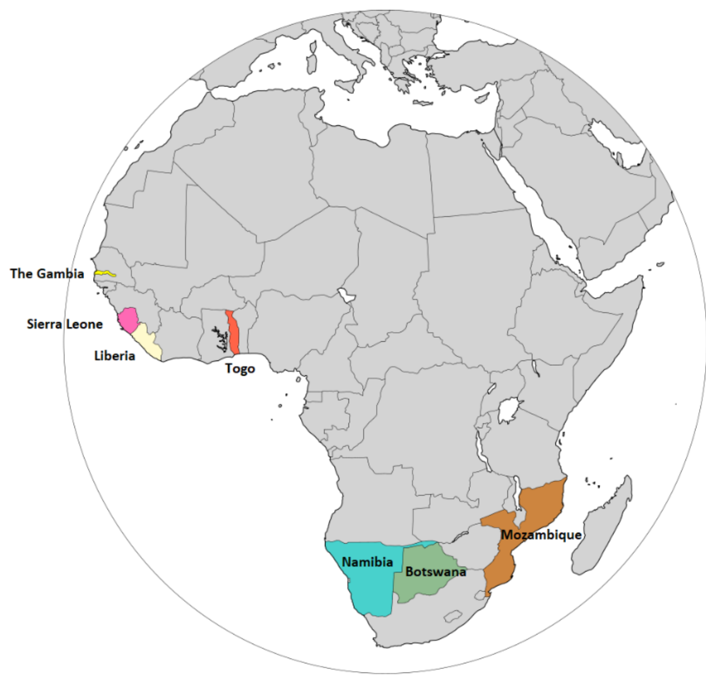
RESADE project

Activity 1.3: Final Report

International Centre for Biosaline Agriculture (ICBA), Dubai, United Arab Emirates



November 2024

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Table of Contents

List of Figures:

List of Tables:

1.Executive Summary

This report provides an assessment of the risks climate change poses to the agricultural sector in six African countries: The Gambia, Togo, Sierra Leone, Liberia, Botswana, and Mozambique. These countries are already experiencing the impacts of climate change through increasing temperatures and shifts in rainfall patterns, leading to more frequent and severe droughts and floods. This analysis, conducted as part of the RESADE project, focuses on understanding how these climatic changes are likely to affect the agricultural sector, which is vital for the livelihoods and food security of many people in these countries.

The report first examines historical climate trends in each country using data from national weather stations and the Climatic Research Unit (CRU) TS4.03 dataset. This analysis reveals a consistent pattern of rising temperatures over the past 50 years. The magnitude of this warming varies between countries, with some experiencing increases of 1°C, while others have seen temperatures rise by as much as 1.5°C. In addition to rising temperatures, the report also notes significant year-to-year variability in rainfall in all six countries, highlighting their vulnerability to both droughts and floods.

To understand how these climate trends might evolve in the future, the report uses projected climate data from the NASA NEX-GDDP Dataset. This dataset provides projections for two different emissions scenarios: RCP4.5, representing a moderate emissions pathway, and RCP8.5, a high emissions scenario where greenhouse gas concentrations continue to rise at their current rate. Under both scenarios, the report finds that all six countries are projected to experience continued warming by the end of the century. The magnitude of this warming is much greater under RCP8.5, ranging from +4.5°C to as high as +6°C, compared to increases of around +2°C under RCP4.5.

The projected changes in rainfall are less consistent across countries and regions, with some areas projected to receive more rain and others facing the possibility of drier conditions. However, the report emphasizes that even in regions where rainfall is projected to increase, the changing timing and intensity of rainfall events could still pose challenges for agriculture.

To evaluate the potential impacts of these climate changes on agriculture, the report creates vulnerability maps based on the concept of **exposure**, which measures the extent to which a system is likely to be affected by climate change. These maps are created using a set of climate indices related to heat and drought stress, with the relative importance of each index determined through workshops with experts in each country. The vulnerability maps show a wide range of exposure levels across the different countries and regions, highlighting the need for targeted interventions to address the specific challenges faced by different areas.

Ideally, a comprehensive vulnerability assessment would go beyond exposure to also consider the **sensitivity** of agricultural systems to climate change and their **adaptive capacity** to adjust to these changes. The report aims to include these components by using socioeconomic data provided by partners in each country. However, the availability of this data has been limited, with only Togo and Botswana providing sufficient information to partially assess sensitivity and adaptive capacity. Despite these data limitations, the report underscores the importance of considering factors such as population density, reliance on agriculture for livelihoods, access to markets, and infrastructure when developing adaptation strategies.

