatial analysis zones. The climate analysis is presented on a zonal basis, for each of these six zones in West Africa. In each zone the baseline climate is presented in context with the socio-economic situation of the zone, followed by the future projections and how they apply to the zone-specific risks. There is also a look-up table that shows which zones each country is in (see Table 1).

Section 4 presents the interpretation of the climate projections in terms of climate risk factors. It is structured by six key development themes: water security; agricultural production and pastoral systems; urban environments and infrastructure; coastal regions; human health and mortality; and biodiversity and ecology.

Focus box 1: Exposure, Vulnerability and Development

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

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

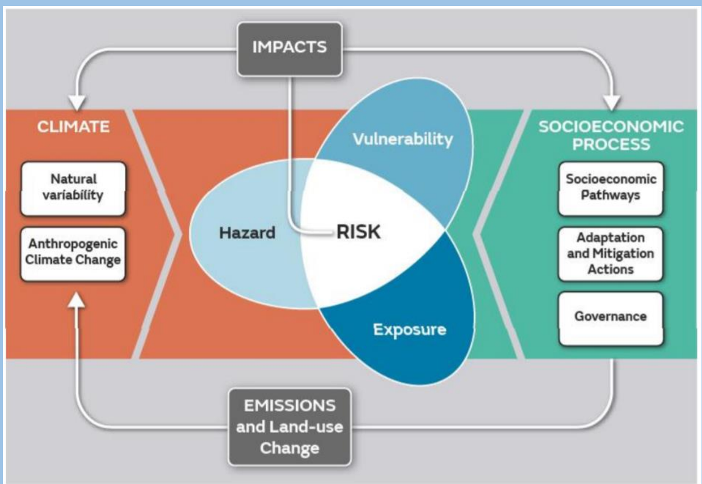


Figure 2: Climate risk is the product of the hazard, vulnerability to the hazard and exposure to the hazard. Image adapted from IPCC (2014).

Image location: Saint Louis, Senegal

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

Development in West Africa is defined by high population growth and urbanisation. However, the pace of these developments is not necessarily matched in equal opportunities or infrastructure to support them. Economic growth in the region is unequally distributed, demonstrated by the inequality adjusted human development index (IHDI) which is about 35% lower than the human development index (HDI) (UEMOA and MOLOA, 2017: 23). Unemployment rates remain high, especially among young people (AfDB, 2019).

The ability to raise investment for development in West Africa has often been held back by political instability, corruption, and conflict (AfDB, 2019). The Boko Haram insurgency in north-eastern Nigeria is estimated to have claimed 35,000 lives and resulted in the displacement of 1.8 million people (UNDP, 2021). The conflict has disrupted livelihoods, forced the closure of schools and damaged social capital and infrastructure, in a region that was already affected by underinvestment (IPI, 2019; UNDP, 2021). When the indirect impacts of the conflict on areas such as food and livelihood security are considered, the total number of fatalities could be over 300,000 (UNDP, 2021). Continued instability linked to the spread of jihadist insurgencies in the Sahel has also raised concerns that the violence could spread further to West African countries (ICG, 2019).

The concentration of economic assets around the coastline has meant that the increasing trend of maritime piracy in the Gulf of Guinea is becoming a regional concern (NSD-S Hub, 2021). One consequence of piracy is a reduction in over-fishing in some areas, as trawlers are reluctant to enter areas where the piracy is prevalent. Elsewhere trawlers are causing enormous damage to fisheries.

Furthermore, in the past decade the region has experienced two major pandemics, with the outbreak of Ebola (2014-2016) and more recently the COVID-19 pandemic (2020-ongoing at time of writing). Both outbreaks have tested healthcare services and had wider impacts on food security and economy through the disruption to livelihood activities (USAID, 2018; WFP, 2020). The impact of COVID-19 pandemic has placed an increasing burden on public finances, which in turn could lead governments to divert funds away from public services, such as water access and maintenance (AfDB, 2020).

Opportunities for economic growth and development in the region are often not balanced against the careful management of ecosystems. Whilst there are calls to modernise and improve the productivity within the agricultural sector, so far modest increases in agricultural output have often been achieved through the expansion of agricultural lands (FAO and AfDB, 2015). The development of the economically important coastal regions has occurred against the backdrop of degradation to important coastal ecosystems, impacting traditional livelihood sectors such as fishing and agriculture (Diop et al., 2014). The erosion of the coastline due to the development of infrastructure is undermining the ability to withstand natural hazard related disasters such as flooding, with impacts counted both in terms of economic costs and in fatalities (Croitoru., 2019; UEOMA and MOLOA, 2017).

What these preceding paragraphs demonstrate is that development trends and crises do not occur in isolation. These trends often intersect, further complicating the response needed to address them and the impact of environmental change will not be felt in isolation of other socio-economic trends. Many of these socio-economic trends are also the same factors that influence an individual's and communities' vulnerability to the impacts of climate change, and further undermine their ability to recover from shocks.

Focus Box 2: Demographic and climate risks in West Africa

Population growth in West Africa is so high as to be creating social instability and severe ecological damage. According to current projections, West Africa's population will double by 2050. The population of Nigeria, which already has more people than the rest of West Africa combined, is projected to increase from its current estimated level of 213 million to over 400 million (United Nations Secretariat, Population Division, 2019). There is some debate over the reliability of population figures and demographic data in West Africa, but the general trend is clear – the population has increased rapidly over the past half century and continues to do so. This is not a 'demographic dividend', it is a demographic burden because there is growing pressure on both rural and urban areas and on the infrastructure, economies, and ecology of the region. Population growth and urbanisation are occurring without industrialisation and rural areas are seeing increasing degradation, declining agricultural and pastoral productivity in many areas, and in some parts of West Africa, conflict. These trends are not uniform; demographic trends are highly variable between communities, socio-economic groups, and regions. There is therefore local and subregional demographic variation within West Africa, and this will determine how demographic pressures play out in relation to the risks from climate change in different parts of the region.

Reference: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019, Online Edition. Rev. 1*.

2.1 Socio-economic context of thematic areas considered for West Africa

The following section outlines the socio-economic trends in relation to each of the six climate risks which have been identified for the region: water security and resources; agricultural production and pastoralism systems; urban environments and infrastructure; coastal regions; human health and mortality; biodiversity and ecology. This section has been designed to provide the reader with the socio-economic context to consider in relation to the climate projections outlined in section 3. The combined impacts of the socio-economic trends outlined here will then be analysed using the climate projections out to 2050 to develop a key set of risks facing the region in section 4.

2.1.1 Water security and resources

Poor water management issues affect both the national and regional level. Policy to help better manage water resources in West Africa is often hindered by a lack of investment and political support, but also a lack of data (Dirwai et al., 2021). Understanding of water resources across West Africa is made more difficult by a lack of large-scale hydrological research and gauge measurements (Ndehedehe et al., 2017).

The West Africa region has many freshwater resources in the form of lakes, rivers and reservoirs. Rivers are a key water source in every mainland West African country. Groundwater supplies, in the form of aquifers supplies are often overlooked but are also vital. The terrestrial water systems provide an important source of drinking water and support livelihood activities such as agriculture and inland fisheries. Trends such as urbanisation, population and economic growth will continue to increase freshwater withdrawals.

West African water resources are defined by a series of transboundary water systems. In total the region has 25 transboundary watercourses, however only six are currently under agreed management and regulation (Dirwai et al., 2021). Although the transboundary management of the Senegal river basin through the *Organisation pour la mise en valeur du fleuve Sénégal* offers a positive example, this success has been difficult to replicate along other shared river basins in the region (Medinilla and Sergejeff, 2021). Difficulties emerge particularly around balancing shared interests against the very nature of intergovernmental organisations that rely on the buy-in from member states (Medinilla and Sergejeff, 2021). The importance of transboundary water management is increasing, as the region seeks to meet its increasing energy demands where along with other renewable energy sources the further development of small-scale hydropower is seen as a solution (Auth and Musolino, 2014).

The management of water resources also requires the balancing between economic development and the reduction in harm. Agricultural production, particularly the use of fertilizers in cash crop production, can lead to the pollution of water resources. Mining of mineral resources is also leading to the degradation of waterways. In Guinea, the industrial mining of bauxite releases dust which has resulted in the degradation of water systems, impacting other dependant economic activities, such as fisheries (Widder et al., 2019). The use of cyanide and mercury during artisanal mining can also pollute groundwater sources (Pare and Bonzi-Coulibaly, 2013).

The implications of these trends within a changing climate will be discussed in more detail in section 4.1.

2.1.2 Agricultural and pastoral systems

Agriculture is a fundamental socio-economic activity across West Africa, where a wide range of crops are grown. Agricultural production is important for food security, both at the household level and through the selling of produce in markets. Some agricultural produce is exported outside the region, but it is production for national and regional consumption that is important. According to one estimate, agriculture employs two-thirds of people in West Africa (Allan and Heinrigs, 2016; Allen et al., 2018). More than half the West African population lives in rural areas and virtually all the rural population depends on agriculture and/or pastoralism, whether entirely or as part of a mixed livelihood strategy. In urban areas agricultural and livestock markets employ people and supply food to towns and cities. In the past decade the intra-West African regional trade of agricultural produce has grown in importance in relation to international agricultural exports (Allen and Heinrigs, 2016).

Key cash crop exports from West Africa include cocoa, cotton, and groundnuts. Côte d'Ivoire and Ghana are the two largest exporters of cocoa in the world, and Nigeria is the world's largest producer of yams (most for domestic and regional consumption, but some are exported globally). However, the most important function of agriculture and pastoralism in West Africa is for domestic food security. Although the region does import much food, the rural population, especially, depends on agricultural production for its own nutrition and for cash income. West African agriculture goes beyond subsistence farming because there is a thriving internal trade and an extensive network of markets within and between countries that supply food across rural and urban areas. This encompasses agricultural produce and livestock from different zones, thus there is exchange between northern and southern areas of the region. The main livestock raised by pastoralists in West Africa are cattle (various breeds, with differing adaptations), sheep, goats, and – in more arid areas - camels.

The staple foods in West Africa are cereal crops (see Appendix C), notably maize, millet, sorghum and rice, and roots and tubers that include yam and cassava. These remain vitally important and popular. There are also indigenous crops such as acha, tamba and many more that are locally important in specific areas, and well adapted to local conditions where they are grown. A wide range of fruits and vegetables are grown, and meat and fish are consumed alongside staple foods, with the frequency and amount broadly depending on income. There are also certain tree species that farmers grow as crops, or which are foraged in tropical forests and savannah woodlands. There is a wide variety of trees harvested by farmers and villagers in West Africa, and these vary depending on the ecology. Some of the prominent ones in savannah areas include Locust Bean (*Parkia biglobosa*), Shea Butter (*Vitellaria paradoxa*), African elemi or olive, also known as Atili (*Canarium schweinfurthii*), Baobab (*Adansonia digitata*) and various fruit trees - mangoes, etc. There are also many other usable plants (including trees) in the savannah and semi-arid regions, and in tropical rainforests the diversity of usable plants is far higher.

In some urban settings, among more affluent socio-economic classes, patterns of food consumption have changed incorporating more imported foods (Staatz and Hollinger, 2016). Rising food costs remain an issue for the region, with a large proportion of household income spent on food, especially urban households. For example, in Côte d'Ivoire it is estimated that 39% of household incomes is spend on food, and in Nigeria as high as 65%. Estimates also suggests that urban households spend 50% more on food than their rural counterparts (Allen and Heinrigs, 2016). This is logical, as rural households produce much of their own food. The overall cost of food items is particularly high when compared with non-food items, and this can be detrimental to accessing good nutritious food, particularly among poorer households (Allen, 2017). To drive down prices, there is a growing need to improve productivity within the agricultural sector to keep up with demand.

However, demand for increases in agricultural output have resulted in more environmentally unsustainable farming methods. For example, the modest increases in agricultural outputs are often the result of expansion of crop producing lands – increasing the area under cultivation - rather than more productive use of land (FAO and AfDB, 2015). Furthermore, land holdings are under increasing pressure from population growth which is leading to increased land fragmentation. These farms are often too small to feed individual households and hold little opportunity for commercial use (ibid). Beyond this, factors such as poor infrastructure increasing the cost of accessing markets; inadequate rural financial services; lack of investment in public goods; weak rule of law; the low priority given to rural education; and lack of vocational training; are all obstructions to agricultural growth (Staatz and Hollinger, 2016).

The region faces an increase in competition for land and water resources (FAO and AFB, 2015). Resource constraints have led to more conflict over land rights and water rights both of which discourage productivity-enhancing investments (ibid). Pastoral systems have come under increasing pressure which has led to conflicts with farmers and also with other pastoral groups. The increasing demand for land for crop production has come at the expense of the blocking of transhumance corridors and reduction in grazing land, resulting in increased tensions between different resource users (United Nations Office for West Africa and the Sahel (UNOWAS), 2018). However, it is not only the management of shared natural resources that is at fault. Political factors such as the land grabbing and the manipulating of ethno-religious divides by political elites, has also been at the heart of rural conflicts in Nigeria and more widely in the region (ibid).

2.1.3 **Urban** environments and infrastructure

For 70 years West African urban areas have grown at an increasing rate. In 1950 only five million (9%) of the region's inhabitants lived in urban areas, by 2010 the number was 133 million (40%) (Curiel et al., 2017). In that same period, the number of cities with more than 10,000 inhabitants grew from only 159 to 2,000 (Curiel et al., 2017). More recent estimates suggest that the percentage of population that is urbanised is 47% (Africa Polis n.d.). However, this figure hides regional variations. For example, whilst the rate of urbanisation in countries such as Nigeria, Ghana, and The Gambia the rate of urbanisation is over 50%, in countries such as Guinea-Bissau (35.33%), Guinea (37.03%) and Sierra Leone (36.55%) the rate of urbanisation is lower (Africa Polis, n.d.). Coastal cities in West Africa include some of the largest concentrations of population in the region, e.g. Cotonou in Benin; Abidjan in Côte d'Ivoire; Serrekunda in The Gambia; Accra in Ghana; Conarky in Guinea; Bissau in Guinea-Bissau; Monrovia in Liberia; Lagos in Nigeria; Dakar in Senegal; Freetown in Sierra Leone; and Lomé in Togo.

Rural-urban migration has been a key factor in driving urbanisation in the region, with many leaving their rural settings in search of better economic opportunities in cities. Often, and in line with migratory patterns globally, it is not the poorest that migrate but instead those with the financial and social capital (De Bruin and Dengerick, 2020). Regional migration has also been part of the urbanising trend. The majority of migration within the West Africa region (84%) is interregional (Devillard et al., 2015), including seasonal or permanent movement from north to south, such as from the Sahel to coastal cities such as Abidjan, Accra, Lagos, Dakar and Banjul, where there are greater economic opportunities (Devillard et al., 2015).

The growth of urban centres is not only defined by the growth of mega cities, but also in situ urbanisation, whereby rural areas are becoming increasingly urbanised creating a network of smaller urban areas (Moriconi-Ebrard et al., 2015). The region is also home to 'metropolitan regions', whereby urban centres - sometimes from across different countries - are connected via economic and social integration, such as the 'Greater Ibadan Lagos Accra Urban Corridor' (Heinrigs, 2020). Such corridors are maintained by economic migrants (Hertzog, 2020). Whilst economically productive, such a dynamic can lead to disparities between cities as connections are built between major hubs, rather than other intermediate cities (Heinrigs, 2020). The region suffers from what are described as 'favoured' cities, whereby capitals and coastal cities tend to receive advantages: access to capital; import-export licenses; and better public services. As a result, these cities attract more migrants which in turn means that they grow at a faster rate (De Bruin and Dengerink, 2020). Nonetheless, there are some large, historic urban centres in the savannah areas inland, especially in northern Nigeria, that continue to grow in population and land area at a rapid pace.

In line with other sub-Saharan cities, the potential development of West African urban areas is undermined by overcrowding, poor infrastructure and high living costs, especially when compared to other developing regions of the world (Lall et al., 2017). In general, African cities are often more expensive than other developing regions, with urban residents paying between 20-30% more for goods and services than urban residents living in other developing regions of the world (Page et al., 2020). In West Africa, the growth in urban areas is not matched by the growth in economic opportunities (De Bruin and Dengerink, 2020). In some cities – Abidjan (79%), Dakar (80%), Cotonou (81%) Lome (83%) – there is still a high percentage of urban residents relying on informal employment (Page et al., 2020).

The implications of these trends within a changing climate are discussed in more detail in section 4.2.

2.1.4 Coastal regions

The West African coastline provides an important economic hub for the region, and the continent as a whole. The coastlines are home to traditional livelihoods, such as agriculture and fishing, and also important trading centres and industry, including extractive industries such as oil and gas. The West African coastal region is estimated to generate 56% of the region's total GDP (UEOMA and MOLOA, 2017; Croitoru et al., 2019). For this reason, the coastal area has become an important destination for economic migrants from both inside national borders and from across the region. Population growth along the West African coastal areas is projected to rise faster than any other region on the African continent (UEMOA and MOLOA, 2017). Coastal areas are home to some of West Africa's most populous cities, with a third of the population living along its coastline (UEOMA and MOLOA, 2017; Croitoru et al., 2019).

The development of the coastline has caused increased pressure on land and resources and led to degradation of the natural environment, contributing to coastal flooding. Environmental degradation along the coastlines of Benin, Côte D'Ivoire, Senegal and Togo, is estimated to cost $3.8 billion per year or 3.5% of GDP. This is mainly due to the impacts of flooding and coastal erosion (Croitoru et al., 2019) The development of manmade infrastructure and sand extraction is contributing to the retreat of the West African coastline (Croitoru et al., 2019). For example, in Benin, Côte d'Ivoire, Senegal and Togo, 56% of the coastline is affected by erosion, averaging 1.8 m per year (ibid). Seafront property developments are a contributing factor, as walls built to protect properties reflect waves which leads to further erosion of beaches (UEMOA and MOLOA, 2017). Other contributing factors include the construction of upstream dam infrastructure, which removes sediment supply. Both the Volta and Nanbeto dam are contributing to erosion in countries such as Benin and Togo (UEMOA and MOLOA, 2017). The destruction of mangrove forests is a continuing problem, although there are conservation efforts in some areas. The removal of mangroves increases the vulnerability to coastal flooding, negatively affects fish stocks, and removes a carbon sink.

The increasing development of the West African coastline is leading to competition for space. For example, much of the region's port infrastructure is going through a phase of redevelopment, which places pressure on coastal cities and the natural environment (UEOMA and MOLOA, 2017). Whilst this is partly driven by the export of commodities, it is also a result of a growing demand of imported goods from a growing middle class and competition to serve as West Africa trading hubs (UEMOA and MOLOA, 2017). The growth of tourism also has an impact. The development of resorts and tourist activity has led to increase sewage and waste and the degradation of coastal vegetation and wetlands (Diop et al., 2014). The development and subsequent erosion of the coastline is also impacting agricultural production through the saltwater intrusion and the salinisation of land. This is already impacting coastal garden crop growing in Senegal and mangrove rice growing areas in Ghana (UEMOA and MOLOA, 2017). These impacts not only affect traditional livelihoods, but also food security in the region.

Other traditional coastal livelihood sectors are also under threat. Whilst domestic fishers are mainly small scale, the region attracts foreign industrial trawlers (Katikiro, 2012; Barange et al., 2018) which are fishing unsustainably, dramatically reducing fish stocks for West African fishers. Fishing is not only economically important, but also important for food security in coastal areas (Katirko, 2012). Fish is a staple food for the West African population who consume seven million tons of fish per year (Barange et al., 2018). The sustainability of fish stocks is under threat, due to the degradation of ecosystems that support marine life and the overexploitation of fish stocks (Barange et al., 2018). With regards to the latter, estimates suggest along the coastline between Senegal and Nigeria, more than half of fish stocks have been overexploited (Daniels et al., 2016). The sustainability of the fishing sector is being further undermined by Illegal, Unreported and Unregulated fishing (IUU), which includes foreign fleets (Daniels et al., 2016). The practice of IUU is estimated to cost the region $2.3 billion in lost revenue, and the preventing the creation of 300,000 jobs in the artisanal fishing sector (Daniels et al., 2016; Doumbouya et al., 2017).

The implications of these trends within a changing climate are discussed in more detail in section 4.4.

2.1.5 Human health and mortality

Health and mortality in West Africa are affected by long running trends and emerging threats. In terms of nutritional levels, estimates suggest 110 million people in West Africa do not receive adequate nutrition, while 58 million are classed as being underweight (van Wesenbeeck, 2018). Conversely, there is a growing trend of obesity in the region, particularly among the urban populations (Agyemang, 2021; van Wessenbeck, 2018). In total, 23% of urban inhabitants are classed as being overweight, and an additional 12% are said to be obese, compared with 13% and 4% for those living in rural areas (van Wessenbeck, 2018).

West Africa continues to be impacted by long term health concerns such as malaria. For example, in Liberia, Sierra Leone, The Gambia, Ghana and Nigeria, the disease remains the primary health concern (USAID, 2019; USAID, 2021a; USAID, 2015; USAID, 2021b). Of particular concern, Nigeria has been highlighted as accounting for 27% of global cases and 23% of deaths (WHO, 2020). In The Gambia, malaria is a leading cause of morbidity and mortality among children aged under five years old (USAID, 2021b). The region also continues to be affected by cholera outbreaks, with the disease affecting urban coastal areas characterised by overpopulation, poor access to clean drinking water and inadequate sanitation such as Accra (Ghana), Abidjan (Côte d'Ivoire), Conakry (Guinea) and Cotonou (Benin) (Zerbo et al., 2020). Sub-Saharan Africa accounts for 83% of worldwide deaths from cholera (WHO, 2018).

West Africa experiences regional wide disease outbreaks which are not only marked by health impacts but also wider social and economic impacts. The spread of Ebola during the 2014-2016 outbreak from Guinea to neighbouring Liberia and Sierra Leone is an example of how outbreaks in one country can become region wide health concerns. Factors such as poor surveillance, weak social and health infrastructure, and distrust for healthcare workers, were identified as factors that allowed the disease to spread and slowed the response (Bell et al., 2016). As a highly infectious disease, the spread of Ebola was difficult to stop but it was eventually brought under control with a considerable public and medical effort in the affected countries and through international medical assistance. The Ebola epidemic led to border closures and transport restrictions, which impacted the availability of food and led to a rise in food prices (USAID, 2018). More recently healthcare services have also had to deal with the global COVID-19 pandemic. Whilst the rates of infections and fatalities have been lower than other parts of the world, government enforced restrictions have halted livelihood activities and led to reported to a rise in food prices (Ali et al., 2020).