In light of these findings, the report recommends that the next phase of the RESADE project should focus on the regions identified as most vulnerable to climate change. It also suggests the establishment of a second Best Practice Hub (BPH) within these regions to serve as a center for knowledge sharing, technology transfer, and capacity building. By focusing efforts on the most vulnerable areas and strengthening local adaptive capacity, the RESADE project can play a critical role in helping these countries cope with the challenges of a changing climate and ensure the continued viability of their agricultural sectors.

2.Introduction

2.1. Background

Climate change poses a significant threat to global ecosystems and economies, with its adverse effects felt acutely in the West and South Africa regions. These regions are considered particularly vulnerable to various climate change-induced hazards, including drought, desertification, floods, sea level rise, and heat waves (Dosio, 2017; Marshall et al., 2012; Masih et al., 2014; Naumann et al., 2014; Spinoni et al., 2015; Zhao et al., 2015). The consequences of these hazards are far-reaching, affecting vital sectors like agriculture, forestry, and coastal resources, thereby impeding economic development and jeopardizing food security.

Communities in West and South Africa, especially those lacking the capacity to adapt, are already grappling with the impacts of climate change, as evidenced by the increased frequency and severity of extreme events such as floods and droughts. These events have led to devastating consequences, including damage to infrastructure, loss of livelihoods, and food shortages. The recurrence of droughts, coupled with rising sea levels and deforestation, poses a growing threat to forest and coastal resources, further amplifying the regions' vulnerability.

The RESADE project, which stands for "Improving Agricultural Resilience to Salinity through Development and Promotion of Pro-poor Technologies Programme," aims to address these pressing challenges by enhancing food security and alleviating poverty among smallholder farmers in salinity-affected areas across seven African countries: The Gambia, Togo, Sierra Leone, Liberia, Namibia, Botswana, and Mozambique. The project's primary focus is on identifying and mapping salinity-affected agricultural areas, with a particular emphasis on communities most susceptible to climate change-induced salinity.

Recognizing the urgency of the situation, the RESADE project prioritizes the assessment of climate change risks through the utilization of climate indices most pertinent to agriculture in the targeted countries. This approach aims to evaluate the exposure of the agricultural sector to climate change-induced extreme events, such as droughts, floods, and heat waves. By analyzing observed and projected temperature and rainfall data, the project seeks to gain a comprehensive understanding of the current climate situation and anticipate likely future trends in these extreme events. This information is then synthesized into a series of vulnerability maps, providing a detailed visualization of the level of climate risks facing each region within the participating countries.

2.2. Scope of work

This report examines the climate change risk profile in six African countries: The Gambia, Togo, Sierra Leone, Liberia, Botswana, and Mozambique. The primary objective is to assess the exposure of the agricultural sector to extreme climate events, including droughts, floods, and heat waves. This assessment utilizes climate indices most relevant to agriculture in each country, with weights assigned based on expert input.

Observed and projected temperature and rainfall data are analyzed to evaluate the current climate situation and project future trends. The report incorporates observed data from national weather stations and open-source gridded data. These data are then synthesized into a series of vulnerability maps, which depict the level of climate risks for each region within each country. The maps, created for two climate scenarios (RCP4.5 and RCP8.5) and four future periods (2021-2040, 2041-2060, 2061-2080, and 2081-2100), serve as a valuable tool for informing adaptation strategies and prioritizing interventions within the RESADE project.

3. Methodology

This section provides a detailed explanation of the methodology employed to evaluate the vulnerability of the agricultural sector to climate change across six African countries: The Gambia, Togo, Sierra Leone, Liberia, Mozambique, and Botswana. Recognizing the complexity of vulnerability, the assessment adopts a multifaceted approach that considers the interplay of exposure, sensitivity, and adaptive capacity. This framework aligns with the one presented by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (AR4), as illustrated in Figure 1, and is designed to provide a nuanced understanding of how climate change impacts agricultural systems and the factors that influence their susceptibility.