There are several issues that affect the quality of healthcare provision in the region. Overall, healthcare systems suffer from a lack of public funding, which has led to systems reliant on donor funding and private user fees that can prove expensive for households (Aidara n.d.). Healthcare systems in contexts such as The Gambia, Ghana, Liberia, Nigeria and Sierra Leone, are undermined by corruption (Onwukekwe et al., 2019). Systems can also lack the development of healthcare workers skills, which can undermine the ability to respond to complex emergencies (World Bank, 2018). The ability to provide efficient access to quality medication is also an issue. Poor communication and transport infrastructure, the lack of raw materials and the facilities to develop medication and the difficulty of gaining international approval for domestic manufacturers, mean that it is difficult to provide an efficient supply of medicines (Ekeigwe, 2019). A lack of sufficient regulation means that the availability of medication on the market is sometimes supplemented by fake or poor-quality medicines (Ekeigwe, 2019).

The legacy of war can also act as a barrier to accessing healthcare in the region. After a decade long civil war Sierra Leone has felt long term impacts on its healthcare system, with the effects undermining the ability to respond to new crises such as the Ebola outbreak in 2014. The civil war resulted in physical damage to healthcare facilities and the flight of healthcare workers, some of whom have never returned to Sierra Leone (Silver, 2016). Similarly, the ongoing Boko Haram insurgency in the northeast of Nigeria has led to a breakdown of healthcare provision that was already underfunded prior to the outbreak of conflict (Debarre, 2019; IPI, 2019). The displacement of rural populations by the conflict to urban areas is placing an additional burden on healthcare facilities (Debarre, 2019; IPI, 2019).

The implications of these trends within a changing climate are discussed in more detail in section 4.5.

2.1.6 Biodiversity and ecology

West Africa is a region with diverse ecologies and high biodiversity of flora and fauna, with large numbers of endemic species. Put in economic terms, the varied ecologies of West Africa render very important ecosystem services, in a myriad of ways. The ecosystem services come from different ecosystems: biodiverse marine and coastal habitats that include mangrove forests and productive fisheries; tropical forests that are habitats for mammals, plants, and insects - many now endangered; savannahs with woody plant species and grasses that are important for large mammals. The economic value is both actual and potential and includes the vital role that forests play in the water cycle and in sustaining rainfall and preventing flooding; the proven impacts that diverse ecosystems have for pollination, not only for plants within those ecosystems but also for crops that are planted; the protective impacts that biodiverse tropical and savannah forests have on soils and fertility; and the economic benefits from tourism, managed timber extraction, pharmacopeia, and a host of local, socio-cultural uses and values (Agbani et al., 2018; Djagoun et al., 2022; Romeiras, et al., 2018; Amin et al., 2015; Soro et al., 2019; Tilahun et al., 2016).

As of 2015, about half of the remaining Upper Guinea Forest was in Liberia, but only around 2% of Liberia's forest was protected (Junker et al., 2015). There is competition between conservation initiatives to protect biodiversity hotspots such as those in Liberia and pressure on governments to issue logging and mining concessions (Junker et al., 2015). There is only limited eco-tourism in West Africa's various protected areas; tourist revenues are more significant in some areas such as the W-Arly-Pendjari (WAP) Complex on the Sudano-Sahelian zone of northern Benin, Burkina Faso and Niger, than others.

West Africa's ecology has been degraded across large areas, with some of the highest rates of deforestation in the tropics in recent decades. This is caused chiefly by population growth and the connected expansion of cultivation, and by commercial logging in both tropical and savannah forests. More than 80% of the original Upper Guinea Forest (tropical forest) in West Africa has already been cleared (Amani et al., 2021). This raises the importance of secondary growth forests; a study in Côte d'Ivoire found that forests can regenerate and gradually recover important levels of biodiversity on cleared land within 25 years or so, especially if in proximity to surviving primary forests, when given the chance to do so (Amani et al., 2021). The current climatic conditions with high rainfall and optimum temperatures in West Africa's sub-humid zone are favourable for forest regrowth. However, deforestation remains a problem and socio-politically cultivated land is not easily reclaimed for forest. To date, the actual value of West Africa's forests in both economic and scientific terms has not brought the level of finance for protection that is needed in the face of competition from extractive industries and growing populations eager for more land.

The implications of these trends with a changing climate are discussed in detail in section 4.

Focus box 3: Risk-informed development

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

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

Image location: Côte d’Ivoire

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

3.1 Climate overview for the West Africa region

West Africa contains a number of diverse bioclimatic regions including arid and semi-arid regions in the north; savannah across the central strip from Senegal to central Nigeria; mangroves, for example in the Niger Delta and Guinea-Bissau; rainforests in areas such as southern Nigeria, Liberia and Sierra Leone; coastal plains such as the Ghanaian Coastal Plain; and lowland plateaus and isolated highlands such as the Guinea Highlands and Jos Plateau. The climate of the region is influenced by the Atlantic Ocean, which bounds the West African coast from the west to the Gulf of Guinea in the south and by the arid Sahelian region to the north. The West Africa region is hot year-round with high annual rainfall totals which vary dependent mainly on latitude. West Africa has a unimodal rainy season (one distinct rainy season) and a single dry season, which ranges from approximately 3-4 months in coastal areas in southern latitudes to 7-8 months in semi-arid areas to the north.

Annual average precipitation amounts, and annual average minimum, mean and maximum temperatures are shown in Figure 3. These maps represent the average annual values over the 30-year baseline climate period (1981-2010). The actual annual and seasonal rainfall and temperature values vary from year to year, resulting in hotter, drier, cooler and wetter periods in relation to the climatological mean. This happens because the local weather is influenced by larger scale processes in the climate system that influence regional and local climate over different timescales, see Appendix D.

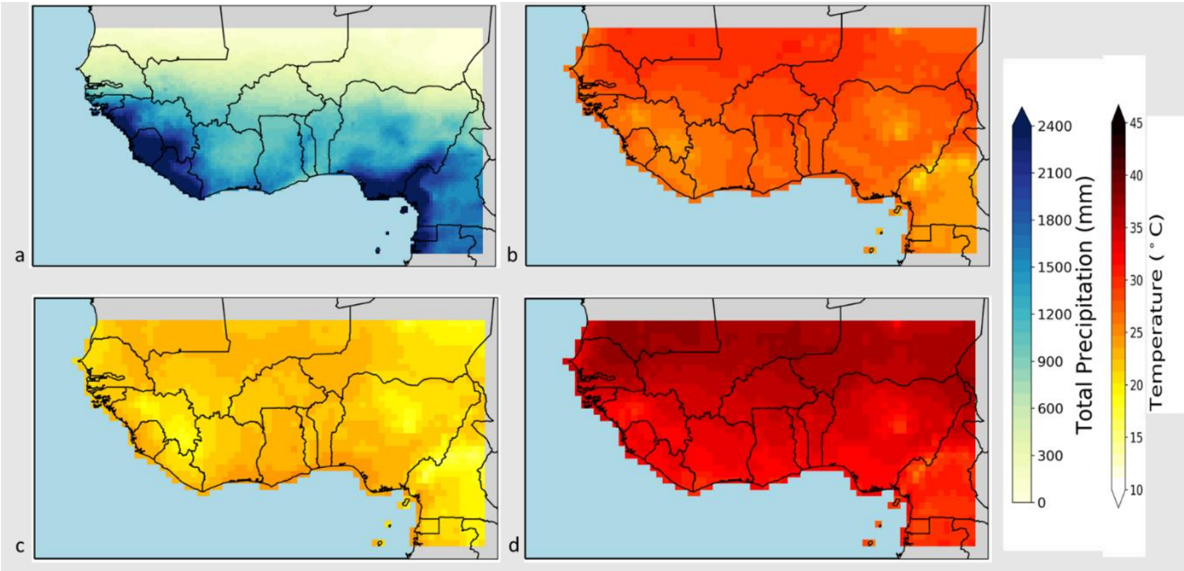


Figure 3: Mean annual values from the CHIRPS and WFDEI observation datasets for the baseline period of 1981-2010 for temperature (°C from WFDEI) and precipitation (mm/year from CHIRPS) for the West Africa region. The maps show a) total precipitation, b) Mean temperature, c) Minimum temperature and d) Maximum temperature.

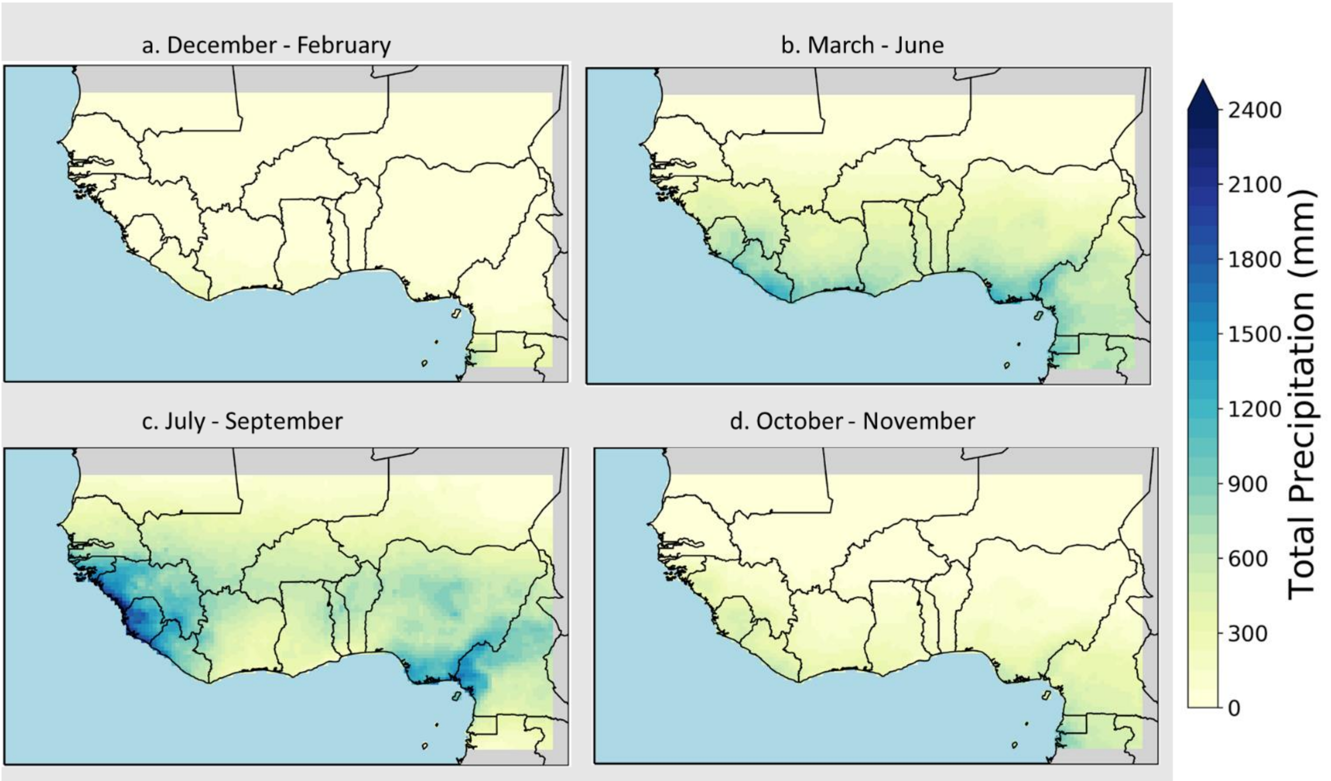


Figure 4: Seasonal total precipitation for the West Africa region over the baseline period (1981-2010) from CHIRPS obs[3]

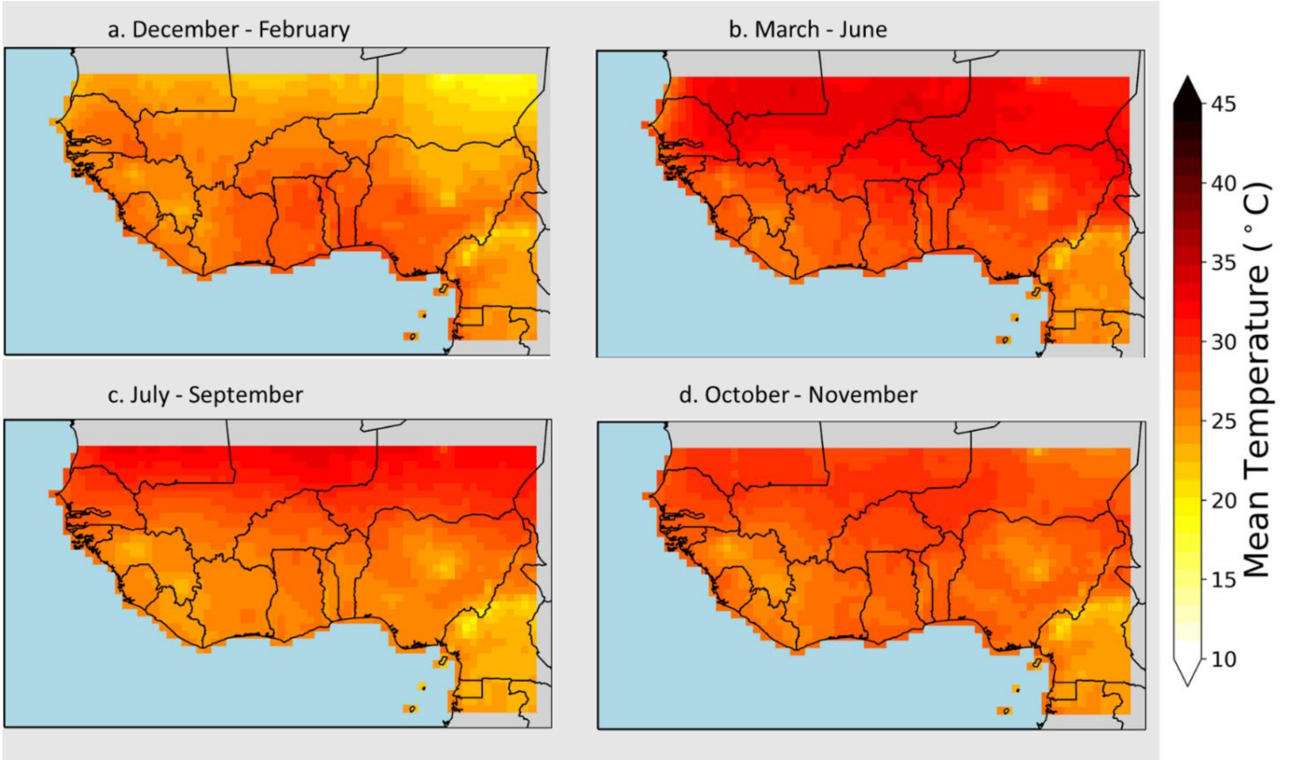


Figure 5: Seasonally averaged mean temperature for the West Africa region over the baseline period (1981-2010) from WFDEI[3].

As seen in Figures 3, 4 and 5, West Africa can be divided into three distinct climate bands from north to south following a latitudinal rainfall and temperature gradient. The lowest rainfall and highest temperatures occur in the north. Northern Senegal (the most north-westerly region examined in this report) typically receives less than 300 mm of rain annually, falling between May and November, and maximum monthly temperatures in the hotter months (February-March) regularly exceeding 40°C (Figure 5). The highest rainfall in the region falls along the southern coast (up to 3,000 mm annually). Coastal temperatures tend to be lower with monthly maximums only occasionally exceeding 35°C in the hottest months of February and March. There is some variation in precipitation along the coast, a central arid zone in southern Benin and Togo, known as the Dahomey gap, receives significantly less rainfall than the rest of the coast due to a complex combination of topography, coastal upwelling of cold water, and land-sea effects (Figures 3a and 4, Jung & Kunstmann, 2007).

The region's precipitation is strongly influenced by the West African Monsoon (WAM) (see Focus Box 6) and dry northerly winds, known as the Harmattan, blowing down from the Sahara, bringing dust (Nicholson, 2013) and reducing visibility. West African rainfall can be highly variable on hourly to daily timescales. This variability is largely determined by systems of heavy, intense rain and organised thunderstorms. The region also currently experiences high interannual variability in both amount and timing of precipitation. Temperatures are less variable year to year.

3.1.1 Drivers of year-to-year variability

The maps in Figures 3, 4 and 5 show the average values over a 30-year time period, which give an indication of the climatological mean. The actual annual and seasonal rainfall and temperature values vary from year to year, resulting in hotter, cooler, drier and wetter periods than this average. This happens because the local weather is influenced by larger scale processes in the climate system that influence regional and local climate over different timescales (see focus boxes 4 and 5).

Focus box 4: Weather, climate variability and climate change

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

Climate varies naturally over shorter periods of several years, and this natural variability can accentuate or dampen longer-term climate change signals. Both average conditions and the variability around that average can change and can result in an increase in events that in the past were rare or extreme. It can also lead to situations where climate change increases the frequency of both heavy rainfall events and increase the occurrence of very dry conditions (IPCC, 2012).

Focus box 5: Teleconnections influencing West Africa

The two main teleconnections for the West African region are the El Niño Southern Oscillation (ENSO) and the Atlantic Multi-decadal Oscillation (AMO) (Ndehedehe et al., 2017). These large-scale drivers strongly influence the year-to-year variability of rainfall and affect the timing of the WAM (Joly & Voldoire, 2009). Figure 6 from Nash and Adamson (2014) shows that the West African region experiences drier conditions during El-Niño years while the warm phase of the AMO has a drying effect along the Guinea coast and the Gulf of Guinea (Martin & Thorncroft, 2013). El-Nino has a cycle of 2-5 years and AMO a much longer cycle as indicated by its name.

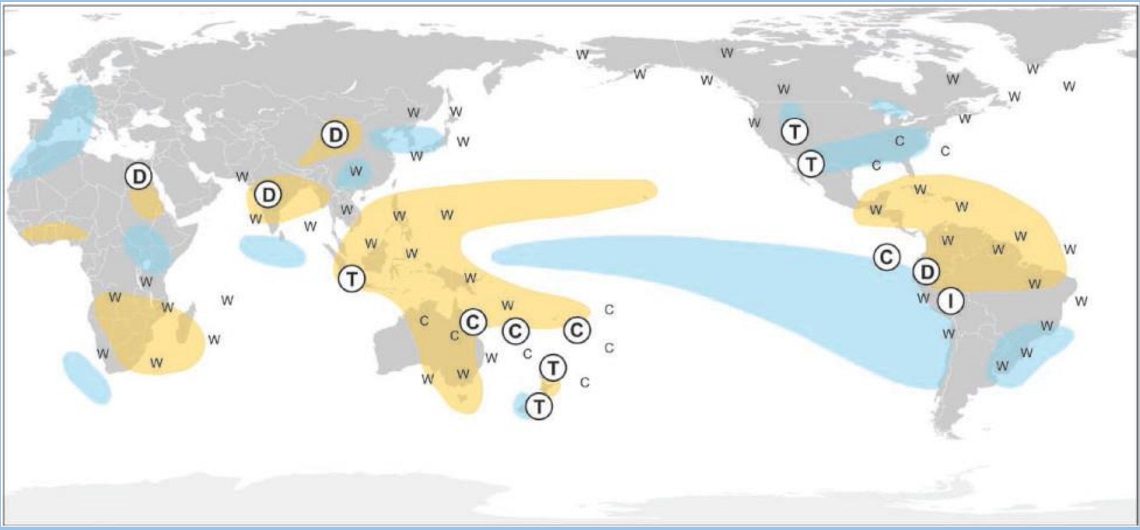


Figure 6: Rainfall anomalies associated with El Niño episodes are represented by orange (dry) and blue shading (wet). Temperature anomalies are indicated by c (cool) and w (warm) annotations; D denotes documentary records of droughts or floods, T tree-ring chronologies, C coral sequences, and ice-core data. From Nash and Adamson (2014).

3.1.2 Observed climate trends since pre-industrial times

The West African region has already experienced an increase in near surface temperature of up to 1.3°C since pre-industrial times (IPCC Atlas, 2021). Figure 7 shows that annual average temperatures have increased by around 0.5°C in the west, and between 1°C and 2°C in the east, over the 1901-2012 period. In recent decades the number of cold days and cold nights has decreased, and the number of warm days and warm nights has increased, along with an observed reduction in extreme cold temperatures and an increase in extreme hot temperatures (Niang et al., 2014).

Observations from our baseline period show a moderate trend in temperature (1981-2010), this is not as pronounced for West Africa as that seen in other regions of the world, e.g. MENA

(Richardson et al., 2021), East Africa (Richardson et al., 2022) and the Sahel (Holmes et al., 2022). However, West Africa has a narrow climatic temperature range compared to those regions, both interannually and seasonally, and this is especially pronounced in the zones on the Gulf of Guinea (Figures 19 and 21). This has implications for risk analysis as even a modest increase in temperature will push the temperatures outside the range currently experienced.

The identification of a past precipitation trend under a warming climate is complicated by the very large inter-annual variability and long-term fluctuations observed in recent decades (Stanzel et al., 2018). However, a drying trend of more than 10% over the 1951-2010 period has been observed in much of the region (where data is sufficient to support analysis). In particular, the coastal regions have experienced drying of over 50% during the 1951-2010 period (Figure 7, right panel). However, during this period the 1950s and early 1960s were very wet (IPCC, 2021), while 1970-1990 was characterised by drought conditions (Le Barbé et al., 2002). Since the late 1980s average annual rainfall has increased in the region (Maidment et al., 2015) although it is not yet back to the levels observed before the drought period. This trend is more pronounced in the east than in the west (IPCC, 2021). A shift in the timing of the rainy season has also been observed in the coastal regions, showing decreases in spring and summer, and increases in autumn (Daron, 2014). The IPCC (IPCC, 2021) attributes the drought conditions in the 1970s-1990s to increases in levels of tropospheric aerosols, which were at a peak during this period and have since decreased, and the later wetter conditions to increases in atmospheric greenhouse gases (GHG). This attribution supports the projections of future increases in precipitation in parts of the region as GHG concentration is on an increasing trend.

The high variability in precipitation has caused a corresponding variability in river discharge with increased peak flow contributing to flooding in the Niger, Senegal and Volta (Nka et al., 2015; Aich et al., 2016; Wilcox et al., 2018; Tramblay et al., 2020) other factors affecting flooding and drought frequency are land use and tree cover changes in the water sheds of these rivers. A decrease in the number of days of extreme rainfall and increase in rainfall intensity have resulted in an increase in the duration of dry spells, and variation in dryness from year-to-year have all been observed (Climate Development and Knowledge Network, 2012).

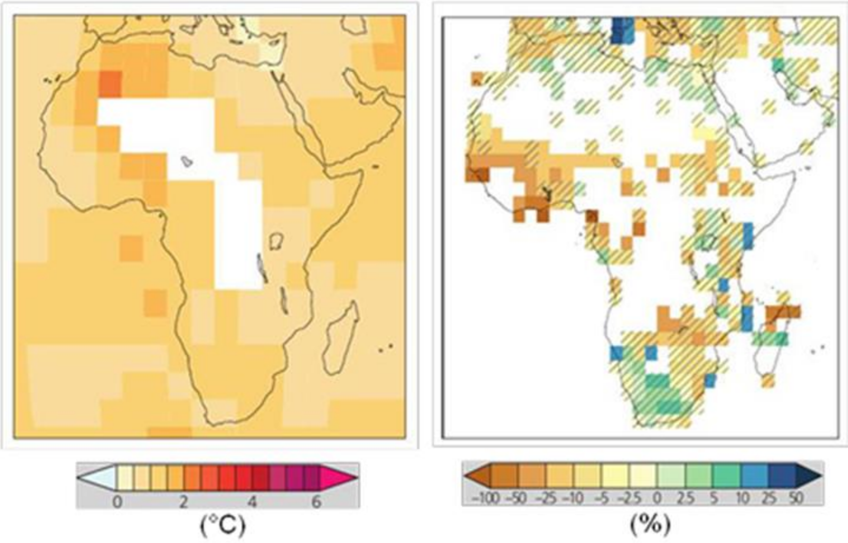


Figure 7: Observed trends in annual average temperature over the 1901-2012 period (left panel) and annual average rainfall over the 1951-2010 period (right panel). Areas where data is insufficient to assess the trend are left white, and diagonal lines indicate regions where the observed trend is small compared to the variability currently experienced in the region. Figure adapted from Niang et al. (2014). (Met Office report on Africa, updated 2020)

3.1.3 Summary of future projections at the regional scale

Climate projections synthesised in the IPCC sixth assessment report (IPCC, 2021) can be summarised as:

- high confidence in an increase in frequency of droughts on a seasonal time scale (Figure 8).
- high confidence that heavy rainfall events will be more frequent and intense, and low confidence that dry spells will be longer and more frequent (Wang et al., 2021).
- seasonal consecutive dry day (CDD) increases in the region for MAM and JJA (Dosio et al., 2020).
- an increase in rainfall-based meteorological drought frequency and magnitude in Niger and Volta river basins (Oguntunde et al., 2020).
- slight increase in rainfall-based meteorological drought for overall region (Spinoni et al., 2020).

Focus Box 6: West African Monsoon (WAM)

The West African Monsoon (WAM) is a system of south-westerly winds which form in the Gulf of Guinea. In the period from May to September the WAM brings rainfall to an area which extends from the southern coast of West Africa to the northern edge of the Sahel (20°N) and from the western coast of Africa (15°W) to the western foothills of the Ethiopian highlands (30°E).

Future changes in the West African Monsoon system are driven by a variety of complex factors, including human-induced climate change. Models indicate medium confidence in a decrease in mean annual precipitation in the west (Wang et al., 2021; IPCC, 2021), medium confidence in a small increase to daily precipitation intensity and medium confidence in increases in frequency of extremes and consecutive dry days.

On the timing of the monsoon, there is medium confidence of a delayed retreat, and low confidence on its increase in duration, projected changes in the onset and cessation are highly uncertain.

Some of these changes have already been identified in the recent historical record, with associated larger variations of rainfall experienced at local scales (IPCC, 2021).

Coasts

Coastal areas in West Africa are under significant threat from climate change and anthropogenic factors (Amosu et al., 2012). There is high confidence of an increase in relative sea level around the coast of West Africa (IPCC, 2021). Both CMIP5 and CMIP6 models project an increase in median regional sea level of 0.3 m between the baseline period and the 2050s (IPCC, 2019, 2021; IPCC interactive Atlas, 2021).

The latest IPCC AR6 concludes that for West Africa there is high confidence of an increase in coastal erosion, as well as high confidence of an increase in coastal flooding. There is high confidence that the vast majority of sandy coasts in region will experience shoreline retreat throughout the 21st century (IPCC, 2021), and CMIP5 projections for the mid-century indicate a median shoreline retreat for West Africa of 65 m under RCP8.5 relative to 2010 (IPCC, 2021, Vousdoukas et al., 2020).

Sea surface temperature is projected to increase by 0.6-1.9°C in the seas around West Africa (IPCC, 2021; IPCC Interactive Atlas, 2021)[6]. Sea surface temperature is a proxy for marine heatwaves, which are also projected to increase across the West African coast with high

[6] https://interactive-atlas.ipcc.ch/

confidence over the 21st century (IPCC, 2021). There is high confidence of an increase in ocean acidity, with the pH of the surface ocean projected to decrease by 0.1 by mid-century (2041-2060) in the West African coastal region under SSP585 (IPCC, 2021; IPCC Interactive Atlas, 2021).

See Section 4.4 for further discussion of coastal and marine impacts in West Africa.

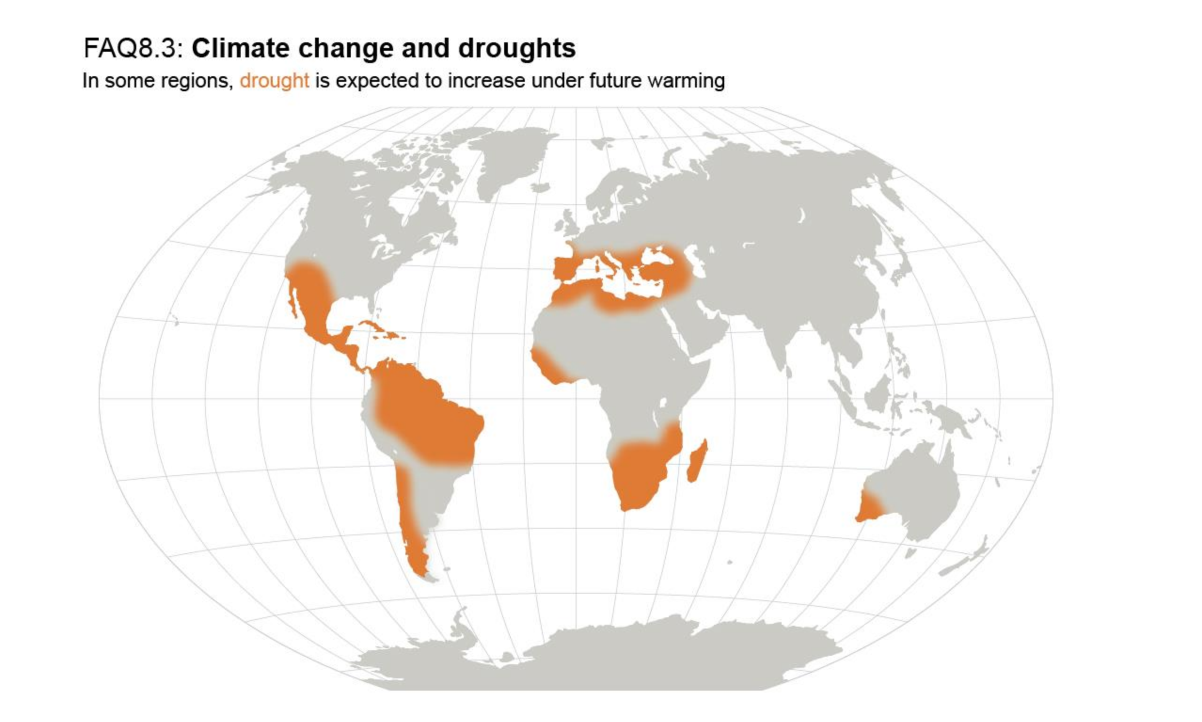


Figure 8: Schematic map highlighting in brown the regions where droughts are expected to become worse as a result of climate change. This pattern is similar regardless of the greenhouse gas concentration scenario; however, the magnitude of change increases under higher emissions.(IPCC, 2021)

3.2 Spatial analysis zones approach

To assess the scale and direction of projected climate trends in this report, we have used spatially aggregated gridded climate data, which is analysed over climatologically similar regions. As the West Africa region represents a large area with a range of climatic conditions, it is not appropriate to average the climate data over the whole region, as the resulting values will not reflect the climate diversity. Nor is it useful to average the climate data by country borders, as these do not reflect the climate and some countries may experience a range of climate types. Therefore, the region is divided into six sub-regional spatial analysis zones that reflect the different climate types, while allowing for socio-economic analysis to take into account specific vulnerabilities of the zones accordingly.

The zones created for this analysis were selected using a combination of the Köppen-Geiger climate classifications (Figure 9) and the Natural Earth[7] country borders (v4.1.0).

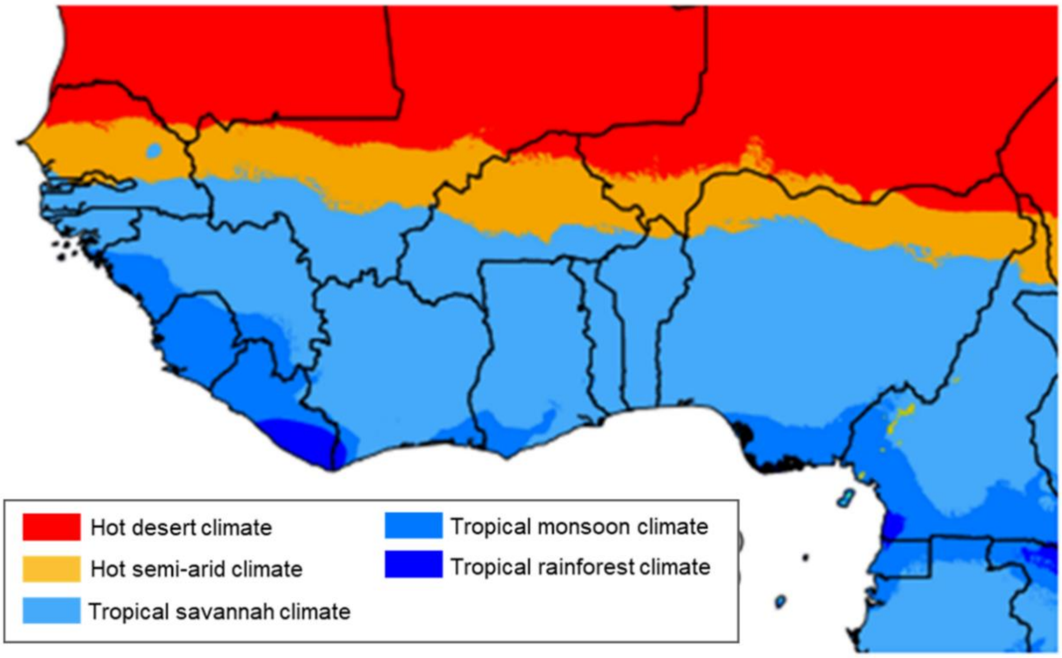


Figure 9: Köppen-Geiger climate classification map for the West Africa region, adapted from Beck et al. (2018)

The six zones used for the spatial analysis are shown in Figure 10. Northern Senegambia (zone 1) and northern Nigeria (zone 2) which are both regions of hot desert and semi-arid climate make up zones 1 and 2 respectively. They are divided due to the distinct rainfall regimes in these two zones. Zone 3 is a tropical savannah climate in the central west of the region from Senegambia to Côte d'Ivoire. Zone 4 to the east of zone 3 is also tropical savannah, distinguished from zone 3 by the west to east rainfall gradient observed across the region. Zone 5 is the more humid coastal zone consisting of tropical monsoon and rainforest climate regimes, this zone includes coastal Guinea, Sierra Leone and Liberia. Zone 6 is the eastern coastal zone consisting mostly of tropical savannah and tropical rainforest (as trophic

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

vegetation, much of it deforested), with coastal areas of tropical monsoon, this zone extends through southern Côte d'Ivoire, Ghana, Togo, Benin and Nigeria.

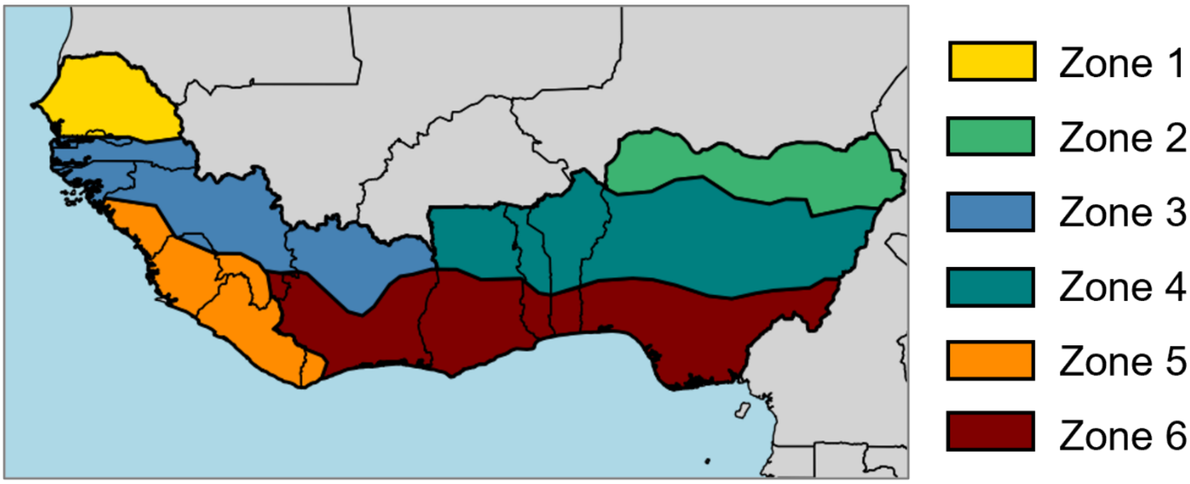


Figure 10: The 6 spatial analysis zones across the West Africa region

Table 1: Countries in the West Africa region and the spatial analysis zones that they are included in (defined in Figure 10).

Country	Climate analysis zones that cover the country
Benin	4, 6
Côte d'Ivoire	3, 5, 6
The Gambia	1, 3
Ghana	4, 6
Guinea	3, 5
Guinea-Bissau	3
Liberia	5
Nigeria	2, 4, 6
Senegal	1, 3
Sierra Leone	3, 5
Togo	4, 6

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

Zone summary:

Baseline climate in context

Zone 2: Northern Nigeria

Current climate:
Arid/semi-arid climate, hot year-round with distinct rainy season April to October **Geographic and socio-economic context:**

- Savannah land widely exploited for arable rainfed agriculture, dry season irrigated farming, and pastoralism
- Lake Chad provides fishing livelihoods, flood recession cultivation, and important trade networks
- Major loss of life and disruption to livelihoods and infrastructure in recent years due to terrorism and conflict

Zone 4: Central eastern West Africa

Current climate:
Tropical savannah climate, hot year-round with rainy season April to October

Geographic and socio-economic context:

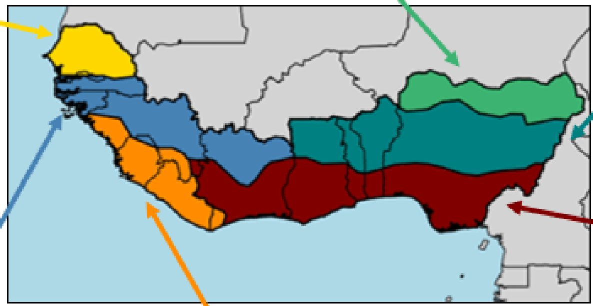
- More than half of the population lives in rural areas dependent on farming and pastoralism
- Important rivers include the Mono and Oti rivers in Togo and Benin
- Major cities include Tamale in Ghana, and Abuja, Kaduna and Jos in Nigeria
- The Volta Basin of Lake Volta in Ghana is a vital water source for Ghana

Zone 1: Senegambia

Current climate:
Arid/semi-arid climate, hot year-round, with wet rainy season May to October/November

Geographic and socio-economic context:

- The Senegal and Gambia rivers flow through this region providing irrigation and hydro-electric power
- Dependent mainly on rainfed agriculture
- City of Dakar is a major commercial, political, and diplomatic hub; other major cities include St Louis and Tambacounda in Senegal
- West African coastline and the Canary Current



Zone 6: South eastern coastal zone

Current climate:
Tropical climate and high rainfall with a double peak during the wet season March to October

Geographic and socio-economic context:

- Highest GDP in West Africa
- Fertile area dependent on agriculture
- Produces the majority of the world's cocoa
- Niger Delta is the centre of Nigeria's oil and gas production
- Contains major cities such as Cotonou in Benin and Lagos in Nigeria which is the largest city in sub-Saharan Africa
- Important ecology including coastal mangroves, marine ecosystems, and tropical and savannah forests, including national parks

Zone 3: Central western West Africa

Current climate:
Tropical savannah climate, hot year-round with wet rainy season April to October

Geographic and socio-economic context:

- Savannah woodland and grasses
- Agriculture and pastoralism are the main economic activities
- Extractive industries are important, such as mining for Bauxite in Guinea and Guinea Bissau

Zone 5: South western coastal zone

Current climate:
Tropical monsoon climate and very high rainfall in wet season March to November

Geographic and socio-economic context:

- Tropical rainforest, merging into savannah woodland in the northern areas
- Agriculture consists of cereals, root crops, fruits and vegetables
- Fishing livelihoods are very important in coastal communities
- Contains major coastal towns and cities such as Conakry in Guinea
- High ecological importance with national parks in Sierra Leone and important coastal ecology

Zone summary:
Future climate trends and relevant risks

Zone 1: Senegambia

Future climate trends:

- Hotter throughout the year, larger increase during warm, dry months (October to November)
- Decrease in average rainfall during rainy season
- Frequency and intensity of drought will increase
- Severe sea level rise, increasing sea surface temperatures and ocean acidity

Relevant risks:

- Water scarcity and depleted groundwater. Changes to stream flow in Senegal and Gambia river basins impacting efficiency of Hydroelectric plants.
- Increased competition for water and risk of heat stress on livestock.
- Considerable risk of heat stress, combined with water shortages, results in high risk of mortality. Working outside during hot months may become impossible.
- Coastal erosion and inundation and warming oceans will negatively impact tourism and fisheries

Zone 2: Northern Nigeria

Future climate trends:

- Hotter throughout the year across all seasons
- Wetter on average, with increased rainfall in wet season but little change in the dry season
- High interannual variability in the pattern of the rains

Relevant risks:

- Increase in water insecurity due to rainfall variability, higher temperatures and growing demand for water. Water quality will decrease.
- Risk of heat stress on livestock. Frequency and intensity of drought will increase, putting current crops at risk. Potential for conflict over land.
- Heat stress due to combined increase in temperature and decrease in water availability

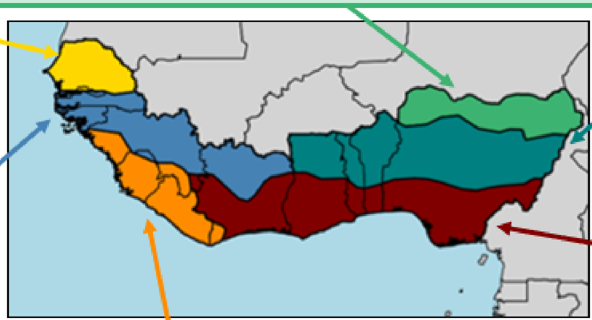
Zone 4: Central eastern West Africa

Future climate trends:

- Hotter throughout the year
- Increased seasonal and interannual variability of rainfall

Relevant risks:

- Water availability and quality will decrease due to greater rainfall variability, higher temperatures, and growing demand.
- Heat stress and flooding, particularly in cities such as Tamale in Ghana, Abuja, Kaduna and Jos in Nigeria



Zone 3: Central western West Africa

Future climate trends:

- Hotter throughout the year
- Increased frequency and intensity of drought
- Rainfall patterns highly variable from year to year
- Sea level rise, increasing sea surface temperatures and ocean acidity

Relevant risks:

- Water insecurity. Changes in river flow may affect energy output of the Kossou dam.
- Heat stress linked to maximum temperatures regularly exceeding 40°C.
- Coastal inundation and shoreline retreat, including in the Bijago Archipelago. Fisheries impacted by warming oceans.
- Increased rainfall variability will impact on biodiversity and ecology across savannah and Guinea Moist Forest. Mangrove ecosystems threatened by sea level rise.

Zone 5: South western coastal zone

Future climate trends:

- Hotter throughout the year, slightly greater increases December to February
- Drier start of the wet season (March-June) with possible delay of onset of the wet season
- Frequency and intensity of drought will increase.
- Sea level rise, increasing ocean temperatures and acidity

Relevant risks:

- Water stress due to greater variability in rainfall, higher temperatures and a growing demand for water. Energy production may decrease in hydroelectric plants such as Mount Coffee in Liberia and the Souapitiin Guinea.
- Coastal inundation, shoreline retreat and loss of beaches due to sea level rise, threatening coastal tourism and coastal agriculture. Warming oceans will impact the productivity of fisheries.
- Amplified risk of heat stress and flooding in cities such as Conarky in Guinea, Freetown in Sierra Leone and Monrovia in Liberia.
- Increased variability in rainfall may threaten the viability of tropical forests such as the Upper Guinea Forest.

Zone 6: South eastern coastal zone

Future climate trends:

- Hotter throughout year
- Higher interannual variability and more frequent and intense rainfall events. Some indication that onset of rainy season may be delayed.
- Sea level rise, increasing sea surface temperature and ocean acidity

Relevant risks:

- Heat stress and flooding. Poor air quality in areas such as Lagos and the Niger Delta.
- Coastal erosion and inundation and warming oceans will negatively impact coastal settlements, tourism and fisheries.
- Amplified risk of heat stress and flooding in cities such as Lagos, Nigeria.
- Endemic species endangered. Mangroves in the Niger Delta threatened by sea level rise.
- Crops and livestock will be impacted by risk of drought and saltwater intrusion within coastal aquifers

3.3 Baseline and future climate by zone

3.3.1 Zone 1: Senegambia

Baseline climate in context

Zone 1 encompasses the semi-arid region of northern Senegal and The Gambia.

The climate of zone 1 is hot year-round with a wet rainy season from May to October/November, with peak rainfall usually occurring in August when as much as 250 mm of rain can fall over the course of the month. Interannual variability in rainfall is very high, with the timing of the peak of the rainy season and the maximum rainfall amounts varying considerably from year-to-year. The warmest time of year is from April to June, with May being the hottest month, experiencing mean temperatures of around 32°C and regularly seeing maximum temperatures of over 40°C (see Appendix). A secondary peak in temperature occurs in October, before temperatures decrease to the coolest months in December to February, which have mean temperatures around 25°C.

Observations of the baseline period show no trend in precipitation and a moderate trend in temperature (based on observations for 1981-2010, Figure 11) however, this is less pronounced for West Africa than other regions of the world (Richardson et al., 2021; Richardson et al., 2022). West Africa has a narrow climatic temperature range compared other regions, both interannually and seasonally, and although this is more pronounced in the southerly zones (5 and 6) it is also a feature in zone 1. This has implications for our risk analysis as even a modest increase in temperature will push the temperatures outside the range currently experienced. i.e., the lowest temperatures in the 2050s will be higher than the maximums experienced in the baseline period. Since pre-industrial times in the West African region has seen average temperature increases of 1-1.3°C (IPCC Atlas, 2021).

Rainfall, as mentioned above has very high interannual variability with no clear wetting or drying trend observable throughout the baseline period.

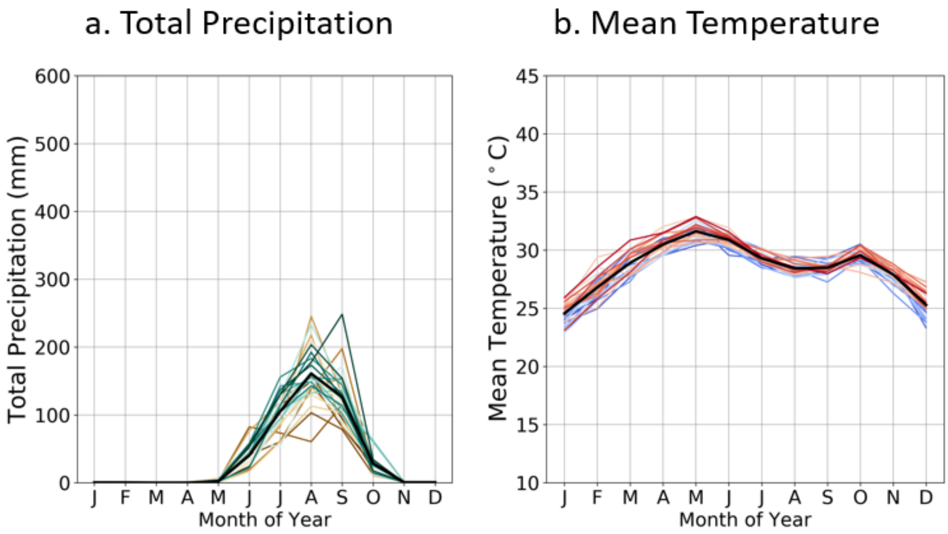


Figure 11: Observations for Zone 1 from 1981-2010 of a. total monthly precipitation from CHIRPS (Climate Hazards group Infrared Precipitation with Stations) dataset and b. average daily mean temperature from WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset, over the baseline period (1981-2010). Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, of a trend over the baseline period). The bold black line indicates the average of the 30-year period.

Future climate projections

Between the baseline period and the 2050s, the mean annual average temperature is expected to rise by 1.5-4°C under SSP5-8.5 (Figure 12). This increase is consistent across all seasons, although more models indicate an increase at the higher end of this range for the warm, dry October-November season. Climate model projections for rainfall show a good consensus for very little change to total amounts in the December-January season, which is currently dry. In the rainy season (July-September) there is much more uncertainty, with a few model outliers showing large increases and a few showing large decreases in total seasonal rainfall. However, the majority of climate models indicated a decrease in total seasonal precipitation of 0—100 mm/season on average over the 2050s (2041-2070) giving us reasonable confidence in an increase within this range.

While the timing of the rainy season is consistent throughout the baseline period for zone 1, interannual variability in rainfall monthly totals is high (Figure 11b). There are no obvious trends in rainfall over the baseline period (Figure 11a) which is indicative that variability in rainfall is currently larger than any change due to climate change over this period. This large interannual variability is projected to continue and may potentially increase in future.

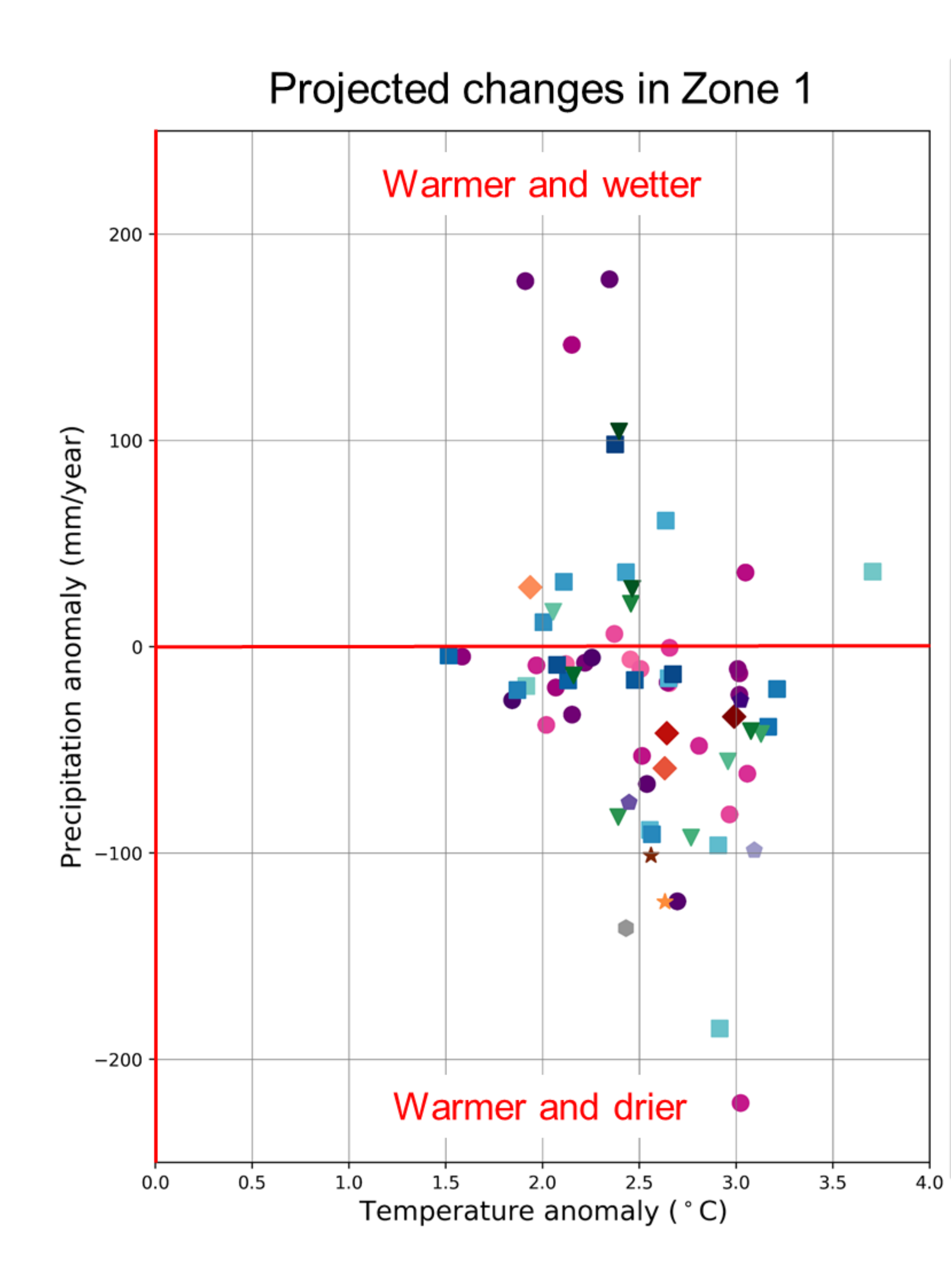


Figure 12: Projected change in average annual precipitation and temperature in Zone 1 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red lines indicate the zero axis i.e. no change in precipitation.

Maximum and minimum temperature will both increase by the 2050s. Both maximum and minimum temperatures are projected to increase by 2-3°C throughout the year. The future minimum temperature is projected to be warmer than any in the baseline climate, with even the coolest values being warmer than the present-day average. This represents a substantial shift in climate norms from the present day – today's 'hot' is tomorrow's normal, or even 'cool'.

In hotter years some of the models project overnight temperatures in excess of 30°C during the hottest months (April-June), although many other models do not. The minimum temperatures are a monthly average for the zone, so local temperatures will be more extreme on occasion and in particular places, such as urban areas. There is an indication in some models that the increase during September-October is larger than in the rest of the year; however, this is not a strong signal as the models do not all agree. If there is a sensitivity to overnight minimum temperatures from September-October, such as in human or livestock heat stress or crop responses, then there may be a risk associated with this change (see sections 4.1 and 4.5).

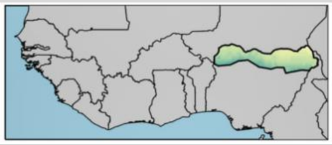
The number of extreme hot days will increase. April to June are the hottest months in the baseline period with maximum monthly temperatures occasionally exceeding 40°C. Projections indicate a 2-4°C increase in maximum temperatures, so maximum temperature are projected to exceed 35°C year-round for most years in the 2050s, with only the coolest years seeing the average monthly maximum temperatures dip below this in December and January. At local levels, for shorter periods of time, higher temperatures will be experienced.

Droughts are expected to worsen and increase in frequency in zone 1 (IPCC, 2021). In addition, in zone 1 substantial decreases in run off and stream flow for both the Senegal and Gambia river basins are projected by the 2050s (Boudian et al., 2018; Stanzel et al., 2018; Sylla et al., 2018). A decrease in the median flood magnitude is projected for The Gambia river by mid-century (IPCC, 2021; Roudier et al., 2014).

Sea levels will rise along the coast of zone 1, as well as along the coastlines of other West African zones, with relative sea level projected to increase on the order of 0.3 m between the baseline period and the 2050s (IPCC, 2019, 2021; IPCC Interactive Atlas, 2021). There is also high confidence of an increase in coastal erosion, coastal flooding and shoreline retreat (IPCC, 2021; Vousdoukas et al., 2018, 2020). Sea surface temperature and ocean acidity are both projected to increase with high confidence around West Africa, which will change the environment of the marine ecosystem along the coast and offshore (IPCC Interactive Atlas, 2021).

The Canary Current is described in Section 4.4.2. Trends in the Canary current over past decades are uncertain, however there is evidence that the lower latitude extents of eastern boundary upwelling systems, such as that driving the upwelling along the coast of zone 1, will moderately decrease over the 21st century (IPCC, 2021).

3.3.2 Zone 2: Northern Nigeria



Baseline climate in context

Zone 2 lies to the northeast of the region and encompasses the semi-arid region of northern Nigeria. The current climate shows a distinct rainy season from April to October, with a slower increase in rainfall at the onset and a more rapid decrease at the end, resulting in the asymmetrical seasonal cycle of precipitation, which is characteristic of the rainy season across much of West Africa. Zone 2 is hot year-round, with the warmest season being March to June, with the mean temperatures typically peaking at around 33°C in April and May. Temperatures then decrease until August as precipitation increases, but then increases again into October before decreasing more rapidly. December and January are the coolest months with mean temperatures of about 23°C.

Throughout the baseline period (Figure 13) a trend can be observed in temperature with earlier (blue) years below the average for the period and more recent (red) years above the average; however, this temperature trend is not as pronounced for West Africa as in other regions of the world (Richardson et al., 2021; Richardson et al., 2022). West Africa generally has a narrow climatic temperature range, both interannually and seasonally this is more pronounced in the southerly coastal zones (5 and 6) but can also be observed in zone 2. This has implications for our risk analysis as even a modest increase in temperature will push the temperatures outside the range currently experienced, i.e. the lowest temperatures in the 2050s will be higher than the maximums experienced in the baseline period. Precipitation has extremely high interannual variation with the maximum precipitation amounts and peak of the rainy season varying from year-to-year. The onset and cessation dates of the rainy season show high variability but no clear trend in the projections.

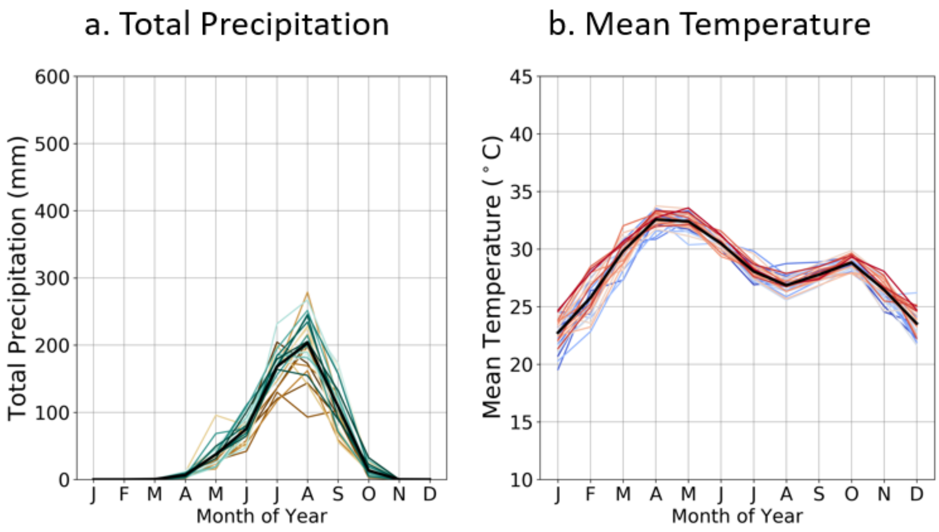


Figure 13: Observations for Zone 2 of a. total monthly precipitation from CHIRPS (Climate Hazards group Infrared Precipitation with Stations) dataset and b. average daily mean temperature from WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset, over the baseline period (1981-2010). Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, of a trend over the baseline period). The bold black line indicates the average of the 30-year period.

Future climate projections

The mean, maximum and minimum temperature projections discussed here are daily temperatures averaged by month over the entire of zone 2, and more extreme temperatures will be experienced locally and for shorter periods of time.

Between the baseline period and 2050s the temperature is projected to rise by 1-4°C (Figure 14), this is consistent across all seasons.

The majority of model projections indicate an increase of up to 100 mm in annual rainfall, with the more up-to-date models (i.e. CMIP6) showing an increase, adding weight to this signal. Seasonally (see plots in Appendix), there is a strong signal for very little change in the December-January season, which is currently already very dry. The biggest change is likely in the rainy season from July-September where there is a wide range in projections of between roughly -100mm and +200mm. The majority of models show an increase in rainfall for this season, however confidence in this is relatively low as there are still a number of models which show a decrease, and this cannot be ruled out. In March-June and October-November seasons, there is much better agreement in precipitation projections between the models. From October-November most models agree on an increase of up to 50 mm per season and in March-June models give good agreement on little change in rainfall.

While the timing of the rainy season is consistent over the baseline period for zone 2, interannual variability in monthly rainfall totals is high (Figure 13a). There are no obvious trends in rainfall over the baseline period (Figure 13a) which is indicative that variability in rainfall is currently larger than any increasing or decreasing trend over this period. This large interannual variability is projected to persist and may potentially increase in future. There is medium confidence that zone 2 will see a delayed onset of the rainy season and a reduced length of the rainy season (Kumi & Abiodun, 2018).

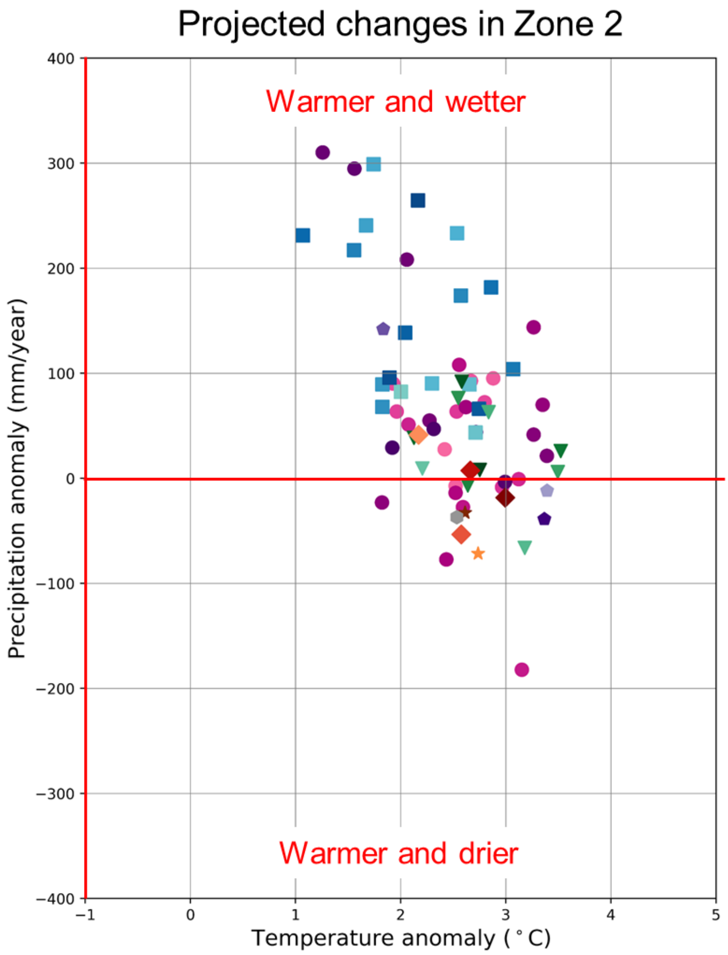
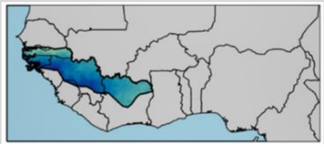


Figure 14: Projected change in average annual precipitation and temperature in Zone 2 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red lines indicate the zero axis i.e. no change in precipitation.

Maximum and minimum temperatures will both increase by the 2050s. Overnight monthly average minimum temperatures may exceed 30°C in April and May in the hottest years in the 2050s, with more extreme temperatures experienced locally.

The number of extreme hot days will increase. Projections indicate that maximum monthly temperature will far more often exceed 35°C in the 2050s, with maximums over 35°C in every month of the year not unusual. Maximum temperatures may reach 45°C in extreme years in April-May in the 2050s presenting considerable heat stress risk.

3.3.3 Zone 3: Central western West Africa



Baseline climate in context

Zone 3 encompasses the southern part of Senegal; the southern part of the Gambia; Guinea-Bissau; and inland regions of Guinea, Sierra Leone and Ivory Coast. Zone 3 is cooler and wetter than the more northerly zones, although maximum temperatures are still above 30°C throughout the year. Zone 3 is largely characterised as savannah, and has extremely high precipitation typically 300 mm/month at the peak of the rainy season (August). The amount of precipitation in this zone is typically greater than the savannah zone 4 which lies further east, reflecting a general west to east gradient of decreasing precipitation. From our analysis of the baseline period 1981-2010 (Figure 15) a moderate trend in temperature can be observed, this is in contrast to the more pronounced trend seen in other regions of the world (Richardson et al., 2021; Richardson et al., 2022). West Africa has a narrow climatic temperature range, both interannually and seasonally. This has implications for our risk analysis as even a modest increase in temperature will push the temperatures outside the range currently experienced. I.e. the lowest temperatures in the 2050s will be higher than the maximums experienced in the baseline period.

The current climate of this region displays a characteristic asymetrical cycle of precipitation, with a gradual increase in rainfall from February-March, to a peak in rainfall which usually occurs in August. During August, monthly precipitation totals are typically around 300 mm, although this varies between years. A rapid decrease in precipitation occurs through September and October, and the dry season generally lasts from November to February. The interannual variabilty in rainfall is high in this zone, although not as great as in the rest of the

West African region. The seasonal cycle in temperature shows less seasonal variability than areas further north, with the warmest months in March and April experiencing mean temperatures of around 29-30°C. Temperatures decrease following the warm season, and August as well as December and January are the coolest months experiencing mean temperatures of around 25°C.

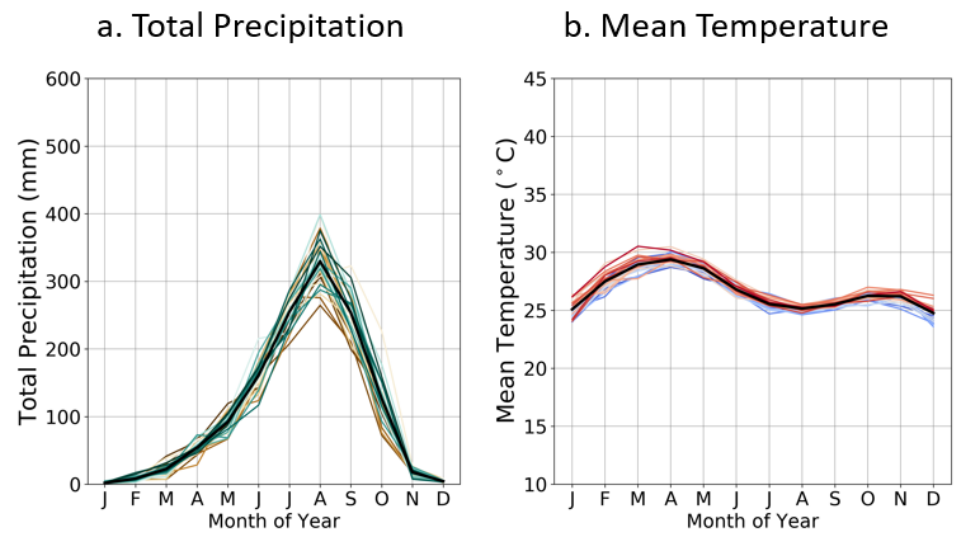


Figure 15: Observations for Zone 3 of a. total monthly precipitation from CHIRPS (Climate Hazards group Infrared Precipitation with Stations) dataset and b. average daily mean temperature from WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset, over the baseline period (1981-2010). Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, of a trend over the baseline period). The bold black line indicates the average of the 30-year period.

Future climate projections

Between the baseline period and the 2050s temperature in zone 3 is projected to rise by 1-4°C (Figure 16). This is consistent across all seasons with some models suggesting larger or smaller changes in the December-February season, meaning confidence is lower for this season (see figures in Appendix).

Change in annual rainfall is uncertain and could increase or decrease. Seasonally, there is a strong signal for very little change in the December-January season, which is currently dry, with the biggest change projected for the rainy season in July-September. There is no consensus in the models on the sign or magnitude of the change during March-November, suggesting high interannual variability. In zone 3 there is high confidence in the literature that the onset of rains will be delayed, this is in agreement with our projections. There is less consensus about changes to the cessation date (Kumi & Abiodun, 2018), indicating that a shorter rainy season is a risk to this zone.

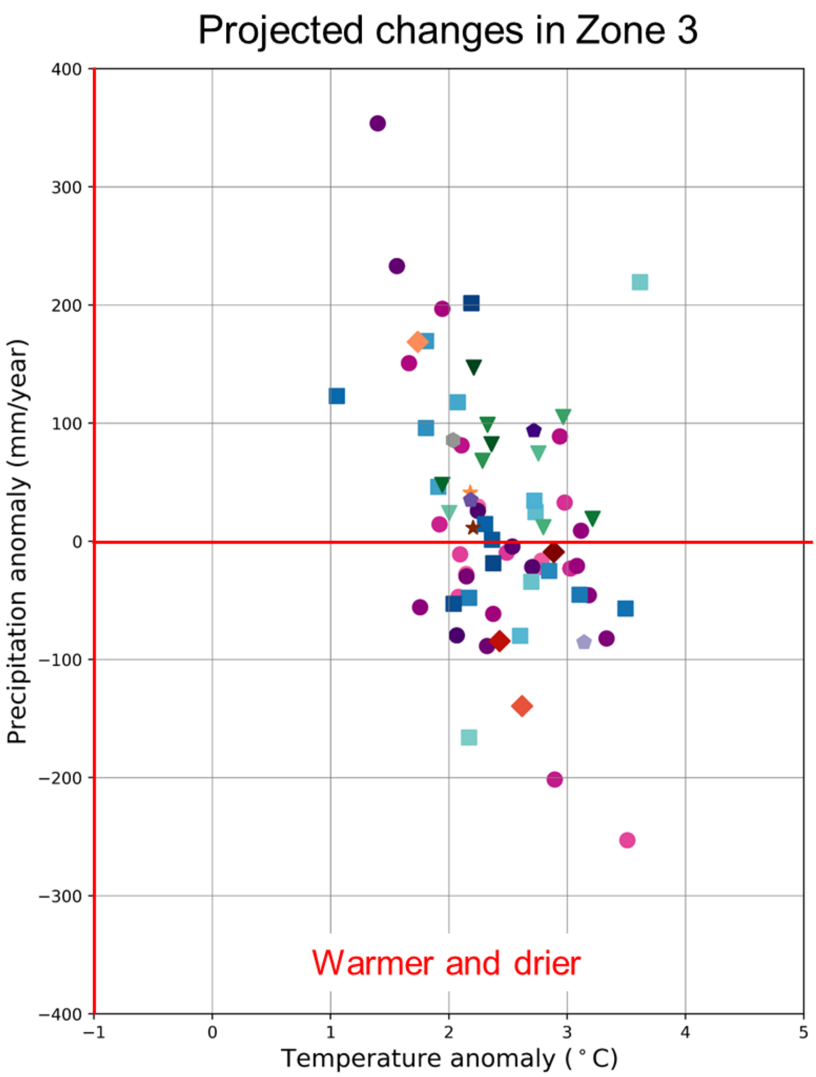


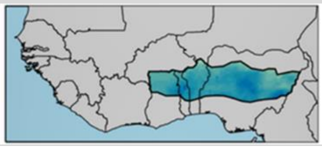
Figure 16: Projected change in average annual precipitation and temperature in Zone 3 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red lines indicate the zero axis i.e. no change in precipitation.

Maximum and minimum temperature will both increase by the 2050s and the number of extreme hot days will increase. Projections indicate that maximum temperature will exceed 35°C between February-May every year in the 2050s and some models indicate that maximum temperature will exceed 40°C regularly during the warmest months of February-April, this presents an increased risk of human and livestock heat stress in zone 3.

Under RCP8.5 (highest emissions scenario), an increase in flood magnitudes by 2050 is projected for countries within the Niger river basin (Roudier et al., 2014; Aich et al., 2016; IPCC, 2021) which includes the west of Guinea in zone 3.

Sea levels will rise along the coast of zone 3, with relative sea level projected to increase on the order of 0.3 m between the baseline period and the 2050s (IPCC, 2019; IPCC, 2021; IPCC Interactive Atlas, 2021). There is also high confidence of an increase in coastal erosion, coastal flooding and shoreline retreat (IPCC, 2021; Vousdoukas et al. 2018, 2020). Sea surface temperature and ocean acidity are both projected to increase with high confidence around West Africa, which will change the environment of the marine ecosystem along the coast and offshore (IPCC Interactive Atlas, 2021).

3.3.4 Zone 4: Central eastern West Africa



Baseline climate in context

Zone 4 is predominantly hot and wet, it includes the inland regions of northern Ghana, Togo and Benin, as well as central Nigeria, and comprises the eastern part of the West African savannah. Zone 4 has lower precipitation rates than the western savannah region of zone 3, which reflects a decreasing gradient in precipitation from west to east. From the onset of the rainy season in March, precipitation totals increase gradually to a maximum of approximately 250 mm, which typically occurs in August, although this varies between years. The interannual variability is significantly less than zones 1-3 with the timing of the peak in rains consistently occurring in August and September throughout the baseline period (1981-2010, see Figure 17a). The dry season is generally from November to February. Temperatures are higher in zone 4 than zone 3, with mean temperatures during the hottest time of year in March and April typically above 30°C. The coolest months experience mean temperatures of around 26°C. The annual and interannual variability in temperature is also much smaller during the baseline period than observed in zones 1-3, and there is no obvious increasing temperature trend observed from 1981-2010 (Figure 17b), this is in contrast to other regions of the world (Richardson et al., 2021; Richardson et al., 2022). West Africa has a narrow climatic temperature range compared to those regions, both interannually and seasonally and this is especially pronounced in this zone and the zones on the Gulf of Guinea (zones 5 and 6). This has implications for our risk analysis as even a modest increase in temperature will push the temperatures outside the range currently experienced. I.e. the lowest temperatures in the 2050s will be higher than the maximums experienced in the baseline period.

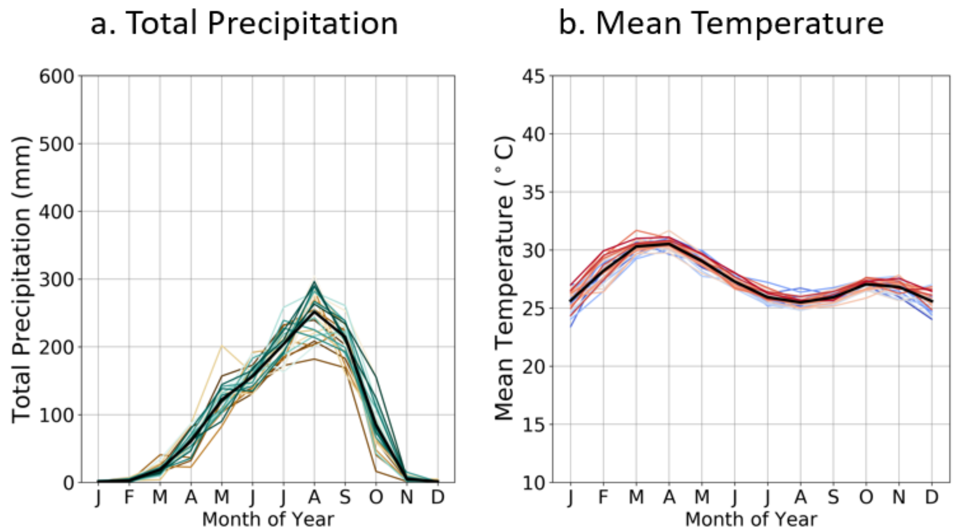


Figure 17: Observations for zone 4 of a. total monthly precipitation from CHIRPS (Climate Hazards group Infrared Precipitation with Stations) dataset and b. average daily mean temperature from WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset, over the baseline period (1981-2010). Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, of a trend over the baseline period). The bold black line indicates the average of the 30-year period.

Future climate projections

Between the baseline period (1981-2010) and 2050s the mean annual temperature in zone 4 is expected to rise by 1-3.5°C (Figure 18). However, there is some seasonal variability to this change with December-June showing a tendency for a higher increase (1-4°C) and July-September a smaller range (1-3°C) (see plots in Appendix).

There is some spread in rainfall projections across the models, but the consensus indicates a small magnitude change in precipitation and potentially some increase. More models indicate an increase in precipitation than a decrease, with the more up-to-date models (CMIP6) showing an increase. Seasonally, the signal during the December-January season, which is currently dry, shows likelihood of very little change with all models agreeing. The biggest change is indicated in the rainy season July-September, where the majority of the models agree on an increase in total seasonal precipitation of up to 100 mm/season. This zone is the least affected by projected changes to the timing of rains (Kumi & Abiodun, 2018). There is high confidence in some delay to the onset of the rainy season, but very low confidence in changes to the cessation.

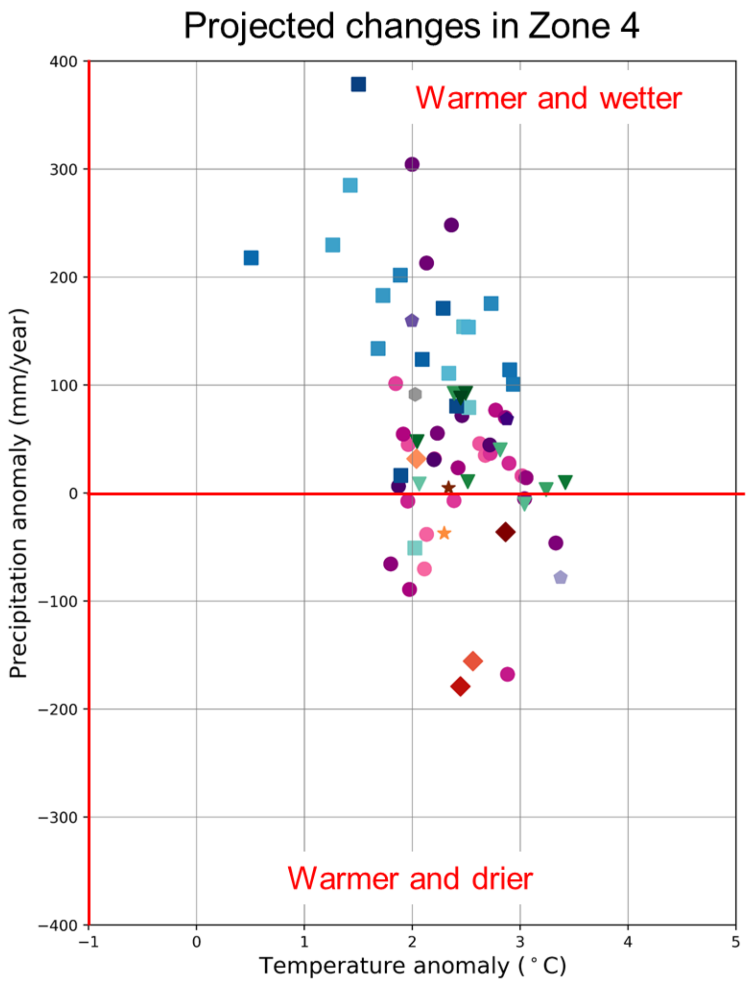


Figure 18: Projected change in average annual precipitation and temperature in zone 4 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red lines indicate the zero axis i.e. no change in precipitation

There is a small range of variability in daily, seasonal, annual and interannual temperature range in zone 4 during the baseline period (1981-2010). This is also seen in the majority of model projections for the 30-year future period, indicating that the temperature range will continue to be narrow. However, while the range may remain small, the whole climate will have shifted to a warmer state by 1-3.5°C, which is a significant amount as a proportion of the variability over all timescales. For average maximum monthly temperature in particular, this takes future temperatures beyond the range that is experienced today.

The number of extreme hot days will increase. Projections indicate that mean maximum temperature will continue to exceed 35°C between February and May every year in the 2050s, with this seasonal period of high temperatures projected to lengthen, in some years lasting from October to July. Average monthly mean temperature is projected to exceed 35°C in the hottest years during in the period March-May. These metrics are averaged over the zone and over the month, so more extreme conditions will be experienced on small scales with daily maximum temperatures much higher especially at specific sites, such as urban areas, which are likely to experience heat island effects.

Under RCP8.5 (high emissions scenario), an increase in flood magnitudes by 2050 is projected for countries within the Niger river basin (Roudier et al., 2014; Aich et al., 2016; IPCC, 2021). An increase in extreme peak flows and their duration is also projected for the Volta River basin by 2050, although there is low confidence in this due to limited evidence (IPCC, 2021; Jin et al., 2018).

3.3.5 Zone 5: South western coastal zone

Baseline climate in context

Zone 5 covers the southwest coastal region of West Africa and includes parts of Guinea, Sierra Leone and Liberia. This region is classified as tropical forests and rainforest.

This zone experiences the highest rainfall of the West African region, with total monthly precipitation at the peak of the rainy season currently reaching above 400 mm. However, precipitation totals in this zone also experience the largest inter-annual variability of all the zones. Peak rainfall is usually experienced in August, although in some years a double peak in precipitation is experienced, with the first peak between in June and July and the second between August and October with lower precipitation totals in between. There is a less pronounced annual cycle in temperature compared to zones further north, with monthly mean temperatures typically ranging from a minimum of approximately 24°C in July and August, to a maximum of approximately 28°C in March and April. There is a moderate temperature trend and very little interannual variability in temperature observed over the years of the baseline period (1981-2010) (Figure 19). This is in contrast to other regions of the world, which show a distinct increasing temperature trend in the baseline period (Richardson et al., 2021; Richardson et al., 2022). West Africa has a narrow climatic temperature range compared to other regions, both interannually and seasonally and this is especially pronounced in this zone and zone 6 (Figures 21 and 22). This has implications for our risk analysis, particularly in zones 5 and 6 as even a modest increase in temperature will push the temperatures outside the range currently experienced, i.e. the lowest temperatures in the 2050s will be higher than the maximums experienced in the baseline period.

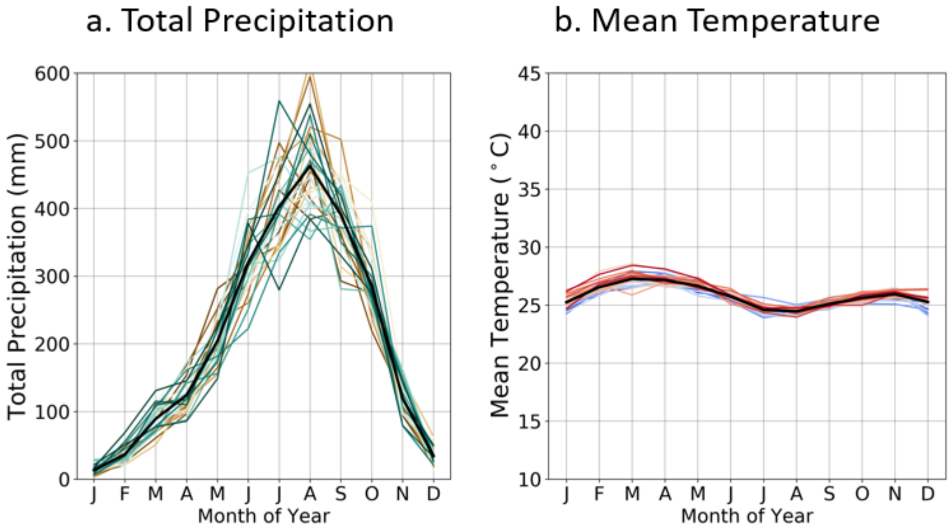


Figure 19: Observations for Zone 5 of a. total monthly precipitation from CHIRPS (Climate Hazards group Infrared Precipitation with Stations) dataset and b. average daily mean temperature from WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset, over the baseline period (1981-2010). Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, of a trend over the baseline period). The bold black line indicates the average of the 30-year period.

Future climate projections

Between the baseline period of 1981-2010 and the 2050s the mean annual temperature in zone 5 is expected to rise by 1.5-3°C (Figure 20). However, there is some seasonal variability to this change, with less confidence in the magnitude of projections for the dry period (December-February), for which the range is 1.5-4°C. Given the low seasonal and interannual variability in temperature commented on above, a change of this magnitude will be very significant, taking temperatures outside the range currently experienced.

Change in annual rainfall is uncertain, with high confidence in continued large variability in rainfall amounts year-to-year. However, there is confidence in a decrease in precipitation in the March-June season, at the start of the rainy season. This is reflected in the literature, which indicates a shift in the onset and cessation of the rainy season (Kumi & Abiodun 2018). There is medium confidence in a geographical gradient to this shift, with the onset delayed more in the west than the east, with the opposite being true for cessation, meaning that the rainy season may get shorter in the west of the zone, but in Liberia it may get longer. A hotspot for global induced delay in onset is identified in the mountain range on the Sierra Leone, Liberia, Guinea border (Kumi & Abiodun, 2018).

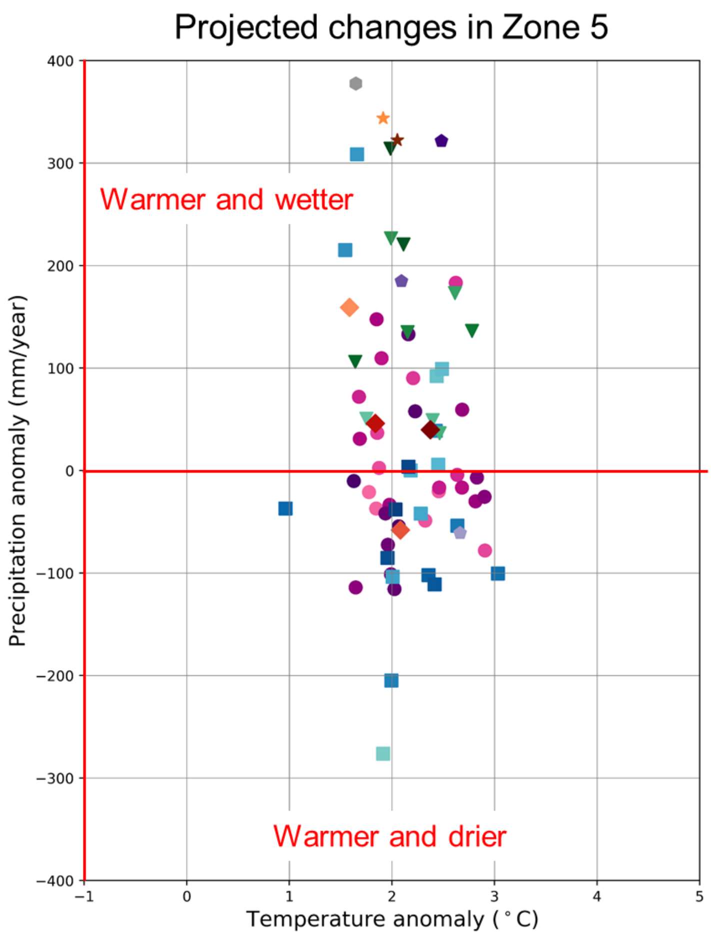


Figure 20: Projected change in average annual precipitation and temperature in Zone 5 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red lines indicate the zero axis i.e. no change in precipitation.

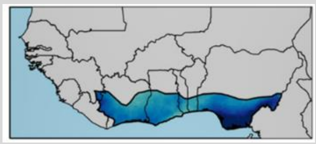
Extreme temperatures (maximum and minimum) are projected to increase by the 2050s. The increase will be for a similar amount at both ends of the scale, meaning the diurnal range will stay of a similar magnitude. There is high confidence that average monthly minimums will stay below 30°C in the 2050s, with good consensus among the models.

The number of extreme hot days will increase as the average and maximum temperatures increase. There is high confidence that average monthly maximum or mean temperatures will not exceed 40°C, however heat stress may still be an issue due to the high humidity in this zone and local temperatures and precipitation rates over a smaller area or shorter time period may be higher than the average. This is particularly likely in urban areas which may feel the effects of heat islands.

Sea levels will rise along the coast of Zone 5, with relative sea level projected to increase on the order of 0.3 m between the baseline period and the 2050s (IPCC 2019, 2021; IPCC Interactive Atlas, 2021). There is also high confidence of an increase in coastal erosion, coastal flooding and shoreline retreat (IPCC, 2021; Vousdoukas et al. 2018, 2020). Sea surface temperature and ocean acidity are both projected to increase with high confidence around West Africa, which will change the environment of the marine ecosystem along the coast and offshore (IPCC Interactive Atlas, 2021).

The Guinea Current flows eastwards along the southern coast of West Africa and plays a major role in modulating the coastal upwelling in the northern Gulf of Guinea, the western extent of which reaches the Côte d'Ivoire coast (Ukwe et al., 2006; Djakouré et al., 2017; Alory et al., 2021). This coastal upwelling brings colder, nutrient-rich waters to the surface and is vital in maintaining the productivity and biodiversity of the marine ecosystem in the region, including fisheries. Future changes in circulation within the tropics remains unclear (IPCC, 2021).

3.3.6 Zone 6: South eastern coastal zone



Baseline climate in context

Zone 6 is the southern coastal area of West Africa and includes the southern parts of Côte d'Ivoire, Ghana, Togo, Benin and Nigeria. The region encompasses grassland as well as some parts of tropical forest focused along the coast.

The current climate of this region displays a double peak in precipitation, with the first peak typically in June and the second in September. This reflects the migration of the Inter Tropical Convergence Zone (ITCZ) over the region, which is associated with the West African Monsoon (see Focus Box 6). Temperatures in this zone show the least variation throughout the year of all the West African zones considered, with monthly mean temperatures typically at a maximum of approximately 28°C in March and at a minimum of approximately 25°C during July and August. In addition, there is no temperature trend observed across the baseline period, this is in stark contrast to other regions of the world (Richardson et al., 2021; Richardson et al., 2022). West Africa has a narrow climatic temperature range compared to other regions, both interannually and seasonally and this is especially pronounced in zones 5 and 6 on the Gulf of Guinea (Figures 19 and 21). This has implications for our risk analysis as even a modest increase in temperature will push the temperatures outside the range currently experienced. I.e. the lowest temperatures in the 2050s will be higher than the maximums experienced in the baseline period.

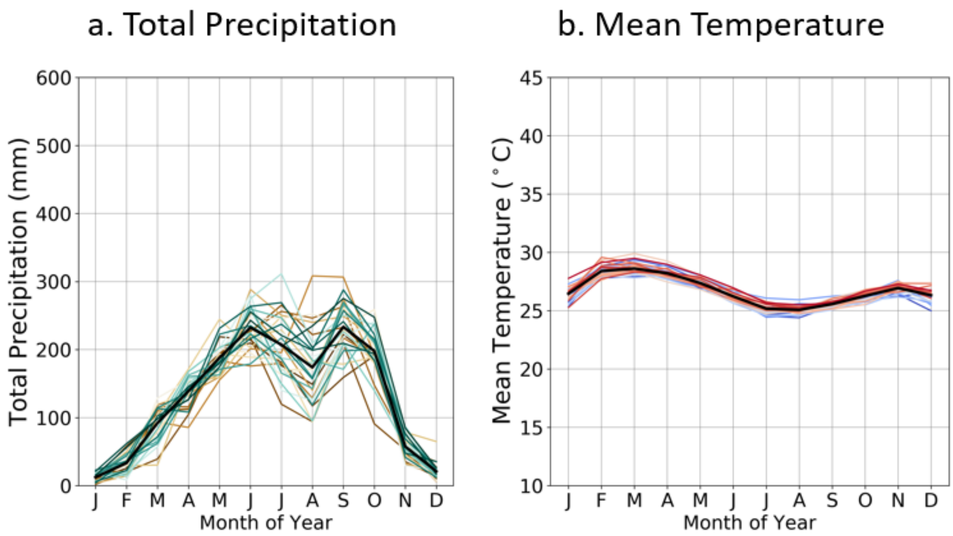


Figure 21: Observations for Zone 6 of a. total monthly precipitation from CHIRPS (Climate Hazards group Infrared Precipitation with Stations) dataset and b. average daily mean temperature from WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset, over the baseline period (1981-2010). Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, of a trend over the baseline period). The bold black line indicates the average of the 30-year period.

Future climate projections

Between the baseline period (1981-2010s) and the 2050s, the mean annual temperature is expected to rise by 1.5-3°C (Figure 22). The signal is different in different seasons, with less confidence (i.e. a larger range in the magnitude of projections) in the dry period December-February with a range of ~1.5-4°C, and to some extent in the March-June season too. Given the low seasonal and interannual variability in temperature commented on above, a temperature change of this magnitude will be very significant, taking temperatures outside the currently experienced range.

The seasonal pattern of dry and rainy season is not projected to change by the 2050s. However, there is existing high interannual variability and the complex rainy season distribution could change, although there is little consensus in the models as to the detail of this. Seasonally, for the December-January season, which is currently already very dry (<=50 mm/month of rain in both December and January), most models indicate no change in the amount of rainfall across the season. A wider spread in projections is seen in the other seasons with generally no consensus in the models on either sign or magnitude of change; although in October-November, more models show an increase than a decrease, and the majority of models indicating a range of 0-100 mm/season. In the literature there is high confidence in the rainy season onset being delayed in zone 6 (Kumi & Abiodun, 2018; IPCC, 2021) with increased variability from year to year, so although on average the rainy season will be shorter in the 2050s, in some years it will be longer.

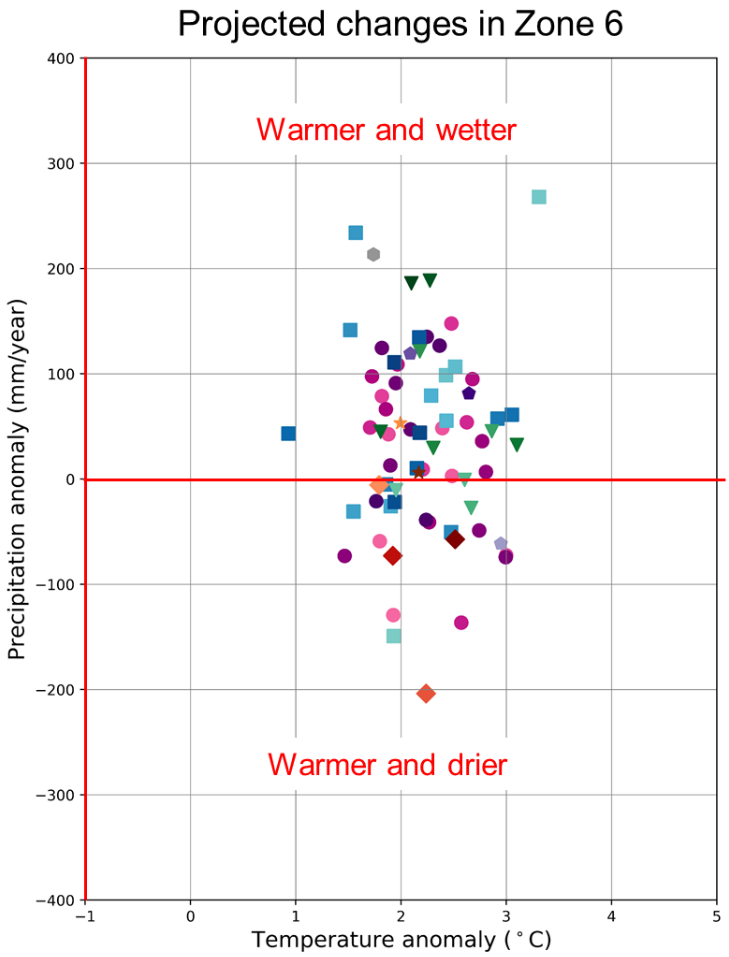


Figure 22: Projected change in average annual precipitation and temperature in Zone 6 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red lines indicate the zero axis i.e. no change in precipitation.

Maximum and minimum temperatures will increase in all seasons. There is high confidence that monthly average overnight minimums will stay below 30°C in the 2050s, with good consensus among the models. The number of extreme hot days will increase as the average temperature increases. But the year-to-year variability and extreme duration events are less noticeable in zone 5 and zone 6 than in the other zones. These are zones with very stable and narrow temperature ranges. These climates will shift to a warmer regime, but the temperature variability is not projected to increase. However, the projected temperature increase (1.5-3°C) will take the temperature experienced in this zone outside of the currently experienced range, so although year-to-year variability is low the overall increase is significant. Also, this is a zone with high humidity so what may be more moderate temperatures in the more northerly zones may still have impacts on human and livestock health and on ecosystems. It should be noted that monthly average values for the whole zone are not representative of conditions at a specific site or over a shorter time period, and there is high confidence that individual areas will see more extreme temperatures and precipitation totals.

Under RCP8.5 (worst case scenario), an increase in flood magnitudes by 2050 is projected for countries within the Niger river basin (Roudier et al., 2014; Aich et al., 2016; IPCC, 2021). There is also a significant increase in the median flood magnitude projected by 2050 for the Sessandra River (IPCC, 2021; Roudier et al., 2014). An increase in extreme peak flows and their duration is also projected for the Volta River basin by 2050, although there is low confidence in this due to limited evidence (IPCC, 2021; Jin et al., 2018). Changes in river flow (see Section 4.2) will also affect hydropower plants, such as the Kossou Dam in Côte d’Ivoire (Kouame et al., 2019).

Sea levels will rise along the coast of Zone 6, with relative sea level projected to increase on the order of 0.3m between the baseline period and the 2050s (IPCC, 2019, 2021; IPCC Interactive Atlas, 2021). There is also high confidence of an increase in coastal erosion, coastal flooding and shoreline retreat (IPCC, 2021, Vousdoukas et al., 2018, 2020). Sea surface temperature and ocean acidity are both projected to increase with high confidence around West Africa, which will change the environment of the marine ecosystem along the coast and offshore (IPCC Interactive Atlas, 2021).

The Guinea Current is significant for coastal activities in this zone, it is discussed further in Section 4.4.

Image location: Nigeria

4 Climate risk impacts and interpretation for the West Africa region

The following section will examine some of the key climate risks identified in this analysis for the West Africa region relevant to development themes. The themes analysed include water security; agricultural production and pastoral systems; urban environments and infrastructure; coastal regions; human health and mortality; and biodiversity and ecology. Each theme will be discussed in turn to identify and outline the most prominent climate risks for the West Africa region; however, there will be cases of overlap and compounding risk across the themes that should be taken into account.

4.1 Water security/resources

Summary of risks relevant to water security/resources

- **West Africa already faces challenges over water resources and water insecurity, and these will likely increase as changes in rainfall patterns and increased temperatures compound pressures already existing on water supplies. Water resource quality and quantity are both projected to decrease, which will have impacts on agriculture, human health and biodiversity.**
- **Groundwater reserves could offset risks from reduced or variable rainfall. However, as groundwater depletion increases from amplified withdrawals due to both increased climatic pressures and increased demand due to population growth, the efficiency of groundwater recharge will be vital, but needs to be better understood.**
- **The frequency and intensity of drought is likely to increase in West Africa, with an increase in consecutive dry days between rainfall events, with particular impacts on agriculture and water resources.**
- **Flood risk will increase as heavier rainfall events will become more frequent. Socio-economic losses from floods will likely increase, with the greatest risks being loss of life, loss of crops, contamination of water supplies, and damage to housing and infrastructure.**
- **Risks to rural water supplies will be elevated as rising temperatures increase evapotranspiration. Deforestation has already weakened the hydrological cycle at local and subregional levels, and further loss of forest cover will compound vulnerabilities over water availability.**

4.1.1 Water resources, storage and management

Water demand in West Africa is increasing and will continue to increase, due to rising demand from a rapidly growing population and likely increases in irrigated agriculture. The region is already water insecure, due to distribution, management and storage issues; variability in rainfall; and uneven access to water due to economic inequalities and poverty.

Over recent decades, West African precipitation has shown very high inter-annual variability with long-term fluctuations observed (Stanzel et al., 2018). Rainfall totals in the northeast (zone 2, northern Nigeria) have been increasing since the 1980s, and along with this, groundwater resources (Leduc et al., 2001). However, the coastal regions have experienced drying of over 50% during the 1951-2010 period (Niang et al., 2014; see section 3.1.2), and a drying trend has continued to be observed up until at least 2015 (IPCC Interactive Atlas, 2021). A shift in the timing of the rainy season has also been observed in this period, with decreases in rainfall in March to June and increases in September to November (Daron, 2014). The high variability in precipitation is correlated to variability in river discharge, although other factors affect this such as withdrawals, dams and deforestation. A decrease in the number of days of extreme rainfall, an increase in rainfall intensity, an increase in the duration of dry spells, and variation in dryness from year-to-year have all been observed (Dunning et al., 2018).

By the 2050s, more of the rain that falls will fall in intense precipitation events, while dry spells will be longer and more frequent (Wang et al., 2021). There is some indication in climate projections of a slight increase in total annual precipitation in the east and a decrease in the west, although these changes are small compared to the current very high interannual variability in West African rainfall, which is magnified by climate change and will remain high, or possibly increase in future.

In addition to these changes to rainfall patterns, there will be higher rates of evaporation and evapotranspiration due to higher temperatures. Precipitation and potential evapotranspiration are the main climatic drivers controlling freshwater resources (Jiménez Cisneros et al., 2014). How changes in these variables impact water resources depends on local conditions, specifically, the relationship between evapotranspiration, soil moisture and land use change.

These climatic impacts on terrestrial water storage will compound pressures already existing on water supplies due to rapid population growth and agricultural requirements. The risks are elevated by poor management of water resources in much of the region, with inadequate storage of water from rainy season downpours, run-off and from rivers. There are some key terrestrial water storage facilities, such as reservoirs, but these are not enough to meet the water requirements of the whole population. At present an estimated 40% of West Africa's population have inadequate access to clean drinking water and 60% lack adequate water for sanitation. We can anticipate these disparities in access to water increasing with climate stress unless remedial measures are taken by governments and donors.

There is a risk the region could see increased diversion of water from rivers and streams to supply urban and rural areas with drinking water and to support agri-business. The sustainability of such diversions should be assessed, both in terms of the long-term viability of such a strategy in conditions of increased temperatures and uncertain rainfall, and population pressure. Over-extraction of water from rivers would impact riverine ecologies and harm biodiversity and affect some of the livelihoods dependent on rivers, such as fishing and local agriculture.

There is high confidence that water resource quality and quantity will reduce in West Africa by the 2050s affecting agriculture (Section 4.2), human health (Section 4.5) and biodiversity (Section 4.6). Predicting specific impacts on the availability, reliability and quality of water resources and water-dependent services remains challenging. This is partly because of the difficulties of downscaling climate models to the local level where planning decisions are made, but also due to the challenge of attribution. Untangling the climate signal from the many other drivers of change affecting water resources and services is challenging, particularly given the lack of observational data required to establish baselines and project impacts. This would therefore require a dedicated study.

Substantial decreases in run off and stream flow for both the Senegal and Gambia river basins are projected by the 2050s (Boudian et al., 2018; Stanzel et al., 2018; Sylla et al., 2018), which will affect the efficiency of the Félou Hydroelectric Plant which provides power to Senegal. Some studies indicate average to below average flows in the Mono Basin and the lower Volta Basin (Ghana, Togo, and Benin in zones 4 and 6), which could lead to a decrease in the availability of water resources for local users. With projections of increasing precipitation, Lake Chad (zone 2) is projected to continue to recover in terms of water availability (see Focus Box 7), though the impact of human activities, such as land use change or irrigation withdrawal in the Lake Chad Basin e.g. in the Komadugu-Yobe Basin (Adeyeri et al., 2020) may have a larger impact. Impacts on groundwater storage are further explored in section 4.1.2 below. The challenges posed on water resources by climate change in conjunction with changing demands highlights the need for better water storage to mitigate changes in water availability from existing water sources.

The low number of dams in West Africa is currently a constraint on water storage and supplies. There are some important dams in West Africa and there is potential, not yet realised, for many mini-hydropower plants that would both supply clean energy to countries in the region and improve water security and access. The current dams are insufficient to meet overall existing demands for water and electricity, but they have an important role where they do exist, for instance an estimated 27% of electricity in the Côte d'Ivoire is from hydroelectric plants. Key existing hydropower plants include: Soubre, Tabbo, and Kossou dams in Côte d'Ivoire; Akosombo, Bui Dam and Kpong hydroelectric power plants in Ghana; Kaleta and Souapiti hydropower plants in Guinea; Kainji Dam in Nigeria; Maka-Diama Dam and Manantali Dam on the Senegal River; Mount Coffee hydropower plant in Liberia; and the Bumbuna hydro plant in Sierra Leone.

The surface temperature of inland water bodies, such as rivers and lakes, will increase in response to the increase in atmospheric temperature, increasing evaporation, and with corresponding impacts on water quality, aquatic habitats and fisheries.

4.1.2 Groundwater (aquifers)

Groundwater sustainability depends on the level of the existing reserve as well as recharge rate through rainfall, with groundwater in higher rainfall areas replenishing more easily during the rainy season. Impacts on groundwater conditions are difficult to predict, although a growing body of evidence highlights the importance of episodic groundwater recharge from heavy rainfall events. An increase in the frequency and intensity of heavy rainfall events could therefore benefit groundwater recharge and storage.

There are large groundwater reserves in most of West Africa, and this deep underground water is largest in the semi-arid areas of West Africa (Macdonald et al., 2012) such as in Senegal (zone 1 and zone 3), which is the country projected to be most impacted by reductions in rainfall due to climate change. Groundwater reserves may therefore become more important as climate change intensifies, and possibly offset some of the risks from reduced or variable rainfall by helping countries supply drinking water to their populations from bore holes. However, drilling deep into underground aquifers is likely to be unsustainable if it does not replenish, because much of the stored water is from geologically wetter periods occurring during the early Holocene 11,000- 5000 years ago (de Menocal and Tierney, 2012).

Climate variability and drought lead to groundwater depletion due to amplified groundwater withdrawals (IPCC AR6, Ch 8). This will be felt in all zones regardless of the projected change in precipitation totals, as even in zones where total annual precipitation increases the increasing number of intense rainfall events may make it less available for human use, depending on other factors such as land use. Urban growth in recent decades has further increased pressure on groundwater resources (Nlend et al., 2018). Throughout West Africa, groundwater reserves often cross political borders, which presents additional considerations around the management of this resource. Some of the arid areas of West Africa have vast quantities of water in their aquifers - from geologically wetter periods. However, much of this is very deep underground (some bore holes in Niger are reportedly around 800 metres in depth). Saltwater intrusion into freshwater aquifers is already occurring in coastal areas of West Africa due to sea level rise (Ohwoghere-Asuma and Essi, 2017), and will be exacerbated in future as sea levels continue to rise (see Section 4.4.1).

4.1.3 Drought

IPCC AR6 (2021) has strong confidence in an increase in meteorological droughts across West Africa on a seasonal timescale, with consecutive dry days (CDD) increasing from March-August (Dosio et al., 2020). IPCC AR6 states that frequency and intensity of drought is likely to increase in West Africa under 1.5°C and 2°C global warming levels and RCP4.5 and RCP8.5 scenarios, with zones 5, 2 and 1 (on the west coast) and the west of zone 3 and zone 6 most severely affected (see section 3.1.3). Zones 1, 3, 5 and 6 to the west and south of the region, are projected to have more dry days per year and a moderate increase in daily precipitation intensity. Zones 2 and 4 in the east of the region, are projected to have fewer dry days per year and a significant increase in daily precipitation intensity. There is also high confidence in increased drought frequency and magnitude in the Niger and Volta River basins (Oguntunde et al., 2020).

The projected risk of reduced rainfall in zone 1 (Senegambia) indicates a heightened risk of meteorological drought there. The drought risks elsewhere are less likely to be from decreases in total precipitation and more likely to be from agricultural drought where the distribution of rainfall is uneven across the rainy season. Interruptions to rainfall during the rainy season can destroy some varieties of crops after they have been planted. If after the onset of rain there is a period of one or two weeks or a month without rain, followed by heavy rain, this can also affect water storage and distribution, as water scarcity is proceeded by flooding, where only a fraction of water from heavy rainfall events is stored compared to if rainfall is more gradual. Meteorological drought could result in migration out of some areas, with the duration and scale of out-migration depending on the severity and length of the drought. Agricultural drought and erratic rainfall would negatively impact agricultural and pastoral production, but adaptations may be possible (see section 4.2).

4.1.4 Increased risks of flooding

In the 2050s, heavier rainfall events will become more common and will contribute to flood risk. As exposure to floods increases, socio-economic losses will increase, with loss of life, livelihoods and damage to infrastructure. Flood risk is not evenly distributed but is highly dependent on local geography, with higher risk in urban areas, where more rainfall is channelled into runoff by urban materials (see section 4.3.1). In addition, sea level rise and increases in storm surge will cause increases in occurrence and severity of coastal flooding both in urban areas (see section 4.3.2) and rural areas (see section 4.4.1).

There is high confidence that upward trends in hydrological extremes, such as maximum peak discharge, have occurred in West African rivers since 1980, and have caused increased flood events in the Niger, Senegal and Volta (Nka et al., 2015; Aich et al., 2016; Wilcox et al., 2018; Tramblay et al., 2020). An increase in flood magnitudes is projected for the Niger river basin and the Sessandra (Aich et al., 2016; IPCC, 2021; Roudier et al., 2014). An increase in extreme peak flows and their duration is also projected for the Volta River basin, although there is low confidence in this due to limited evidence (IPCC 2021; Jin et al., 2018). For The Gambia and Senegal, the projected risk of flood decreases under several emission scenarios (Roudier et al., 2014, Boudian et al., 2018; Stanzel et al., 2018; Sylla et al., 2018).

Combined with land use changes, climate change will increase the frequency of all types of flooding and associated erosion by the 2050s. Risk is highly related to land use within the basin and the response of vegetation to flood regimes (Hiernaux et al., 2021; Hassan et al., 2020; Aich et al, 2016). More intense precipitation onto drier soils will see an increase in run off and frequency of pluvial flooding, this will cause large, short term increases in river flow increasing the frequency of fluvial floods.

4.1.5 Deforestation and water storage

The greatest biophysical impact on water supplies and storage may be from temperature increases resulting in increased evapotranspiration. The impact of rising temperatures will be exacerbated because the hydrological cycle has already been greatly disturbed by massive deforestation. Forests continue to be cleared at an alarming rate across West Africa which, when combined with increased evapotranspiration, will reduce water supplies, as forests are known to play a key role in local and sub-regional water cycles. Further losses of forest cover will compound water supply vulnerabilities and could reduce rainfall and water availability at local and subregional levels, as hydrological cycles are further weakened. In policy terms, this indicates the need to combine biodiversity conservation and climate change adaptation (see Section 4.6).

Focus Box 7: Lake Chad

Lake Chad is located in the Sahelian zone of west-central Africa, at the conjunction of Chad, Cameroon, Nigeria and Niger (zone 2). The lake provides food and water to ~50 million people and supports unique ecosystems and biodiversity (Pham-Duc, et al., 2020). Lake Chad, once the sixth largest lake in the world, decreased in area by more than 90% between the 1960s and 1980s (Gao et al., 2011). In recent decades it has become a symbol of climate change, signified by its dramatic 'shrinking' – although narratives of a 'disappearing' lake have been widely critiqued (e.g., Magrin, 2016; Vivekananda et al., 2019). While some studies link precipitation and temperature variations to changing river flows into the lake (e.g., Coe and Foley 2001; Nour et al., 2021), others identify irrigation withdrawals as the major cause of recent low river flow and the lake's minimal recovery since the 1970s-80s (Zhu et al., 2019).

The lake's unique shape and depth, which enables its division into two smaller lakes, further increased its vulnerability to water loss (Gao et al., 2011). The lake saw a partial recovery in response to increased Sahelian precipitation in the 1990s but still faces great uncertainty on its current variability under climate change. However, since the 1990s the lake's total surface area has been relatively stable and in recent years it has expanded to a total area (including open water and water under vegetation) of ~12,000 km^2, despite a slight decrease in the northern pool (GIZ and LCBC, 2013; Lemoalle and Magrin, 2014; LIS, 2020; Pham-Duc et al., 2020; Vivekananda et al., 2019). Since the 2000s, groundwater, which contributes to ~70% of the lake's annual water storage change, is increasing due to water supply provided by its two main tributaries (Pham-Duc et al., 2020; Vivekananda et al., 2019). Pham-Duc et al. (2020) conclude that Lake Chad has not been shrinking over recent decades and the lake recovers seasonally its surface water extent and volume and remains relatively stable.

Rainfall levels have increased across the Lake Chad basin since the 1990s (Adeyeri et al., 2019, 2020; Okonkwo et al., 2014; Zhu et al., 2019). However, this could change with future climate change in the region with increasing mean temperatures and variable rainfall. Nonetheless, the lake remains much smaller in area than it originally was, and Gao et al. (2011) conclude that under current climate and water use, a full recovery of the lake is unlikely. In response to the 'shrinking' of Lake Chad, regional actors have proposed an inter-basin water transfer to 'refill' Lake Chad to channel water from the Oubangui River in the Congo Basin to the Chari River and Lake Chad (Adeniran and Daniell 2020). However, the project has been criticised for its potentially limited effects on lake levels (especially given its current stability), potential ecological and livelihood destruction, security concerns, and cost (CIMA International, 2011; Magrin, 2014; Sayan et al., 2020).

Fisheries, agriculture, livestock production and other goods and services provided by the Lake Chad Basin, have been undergoing a steady decline since the 1970s due to the major environmental changes resulting from climate change and human stream-flow modifications (UNEP-GIWA, 2004). Increased evapotranspiration with increasing temperatures with climate change affects the lake's water quality and temperature, with knock-on effects to the immune function of fish (FAO, 2012), rates of bacterial infections in aquaculture systems (Wedemeyer, 1996), and presence of certain fish pathogens and transmission rates of certain parasites (Roessig et al., 2004). Parasitism and disease outbreaks can cause increased fish mortality, slower growth rates and lower marketability and economic returns of fish (Harvel et al., 2002).

Impacts on fish biodiversity will also have serious consequences for livelihoods and wellbeing of the communities dependent upon fisheries. However, communities around Lake Chad have engaged in long-standing forms of adaptation to environmental changes, including changing lake levels and flood patterns, including shifting between farming (including flood recession cultivation), pastoral, and fishing activities (Magrin and Pérouse de Montclos, 2018; Okpara et al., 2015; Rangé and Abdourahamani, 2014).

Furthermore, ongoing insecurity and military responses in the Lake Chad region (and not only environmental change) have significantly affected agricultural, pastoral, and fishing livelihoods. In Niger and Chad, emergency measures imposed since 2015 as part of military operations against Boko Haram include restrictions on crop planting, fishing, herding, and other movement, on forms of everyday transport, and on access to fields, fishing areas, and markets (Magrin and Pérouse de Montclos, 2018; van Lookeren Campagne and Begum, 2017).

4.2 Agricultural production and pastoral systems

<u>Summary of risks relevant to agricultural production and pastoral systems</u>

- **Crops are grown in all ecological zones of West Africa (outside desert areas) and farming is essential to food security throughout the region.**
- **Climate change will alter agro-ecology, favouring crops that can tolerate higher temperatures and fluctuations in rainfall. This will negatively impact some of the main crops currently grown in the region, reducing yields in crops such as maize.**
- **Competition for water will increase, particularly in areas where irrigated farming practices are or could be undertaken.**
- **The viability of irrigation schemes will vary and will be limited in places where river flow volumes and surface water are reduced by decreases in rainfall, higher temperatures, and increased demand from growing populations.**
- **Ecological degradation and biodiversity loss will reduce crop yields, creating a negative feedback loop that will be exacerbated by higher temperatures.**
- **Pastoralism and livestock are important for food security and rural economies in most of West Africa. They will be impacted as higher temperatures cause heat stress, decreased biomass, reduced pasture, and increased evaporation of water sources, exacerbating existing problems of grazing land being lost to cultivation and potentially raising farmer-herder tensions.**
- **Adaptation will likely revolve around the selection of crop varieties and species that can cope with elevated temperatures and increased rainfall variability, with indigenous crops likely to become more important.**

4.2.1 Risks to agricultural productivity and livelihoods

West African farmers already respond to inter-annual variations in rainfall and to periods of drought by adjusting their cropping systems. The question is whether the new conditions brought on by climate change will be within the limits of adaptability for the population, especially given rapidly increasing demographic pressure and already reduced availability of land.

Historically there has been a low level of state investment in agriculture, and farmers tend to have limited access to capital, therefore intensification is lacking and pressure on land continues to grow as more areas are cleared for agriculture. Climate risks to livelihoods and security will be higher where crop and livestock rearing are in competition rather than integrated. A further land degradation impact associated with the pressure on land is the reduction or loss of fallow periods. Fallow is where land is left uncultivated for several years to regenerate its fertility. Loss of fallow land is a constraint on agro-pastoral systems, as it is often used for livestock grazing.

Crops are grown in all ecological zones of West Africa outside desert areas, and farming is essential to food security across the region. Agricultural production systems in West Africa are adapted to specific ecological conditions, to the environmental requirements of different crops, and to socio-cultural and economic dynamics.

Crops tend to be selected for current environmental conditions, factoring in interannual variation in the eco-climatic areas they are grown in; therefore, the large increases in temperatures that are projected for the region will be significantly above the optimal temperatures for many crops. Rising temperatures will be a particular issue for crop yields in the north of the region (zones 1 and 2) where projected increases will result in critical temperature thresholds being exceed earlier and for longer periods. Crops such as maize, which is less heat and drought resistant than millet and sorghum, will be less viable as temperature increases will reduce crop yields. Millet is better adapted to hotter and drought prone conditions and less reliant on chemical fertiliser and can grow in nutrient poor soils.

4.2.2 Agricultural risks associated with rainfall projections

Most farming in West Africa is rain-fed; however, irrigated farming is especially important in some areas, especially along rivers and where there are other water sources.

A delay in the onset of rains by a few days is insignificant, however, if delays extend to weeks or more it critically impacts the crop cycle and the timing of harvests. Some of the problems associated with delays to the start of the rainy season can be counteracted if the rains continue for longer (as was observed in parts of central Nigeria in 2021, for example). This would still enable long-cycle crops to be grown (crops that need longer to grow and ripen) and consequently may give higher and more nutritious yields, or at least higher biomass (which includes straw used as animal feed), compared to short-cycle crops which are better suited to lower rainfall totals and shorter rains. In savannah and semi-arid zones, the late onset of the rains may be compensated for by prolongation of rains at the end of the monsoon as indicated in some regions of West Africa in the literature (Kumi & Abiodun, 2018). There is a pronounced impact on agricultural yield from a shorter duration rainy season, this risk is projected to be highest in zone 1, in Senegambia.

In general, an even distribution of rainfall through the rainy season is optimal for most crops. Interruptions and fluctuations in rain after the onset of the rains, with heavy downpours – which can produce flooding – followed by days or weeks with no rain, impacts many crop species and varieties and reduces yields. Our climate analysis indicates that there will be an increase in dry spells and intense downpours within the rainy season.

The frequency and intensity of heavy precipitation events is projected to increase in West Africa as the climate warms. Heavy rainfall events can cause damage to crops, and the increased risk of flooding and waterlogging of soils will result in crop losses, soil degradation, displacement of livestock, and in severe floods, livestock deaths. Flooding is compounded by deforestation, and the acceleration of already high levels of soil erosion and land degradation across the region will have negative impacts on future agricultural productivity. The waterlogging of soils after prolonged and heavy rainfall, even when flooding is not severe, can still damage many varieties of crops. Crops have different levels of tolerance to waterlogging – some are intolerant, but others can survive (see Appendix C).

The risks presented by increased variability of rainfall are compounded by the degradation of ecosystems in West Africa associated with deforestation and biodiversity loss, which affects the watersheds of rivers, renders them more prone to drying and flooding, and reduces soil fertility. This is because forests moderate the flow of water, generate precipitation, while biodiversity protects and enriches soils and enables the pollination of crops. Additionally, the destruction of mangroves in coastal areas renders coastal agriculture, such as rice cultivation, more susceptible to sea water inundation. The compound impact of climate change on West Africa's ecosystems, will lead to further negative impacts on agriculture. Ecological degradation and biodiversity loss associated with climate change will reduce crop yields, creating a negative feedback loop that will be exacerbated by higher temperatures.

4.2.3 Agricultural risks associated with drought and competition for water

Drought frequency and intensity are expected to increase across the region. Without adaptations, temperature increases could limit the water available to crops in much of the region. The extent to which the agro-ecology changes will need to be monitored, as will the impacts this has on yields, production and food security. The north of West Africa analysed in zones 1 and 2 is already vulnerable to drought, and drought risk will increase in zone 1 so that by the 2050s, food insecurity in these zones will increase.

There is some indication from a minority of climate models that a severe reduction in annual rainfall totals may be seen along the coast of the Gulf of Guinea by the 2050s (zones 5 and 6). Although this signal has very low confidence, the impacts of such a change would be severe and so may need to be considered in development planning. Reductions in rainfall in these zones, with their tropical forests and tropical crops, would have severe negative impacts on agriculture, biodiversity, and ecology. Reduced precipitation would damage crops that grow under tropical conditions, requiring high levels of rainfall over a long rainy season. It would also impact forest ecology, and therefore biodiversity, with direct negative consequences for the pollination of crops as insect populations are reduced, subsequently decreasing crop yields.

To a large extent, changes in soil moisture follow the same trends as precipitation, although varying evapotranspiration is also a factor. Soil moisture is projected to decline in the west and south of the region (zones 1, 3, 5; high confidence) and increase in the northeast (zone 2; low confidence) for mid- and high-emissions scenarios (IPCC, 2021). Changes in soil moisture are an important consideration for ecological and agricultural drought, which will reduce the yields of crops that require more water and require a switch to crops that are more tolerant to the increased aridity.

Competition for water will increase, particularly in areas where irrigated farming is possible. Irrigated farming is practised across all West Africa but is especially important in areas with a long dry season: zones 1 and 2 in the north and parts of zones 3 and 4 in the central region of West Africa. Irrigation is particularly important for horticulture. Irrigated farming is less dependent on local rainfall variability unless the variability impacts the flow of rivers and streams and the recharge of ponds and lakes. Currently, it is a productive and profitable economic activity, with dry season farming and horticulture providing fruit and vegetables to markets and urban centres. The viability of irrigation schemes will vary and will be limited in places where river flow volumes and surface water are reduced by decreases in rainfall, higher temperatures, and increased demand from growing populations.

Demand for food from the growing population will incentivise dry season agriculture, which will result in increased competition for agricultural land which has the potential for irrigation. However, the area in which dry season irrigated farming is viable may decrease. Demographic pressure on rural water supplies will increase and be further strained by the extraction and diversion of water for irrigated agriculture. This will affect cash crops requiring more water, such as groundnuts and cotton, and limit the range of horticulture and dry season cereal production (see also section 4.1).

4.2.4 Risks to pastoralists livelihoods

Pastoralism and livestock are important for food security and rural economies in most of West Africa. The impacts of higher temperatures and more variable precipitation will be felt by pastoralists through increased livestock heat stress, dehydration and death. The availability of suitable grasses, browse (from trees and shrubs), water and minerals will decrease which will affect livestock nutrition. The volume of drinking water required by domestic livestock will increase as temperatures rise, which may increase competition for water (Toulmin, 2010: 59). This will be most pronounced where rainfall decreases, as is projected in Senegal for example.

Higher temperature predicted across West Africa also means loss of soil moisture and consequential replacement of perennial grasses with short-cycle annual grasses as aridity increases (Toulmin, 2010: 60). Some of the short-cycle annual grasses are nutritious for livestock, but grow for a shorter period, meaning animals must move between pastures. This favours mobile pastoralism and transhumance over sedentary livestock rearing; however, the regional trend in policy is towards the settlement of pastoralists.

In principle, the mobility of pastoralists is an adaptation strategy, enabling them to respond to irregular rainfall, as they migrate to available pasture and water. This livelihood strategy is adapted to respond to patchy and seasonally variable vegetation and water, between wet and dry seasons and within each season, if there is suitable land to migrate to. Migration constraints include pressure on land, competition with farmers and other herders for access to land and water, as well from the impacts of rapid population growth and the political economy of land, which often does not recognise pastoral rights. The reduction in grazing land has become particularly acute over the last ten years and the problem is intensifying each year as demographic pressure increases.

There is also potential for increased conflict as farmers and pastoralists fight for control over land. Disputes may arise over the destruction of crops by livestock, or the blockage of transhumance routes and cultivation of grazing land. This is already happening throughout the region, and demographic and climate pressures will exacerbate the problem.

The livestock that West African pastoralists raise are adapted to the ecological conditions of the areas that they migrate through and graze in. Movement and relocation between contrasting ecologies must be done slowly, over a period of years, to enable the animals to adjust to the new ecology and avoid disease outbreaks, or to interbreed with local stock in the new location. Goats, sheep and camels are better evolved to cope than cattle, but there is also significant variation in the adaption of different cattle breeds to the varied conditions of the semi-arid, savannah and sub-humid areas of West Africa. Changes in the distribution of livestock and pastoralists in response to climate change may occur but will need to be gradual and will be driven by socio-political as well as ecological factors.

Over the past three decades there has been a process of ‘migratory drift’ (Stenning, 1959) from north to south in much of West Africa, the biomass in the sub-humid zone (zones 3, 4, 5) is productive and herders have found ways to protect their livestock against diseases that previously limited their ability to graze there. This has led to the spread of pastoralism, as some herders relocate southwards, but others remain in semi-arid areas. Increasingly there is also an eastwards movement of pastoralists from West Africa (especially Nigeria) into Central Africa, where the population density is much lower. This trend will also increase in the coming decades, with the projected drying in the west of the region and potential for higher annual rainfall totals to the east and will increase ecological pressures on savannah environments and forests of central Africa.

Intensification of production on a more sedentary basis is increasingly occurring as a pastoralist adaptation in West Africa, using animal feed in the dry season to sustain livestock. This is limited by a lack of suitable land available for ranch type systems. Further, in semi-arid areas of West Africa the dry season is long (ranging from about 7-9 months) and in the rainy season pastures are not usually sufficient in a fixed area, requiring mobility between pastures. Sedentarisation therefore tends to lead to sharp reductions in livestock numbers and will require a higher degree of integration with crop farming to succeed, so that livestock and crops can be rotated. Projected changes in climate, including increasing temperatures and changes in rainfall variability which may delay and shorten rainy seasons and intensify drought, has the potential to put sedentary pastoralisation at risk.

Another trend which may be exacerbated by the increased pressure on land and water supplies due to climate change, is for pastoralists to sell their livestock and look for alternative livelihoods. Due to the high market value of cattle, pastoralists inject large amounts of money into rural economies through the buying and selling of cattle, and through their purchase of grains and other foodstuffs on which they depend. If cattle and sheep reduce in number, as a per capita ratio to the human population, there will be less (and more expensive) milk and meat available in rural areas.

Risks to pastoralists will vary depending on local climatic conditions and how this combines with local politics and land rights, the degree of mobility, the level of cooperation and integration with crop farmers, and investments in planting nutritious and resilient grasses and trees on degraded soils. The risks pastoralists face from climate change will amplify current vulnerabilities over access to land, shrinking herds in many areas, and limiting diversification options.

Focus box 8: Gender and social vulnerability to climate change

Women and girls usually have responsibility for fetching water, from wells, bore holes and streams, and in more arid areas of the region in the dry season they often have to walk long distances to collect water, as head loads or on pack animals like donkeys. Increased incidence of drought and water stress could increase this labour burden on female members of households.

Household incomes and subsistence capacities would be reduced by crop or livestock losses, increasing food insecurity and poverty and pushing more people into non-farming areas of the labour market, for example into casual dry season labour. Loss of household income from climate shocks to agricultural and pastoral systems would pose direct risks to maternal and child health.

The social vulnerability of uneducated people to climate change is generally higher due to reduced adaptive capacity, and gender disparities in education in the region – higher in some areas than others - make economic adaptations more difficult for women and girls in those areas. For example, there are strong disparities in education between northern and southern Nigeria, and the access for girls to formal education is lower than for boys. The North reportedly now has the highest number of out of school children in the world, whereas the South has literacy levels well over 70% in many states, and generally high levels of school enrolment (Demographic and Health Survey for Nigeria, 2018). In general, the coastal areas of West Africa are more educationally advanced in terms of modern education than the semi-arid areas to the north. Under a changing climate women and girls may be increasingly vulnerable due to a reduce adaptive capacity from lower education.

4.3 Urban environments and infrastructure

Summary of risks relevant to urban environments and infrastructure

- **Urban heat Island Effects will place increasing pressure on urban infrastructure and expose urban populations to increased risk of heat stress.**
- **Increase frequency of heavy rainfall coupled with a hardening of the urban environment and inadequate infrastructure to deal with high quantities of water, mean that that the regions urban areas are likely to face an increased risk of flooding.**
- **A rise in sea level will expose both urban populations and infrastructure to an increased risk of flooding and storm surges.**
- **Access to clean water is not only being undermined by urban population growth but also contamination through flooding.**

4.3.1 Risks from extreme heat and flooding in urban centres

The effects of significant increases in temperature projected for West Africa, with a large increase in the number of days above 40°C in zones 1 and 2 and parts of 3 and 4, will be compounded in cities by Urban Heat Island (UHI) effects (See section 3.3.4.2). In urban areas the impacts of increased temperatures are exacerbated by the urban setting itself, as the large thermal mass of buildings reduces the diurnal temperature range by trapping daytime heat and releasing it slowly overnight. The UHI effect means that cities are often 2-3°C warmer than the surrounding area (IPCC, 2021). High levels of warming, which are further exacerbated in urban areas, could have major impacts on infrastructure, such as electric power reliability (including inhibiting solar photovoltaic efficiency) and transport networks (e.g., buckling railways, roads and runways).

The rate of urbanisation has not been matched with adequate infrastructure within cities. Growing urban areas can lack adequate housing, with informal settlements growing in some locations (The World Bank, 2015). Most modern buildings in West Africa are constructed without sufficient attention to heat efficiency and cooling. The use of concrete is prevalent, which absorbs heat. Infrastructure, including concrete buildings, will crack and weather more quickly under elevated temperatures, and more buildings will become too hot to tolerate. Traditional building techniques and materials, such as the use of mud bricks and with architecture designed to ventilate, may increase as an adaptation strategy. At the same time, more efficient modern building techniques and materials might be increasingly promoted, with potential economic opportunities.

Access to basic services, such as water, sanitation, and electricity, can be limited. For example, in Côte D'Ivoire 50% of those living in urban areas were not connected to the national electricity grid (The World Bank, 2015). In Conakry, Guinea, access to basic services lags behind other sub-Saharan African countries (The World Bank, 2018). This increases risk to habitability, health and infrastructure. The urban poor do not have air conditioning, and more seriously a large percentage have only erratic power supply, therefore even electrical fans may not work. Deaths related to heat stress, which can be attributed to cardiovascular and respiratory disease, are already being recorded in the region (USAID, 2018). (See section 4.5.3).

There is a risk that heat stress will be compounded by water shortages, and the need for drinking water will increase as temperatures rise and as populations continue to grow. Increasing temperatures will also exacerbate air pollution, as heat traps pollutants and in some topographical and atmospheric conditions creates smog. Temperature increases are projected to be very marked in coastal areas, where most of West Africa's capital cities are located, but less severe than inland. However, coastal cities are far more humid, and as high temperatures combine with high humidity the coastal cities will feel very hot indeed even if temperatures are lower than in the savannah cities which typically have a dry heat (see section 4.5).

The impact of flooding will depend on changes to rainfall patterns and infrastructure. Areas currently prone to flooding could experience more severe flooding events in future. Urban areas will be at greater risk from heavy rainfall events (e.g. flash floods), especially if they lack the infrastructure to deal with increased rainfall and runoff. Non-climate resilient storm and wastewater systems, combined with loss of green urban spaces, increase the risk of urban flooding during heavy rains. Those at particular risk live in informal settlements which suffer from both high exposure and vulnerability to hazards due to their locations and lack of infrastructure.

4.3.2 Sea-level rise (urban)

The concentration of infrastructure, economic activity and people along the West African coastline, mean that the impacts of sea level rise (SLR) could be significant for urban areas. Most of West Africa's largest cities are coastal and low-lying and would be susceptible to flooding and inundation by sea water, depending on the scale of SLR. At 0.3 metres SLR (30 cm, 12 inches), a median of 65 metres of beaches and coastal land along the West African coast is projected to be lost to inundation by 2050 (IPCC, 2021; Vousdoukas et al., 2020; Focus box 9). Compound effects will be especially important as the combination of SLR, increasing risk of coastal storms (low confidence) and storm surges may cause extreme sea level events (high confidence) and lead to damage to both natural and man-made coastal defences. SLR is also highly likely to cause greater frequency of saltwater intrusion into coastal aquifers, which can corrode construction materials and when combined with urbanisation is causing groundwater level rise leading to flooding both on the coast and at inland locations with close proximity to affected aquifers (see section 4.4)

Sea reclamation developments could be directly at risk, or alternatively they could be viewed as models for maintaining cities in the face of sea level rise. Eko Atlantic, a large urban development in Lagos, Nigeria, being built on reclaimed land along 8.4 km of coast, has 18-metre-high flood defences to protect the high-cost real estate of Eko Atlantic. The sea wall reportedly protects some areas of Lagos from flooding (especially Eko Atlantic) but at the same time it increases the vulnerability and coastal erosion of parts of the city around and outside the wall, as it produces currents (BBC, 'How Africa's Largest City is Staying Afloat', Future Planet, 21 January 2021). There are areas of Lagos that are built on stilts in the creeks – notably Makoko, a low-income area, where transport is by boat. Such a strategy may be required for adaptation in more areas of Lagos and other West African cities under sea level rise projections (see section 4.4).

Further analysis of coastal topography is needed to understand the specific susceptibilities of different cities along the West African coast to inundation by the sea. SLR also increases the risks and exposure of coastal cities during storms and strong winds. Cities with estuaries will be even more vulnerable to flooding and inundation. This includes Saint-Louis (Ndar), in northern Senegal. The Island of Saint-Louis has been a UNESCO World Heritage Site since 2000. It is surrounded by tidal marshes where the river overflows during the rainy season. SLR threatens the city centre and historic areas of Saint-Louis. To the south, Banjul, the Gambian capital, is situated at the mouth of the River Gambia. Estuaries such as these and of the rivers Saloum and Casamance are also important ecosystems, with biodiverse habitats and mangroves. The risk of urban areas flooding may be partly mitigated by good management of the estuaries and rivers, for example protecting mangrove forests (see section 4.6).

4.3.3 Access to safe water in urban areas

The increasing rate of urbanisation in the region puts pressure on urban water supplies (OECD, 2021). Those living in disadvantaged or informal settlements are most at risk from water shortages, due to poor infrastructure and lack of pipe borne water, and often find themselves relying on an unregulated informal water sector (Ainuson, 2010). High population density around rivers and dams can result in contamination of underlying groundwater through the disposal of waste (Pare and Bonzi-Coulibaly, 2013). The challenge of equitable access to potable (safe) water and sanitation is often associated with poor management rather than availability. For example, in Freetown, Sierra Leone, the availability of fresh water for households competes with industrial uses and food production (Kanasal and Amara, 2018).

Urban areas are expanding geographically and demographically in West Africa. Demand for water is therefore increasing in urban areas and will continue to do so over the next three decades, especially if the population doubles as is forecast (UN Population Division, 2019 – see box below). Therefore, the volume of water available to urban areas and its supply and distribution will all need to increase. This will be most challenging in cities that see reductions in rainfall associated with climate change, but even where rainfall is sustained the pressures will increase due to population growth. The people most at risk from water shortages will be those in informal settlements with weak infrastructure and lack of pipe borne water, which applies to large areas of most West African cities.

In coastal cities contamination of groundwater and surface water due to sea level rise (SLR) will be a risk. The severity of the risk to drinking water will depend on the exact scale of SLR and on the topography and settlement patterns of specific cities. Coastal defences and the ability to tap reservoirs that are safe from SLR will be determinant. The other very real risk of contamination of water supplies comes from increased flooding, which is a threat to urban and rural areas due to the projected changes in rainfall – with heavier bursts of rain becoming more likely –, exacerbated by land use change, for example if forests and trees continue to be cut down in water basins. Furthermore, with just a few exceptions (such as central Abuja, Nigeria and specific neighbourhoods in other cities) green spaces and trees in West African cities are relatively few, forming a low percentage of the overall surface area, which is dominated by buildings, concrete and tarmac. Combined with inadequate drainage in many neighbourhoods this makes them prone to flooding during heavy or prolonged rainfall. In principle, urban spaces could be adapted to mitigate against such risks and to improve water storage and urban ecology, such as by planting more trees and improving drainage, but investment and good planning would be required.

4.4 Coastal regions

<u>Summary of risks relevant to coastal regions</u>

- **Sea level rise along the West African coast will impact coastal settlements through inundation, shoreline retreat and loss of beaches. Low-lying villages and settlements may require relocation further inland.**
- **Saltwater intrusion of coastal aquifers may be further exacerbated due to sea level rise, which can negatively affect water supplies.**
- **West African fisheries are already under threat due to overexploitation. Climate change will further negatively impact fish stocks as ocean temperature, acidity and deoxygenation all increase.**

4.4.1 Sea-level rise – risks to islands and coastlines (non-urban)

Sea levels along the West African coastline have been rising and will continue to rise, with relative sea level projected to increase on the order of 0.3 m between the baseline period and the 2050s (IPCC, 2019, 2021). The risk from sea level rise is acute, especially given the uncertainty margins around how large sea level rise will be (with possible feedback impacts from accelerating polar and glacial melting, see Focus Box 9). A projected 0.3 metres (30 cm) sea level rise will impact coastal settlements through loss of beaches and inundation of low-lying areas. A median shoreline retreat of 65m is projected for the West African coastline, with this extent varying depending on the topography of the coastline (IPCC, 2021). Villages and dispersed settlements along the coast would be vulnerable to inundation; relocation some distance inland could be required.

Saltwater intrusion to coastal aquifers is already a risk in West Africa due to increasing groundwater withdrawals, particularly due to rapidly expanding coastal populations and the associated demands on water supplies. As sea levels rise, saltwater intrusion may be further exacerbated, which can negatively affect water supply from coastal aquifers (see section 4.1).

West Africa has many long and beautiful white sand beaches, fringed with palms and in some areas tropical forest. This attracts international tourists and, more importantly, they are spaces for the inhabitants of coastal regions to enjoy and to profit from tourism or from fisheries. A risk of sea level rise is that these beaches will disappear resulting in severe impacts for tourism, in Senegal, The Gambia, Ghana, Côte d'Ivoire, Liberia, and Sierra Leone.

Also, under threat from sea level rise is the Bijagos Archipelago (also known as Bissagos), which consists of about 88 islands. They are located in the Atlantic to the west of Guinea-Bissau and form part of the territory of Guinea-Bissau. The Bijagos Islands are very important ecologically and culturally and are a designated UNESCO World Heritage Site. The Bijagos are low-lying and at direct risk from sea level rise. The culture, languages and production systems of the Bissagos islands are unique in Africa. About twenty of the islands are inhabited. They have a special farming system that prevents sea water intrusion, consisting of raised gardens where they grow rice. In this case, SLR is a threat to cultural heritage and to an ecologically unique place (see also 4.6).

Sea level rise in urban areas is addressed in section 4.3.2.

4.4.2 Fisheries

The sustainability of West Africa's fish stocks is under threat, due to both the degradation of ecosystems that support marine life and the overexploitation of fish stocks (Barange et al., 2018). The current economic strain of fishers in coastal regions makes them vulnerable to any additional adverse climate change impacts. Fish traditionally make up a high percentage of diets and calorific intake in coastal areas, but this has diminished in most places due to declining fish stocks associated with overfishing. Fisheries are important to coastal economies especially at the household level, and the decrease in fish stocks across the region has harmed livelihoods. Marine conservation areas do exist and if enforcement was strengthened they would be effective in sustaining fisheries (see section 4.6).

Climate risks to fisheries up to 2050 are likely to be outweighed by the continuing damage being caused by destructive trawling. The climatic risks are associated with warming oceans and an increase in Marine Heatwave (MHW) frequency and intensity, as well as an increase in ocean acidity and ocean deoxygenation, which together will also negatively affect coastal fish stocks and present a substantial challenge to marine ecosystems along the coast. Disruption to ocean currents and upwellings could also impact the nutrients supply that marine life require. There are no reef systems in West Africa, so unlike the East African coast, this is not an important part of fisheries in West Africa.

Focus box 9: Sea level rise

Sea-level reconstructions based on tide gauge data indicate that the relative sea levels around the African continent have increased since 1900 (Frederikse et al., 2020; IPCC, 2021). Satellite altimetry based reconstructions have shown that the rate of this sea level rise has accelerated in recent years, with the rate of increase in the oceans around Africa currently above that of global mean sea level for the 1993-2018 period (Frederikse et al., 2020; IPCC, 2021).

It is virtually certain that relative sea level rise will continue in the oceans off the West African coast (IPCC, 2021). Under SSP585, CMIP6 projections indicate a median projected relative sea level rise of 0.3m for the mid-century (2041-2060) from a baseline of 1995-2014, with a 5th-95th percentile range of 0.2-0.4m (IPCC Interactive Atlas, 2021). The less recent CMIP5 models projected median regional relative sea level change for around West Africa at 0.3m for 2046-2065 under RCP8.5, relative to a baseline of 1986–2005 (IPCC, 2019).

West Africa has many of its largest and most economically important cities in low-lying, coastal locations. The majority of these cities are experiencing growth and have large, rapidly expanding populations, and there is currently little in the way of coastal defences. This leaves West Africa particularly vulnerable to sea level rise, and the associated increases in coastal erosion, coastal retreat and coastal flooding.

There are many contributing factors to both global and regional sea levels (i.e., thermal expansion, glacial isostatic adjustment, Greenland and Antarctic ice sheet melt, glacier melt, changes to land water storage and ocean dynamics). There is no single model that can compute all of these contributions to sea-level change directly and, instead, the contributions to sea level are all computed separately and then combined (IPCC, 2021). There is large uncertainty around the possible effects of additional ice-sheet processes, such as Marine Ice Sheet Instability and Marine Ice Cliff Instability (DeConto et al., 2021), for which there is low confidence (IPCC, 2021). However, to address this, additional low-likelihood, high-impact storylines under high-emissions scenarios were run for IPCC AR6 to explore the potential impact of the abrupt and sudden onset of these processes, which would take sea level rise outside of the likely projected ranges for the 21st century (IPCC, 2021).

4.5 Human health and mortality

Summary of risks relevant to human health and mortality

- **Increasing temperatures will increase the risk of heat stress and heat stroke with heatwaves becoming more dangerous when combined with water shortages.**
- **Working outside during the hotter months may become impossible, especially in the north (zones 1 and 2)**
- **Vector borne diseases may be reduced as increased evaporation reduces areas of stagnant water**
- **Urban areas will be hardest hit by higher temperatures due to UHI effect and large populations living in poverty**
- **Health impacts from poor air quality will be a greater risk as drier conditions increase dust content in the atmosphere**

4.5.1 Extreme temperatures

High temperatures are already a significant issue in West Africa, particularly during warmer months, with daily maximum temperatures already exceeding 40°C from March to May in some areas (zones 1 and 2). Climate projections show a strong and consistent signal for further warming and an increase in the number of extreme hot days. Given the physiological limits of humans to withstand extreme heat, heat stress is an increasing risk and even the basic habitability of some regions is in question (Raymond et al., 2020). In the southernmost zones 5 and 6, temperatures are not projected to reach such extremes, but these zones experience high humidity which means wet bulb temperature thresholds can still be exceeded causing danger to human health.

The diurnal and seasonal temperature range in West Africa is extremely narrow. By the 2050s temperatures are projected to be completely outside the range currently experienced. Day time maximum temperatures will increase and so will minimum daily (overnight) temperatures. Low overnight minimums are important for the body's ability to cool down, they have a critical relationship with overall mortality and morbidity. An increase in the entire diurnal temperature range will lead to increased threats to public health and danger of death.

In a warmer climate risk of death by heat stroke will increase, especially for the elderly, infants and those with underlying health conditions. Water shortages during heat waves would increase vulnerability to this risk, both in areas where rainfall is projected to decrease, in the west, and in the east where high variability in rainfall patterns, a projected doubling in population, and increased evapotranspiration due to rising temperatures will exacerbate the problem. Water shortages would pose serious problems for both human and animal populations in conditions of extreme heat, with risk of death by dehydration and heat stroke.

With temperatures exceeding 40°C-45°C, working outside becomes difficult or impossible. The hot season is projected to lengthen by the 2050s and the area over which these high temperatures are reached will also increase, meaning outdoor work will be limited over a longer period and larger area, or to certain hours of the day. Deaths related to heat stress, which can be attributed to cardiovascular and respiratory disease, are already being recorded in the region (USAID, 2018).

Focus box 10: Limits to adaptation

The rate and magnitude of climate change in the coming decades may exceed the limits to adaptation of some socio-ecological systems (Adger, et al., 2009). The limits to climate adaptation are a complex set of thresholds that can be physical or social. In a social context the limit to adaptation comes when no adaptation actions are available or sufficient to manage risks to a level considered tolerable to achievement of objectives (Dow, et. al., 2013). From a physical perspective, a limit to adaptation is more straightforward in the exceedance of the absolute physical limit of survivability of the climate, so that no adjustment in exposure or vulnerability can compensate. In some parts of West Africa, where the climate is already extremely harsh, climate change, even at relatively low levels, has the potential to exceed limits to adaptation in some regions at some periods of the year. The main example of this is associated with thermal stress. A wet-bulb temperature (air temperature measure by a saturated thermometer) of 35°C marks the upper survivable physiological limit for humans, although much lower values have serious health and productivity consequences. Parts of West Africa already exceed this threshold regularly, in particular the northern zones 1 and 2. Climate model projections indicate that this threshold will be exceeded more frequently and for longer periods by the 2050s.

4.5.2 Disease

Vector borne disease such as malaria and dengue fever are spread by mosquitoes, which require stagnant water for breeding. Higher temperatures in the 2050s will cause increased evaporation, which will reduce the amount of stagnant water available, except possibly after heavy rainfall events. Mosquito borne diseases may therefore decrease across much of the region. However, increased freshwater temperatures could act to increase the prevalence of vector-borne diseases, such as Malaria, in areas where stagnant water bodies are not much reduced.

Where there is increased flooding, cholera outbreaks are possible. Vector borne disease outbreaks may also occur if flood waters persist and become stagnant.

Trypanosomiasis, carried by the tsetse fly causes sleeping sickness in humans and is also a livestock disease. If climate change contributes to changes in the ecology of West Africa, such as reducing subhumid forest cover, the habitat of the tsetse fly will be reduced, potentially lowering the prevalence of the disease.

4.5.3 Air quality

Air quality is already negatively impacting the health across West Africa, particularly in urban and industrialised areas such as Lagos and the Niger delta in Nigeria, which has the highest number of premature deaths due to poor air quality in the region (Croitoru, 2019) - caused by gas flaring by oil companies. Airborne dust will likely increase across the region, especially during the Harmattan winds where dust is blown in from the Sahara, impacting air quality and visibility and increasing the risk of respiratory infection.

4.6 Biodiversity and ecology

<u>Summary of risks relevant to biodiversity and ecology</u>

- **Future changes in temperature and precipitation will alter the conditions of West Africa's habitats at an unprecedented rate.**
- **For some species, there may be sufficient time to shift to new, more climatically favourable habitats, if such an area exists. Species may also be pushed into new areas that are not protected or where the vegetation and land use is already degraded.**
- **Marine heatwaves will become more frequent threatening marine ecosystems.**
- **Careful management of protected areas and marine protected areas are essential for helping biodiversity and ecology in West Africa to adapt to increasingly challenging climatic changes.**

4.6.1 Shifting climatic conditions for West Africa's habitats

Future changes in both temperature and precipitation will alter the conditions of the habitats that different species of flora and fauna currently inhabit across West Africa. High temperatures are already a significant issue in this region, particularly during warmer months, with daily maximum temperatures already exceeding 40°C from March to May (zones 1 and 2). As temperature thresholds will be exceeded more frequently and for longer periods of time, this will place flora and fauna under increasing stress, and potentially bring temperatures outside of some species' range of tolerance. Precipitation is currently highly variable, seasonally and interannually, and this will continue into the 2050s or potentially increase. Total annual rainfall totals are indicated to decrease in the west and increase in the east, with low confidence. There is medium confidence that consecutive dry days will increase across the region and that risk of drought will increase in the west. There is also an indication that the onset of the rainy season will be delayed, although to what extent will vary across West Africa (Kumi & Abiodun, 2018).

For some species, there may be sufficient time to migrate habitats to new, more climatically favourable areas. However, even if it is possible for certain species to move there may not be another suitable environment with a more tolerable climate to move into. For example, species living in highland areas in cooler, higher altitudes are restricted by the height of the range in terms of whether they can migrate upwards to stay in cooler temperatures as overall temperatures increase. This a particular issue for West Africa's endemic species, which may be lost if the climatic niche they inhabit disappears.

4.6.2 Protected areas and endemic species – forests and savannahs

Protected Areas (PA) are the pillar of conservation efforts globally, and West Africa is no exception, but the number, size and management of PAs varies between countries. Studies show that PAs, such as National Parks, improve the conservation of plants and animals compared to non-protected areas. However, there are many challenges and pressures on PAs including: lack of investment and corrupt management; poaching, which has significantly reduced wildlife numbers in virtually all protected areas; and problems of illegal logging, mining and grazing within PAs. With these existing threats to West Africa's biodiversity and specifically to PAs being so severe, much of the ecology has become more fragile and therefore more vulnerable to climatic change and disruption.

Plant ecology and phytogeography (the distribution of plant species) could change through trophic cascades caused by changes in temperature and rainfall, whereby vegetation alters, transforming ecological niches and species. This could push species into less favourable environments which are not protected, or where the vegetation and land use is already degraded. Careful management and investment are required to make PAs large enough and preferably interconnected, spanning different ecologies and niches, so that ecological changes can be better absorbed by wildlife.

Some species will be susceptible to direct impacts of high temperatures and drought, which can lead to reduced biomass and lack of pasture and browse, this will lead to animal deaths in national parks. Savannah areas could be more at risk, especially around zone 1 in the north and zone 3 in the west, where rainfall reductions are projected. But sustained high rainfall in coastal areas and in the Upper Guinea Forest zone could also change, whether in pattern and distribution or in volume.

Increased variability in rainfall may also threaten the viability of tropical forests. These are biodiversity hotspots in West Africa with many rare and endangered species of plants and animals. PAs, spanning Sudano-Savannah, Guinea-Savannah and Guinea Moist Forest (Guinea), are important for migrating birds (including between Africa and Europe), and are important habitats for large mammals such as elephants, lions and diverse primates. They also host botanical diversity, with high levels of endemism in some places. All tropical forest PAs are already under severe pressure from logging, cultivation, grazing, population pressure, and climate change is both an exacerbating factor and an additional, serious direct risk.

Climate change will worsen human impacts on PAs, as it will accelerate land degradation in rural areas and the demands for more space for settlements and agriculture. This is crucially driven by population growth, but elevated temperatures and erratic rainfall will reduce the productivity of land and thus of crops and livestock. Encroachment into PAs, such as national parks, by farmers and herders is already a problem and will be exacerbated. As legitimate livelihoods come under pressure the incentives for poaching, illegal logging and illegal mining and other activities in PAs that reduce biodiversity will increase. Pollination of crops is higher when the ecosystems are healthy and where insects are in larger numbers. Yields are shown to be higher in fields close to biodiverse PAs. Economically, local populations would also be impacted by biodiversity loss as many depend on forest resources of various kinds, including non-timber products.

4.6.3 Marine Protected Areas and the biodiversity of the ocean and coasts

West Africa contains many important marine and coastal areas for wildlife including mangrove ecosystems (e.g. in Guinea-Bissau and Nigeria). It also supports the coastal population, a large proportion of whom are fishers or rely on fish as a staple of their diet (see Section 4.4). A number of Marine Protected Areas (MPAs) exist around the coast of West Africa, the majority cover coastal areas, like vegetated wetlands and coastal reefs, which can be important for marine megafauna species and help conserve fish stocks. The key determinant of how effective they are is enforcement of the laws protecting them. Incursions by trawlers that over-fish is a major problem.

Mangrove ecosystems are threatened or destroyed across large areas of coastline, but there are also conservation efforts underway. Mangroves are breeding grounds and nurseries for fish, and provide natural protection against coastal flooding and inundation, which will be elevated risks due to sea level rise from climate change. These ecosystems need far greater investment and protection, in a way that also supports the livelihoods of fishers and farmers along the coast.

There are multiple threats to marine ecosystems and MPAs from rising sea surface temperatures and changes in ocean circulation, upwelling and marine nutrients. Both natural ecosystems and livelihoods are threatened by climate change as sea temperatures warm and marine heatwaves become more frequent, ocean acidity and deoxygenation increase, and circulation changes affect the availability of nutrients (see Section 4.4).

5 Summary

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

The climate of West Africa is hot year-round with high annual rainfall totals, a distinct rainy season and long dry season. The climate in the northern extent of the region is hot and arid, bordering on the Sahel and sharing the same characteristics. The southerly and westerly extent of the region has coasts on the Gulf of Guinea and the Atlantic and is more humid and slightly cooler, being influenced by the maritime air. The rainfall in the region is driven by the West African Monsoon (WAM) and is highly variable from year-to-year. Climate change projections for the 2050s show high confidence for a substantial warming trend. There is less confidence around the direction and magnitude of rainfall changes, but modelling suggests an increase in mean annual rainfall across most of the region except the far west for which a decrease is indicated. Interannual variability in seasonal rainfall amounts and timings is expected to increase, as is the frequency and intensity of heavy rainfall events. This combination of increasing temperatures and increasingly variable seasonal rainfall, together with exposure of the large coastline to sea level rise and erosion, means that climate change will increase stress on existing vulnerable populations in the next few decades.

Some of the key risks identified in this report include food and water security, risks to human health and to cities and infrastructure, as well as specific risks associated with coastal zones and the biodiversity and ecology of the region. Climate change will undoubtedly test human and agricultural systems, yet not all problems across the region will be driven by climate change, land use changes, increased pressure on water supply and migration will all have a significant impact. Climate risks are not isolated threats; how they interact with, and compound other sources of risk can be difficult to disentangle. For example, water use and availability across the region is a complex issue affected by a multitude of factors spanning beyond climate change. It is important to consider the climate risks presented within this report in the context of development objectives and the wide range of intersectional risks that include socio-economic stresses and other drivers of change.

Long-term climate risks will present considerable challenges, both in terms of average climate conditions which require adaptation to new ways of living, and through climate extremes and shocks, such as heat waves and floods, that exacerbate pre-existing and complex compounding risks. Development that accounts for climate risks includes low and no-regrets investments in adaptation and resilience aligned to development goals, such as sustainable agricultural intensification, environmental stewardship, social protection, water supply and sanitation and health, all of which support broader development aspirations. This kind of incremental adaptation develops climate resilience within systems and generates widespread benefits for people across a range of plausible climate futures. However, in some areas and localised hot spots where pressures combine and intensify socio-economic structures are already under stress, and in some instances functioning at the limits of climate tolerance. In West Africa this includes coastal urban areas at risk from extreme heat, sea level rise and erosion. These areas already have high levels of incoming migration, increased demand for water and power and pressure on natural ecosystems. As climate change pushes systems further, acting as a 'risk-multiplier', transformational adaptation may be required to develop entirely new approaches to job creation and environmental management where existing livelihoods, such as pastoralism are no longer viable.

Water availability and quality is an overarching theme throughout this report, impacting on all the other socio-economic sectors discussed. The West Africa region is already water insecure, mainly due to distribution, management and storage issues, variability in rainfall, unevenly distributed terrestrial water storage features, and uneven access to water due to economic inequalities and poverty. There is a risk the region could see increased diversion of water from rivers and streams to supply urban and rural areas. Water demand in West Africa is rising and will continue to rise, due to usage by rapidly growing populations and likely growth in irrigated agriculture. Threats to water supplies through salt-water intrusion, changes to river flow rates, increases in the variability of rainfall patterns and a possible delay in the onset of the rainy season will occur in concert with this rise in demand, exacerbating the insecurity.

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

Image location: Gambia

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Image location: Accra, Ghana