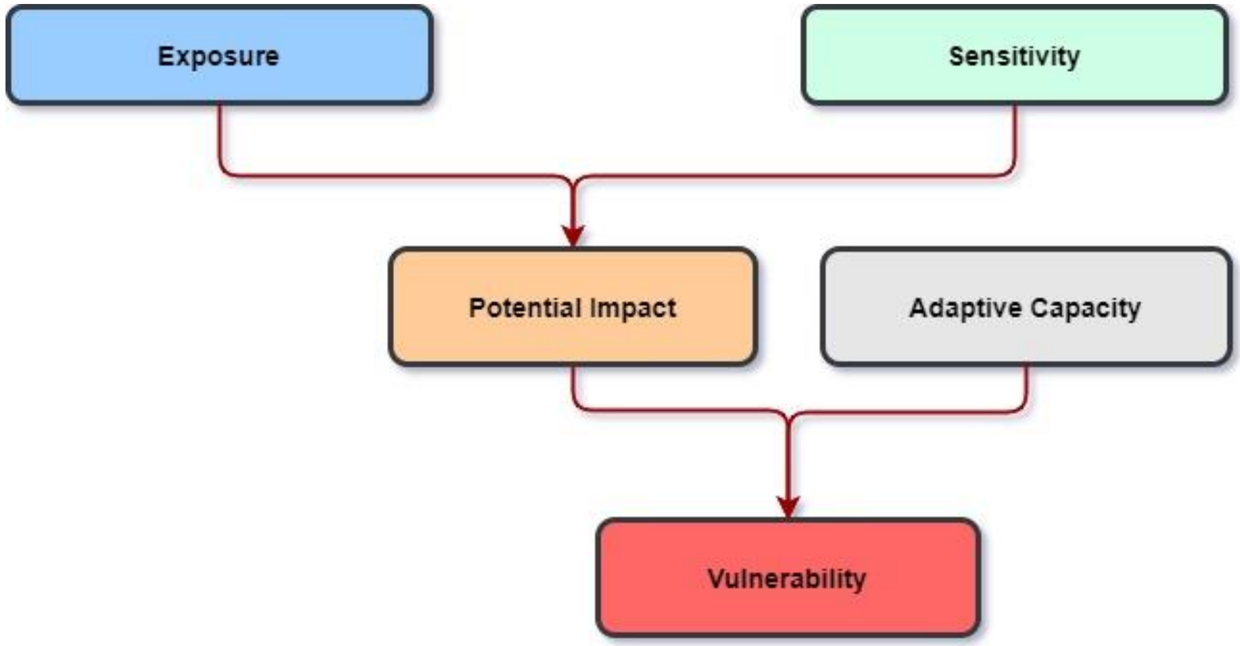


Figure 1: Components of vulnerability based on the IPCC AR4 approach

Vulnerability, within the context of climate change, is a multifaceted concept that encapsulates the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. It is not solely determined by the magnitude of climate change impacts but also by the system's inherent characteristics and its ability to adjust to these changes. The IPCC's AR4 framework provides a structured approach to understanding vulnerability by dissecting it into three fundamental components:

- **Exposure:** This component characterizes the nature and extent to which a system is subjected to changes in climate parameters. These parameters, primarily temperature and precipitation, undergo alterations in terms of their quantity, quality, spatial distribution, and temporal patterns due to climate change. A system's exposure is determined by its geographical location and the specific climate change projections for that region. For instance, a region experiencing a significant increase in the frequency and intensity of droughts would be considered highly exposed to climate change.
- **Sensitivity:** This element reflects the inherent characteristics of a system that make it susceptible to climate change impacts. A system's sensitivity is shaped by a wide range of factors, including topography, land use, land cover, population distribution and density, the built environment, and proximity to the coast. For example, agricultural systems reliant on rainfed agriculture in regions

with low water storage capacity are inherently more sensitive to changes in rainfall patterns than those with irrigation infrastructure.

- **Adaptive Capacity:** This component denotes the capacity of a system to adjust to climate change, moderate potential damages, capitalize on emerging opportunities, and effectively cope with the consequences of climate change. Adaptive capacity encompasses a system's ability to implement measures that reduce its vulnerability. Factors influencing adaptive capacity include socioeconomic conditions, access to technology and information, institutional arrangements, and the effectiveness of governance structures. A community with strong social networks, access to climate information, and the ability to diversify its livelihood strategies would exhibit higher adaptive capacity than one lacking these attributes.

The interaction of these three components, exposure, sensitivity, and adaptive capacity, determines the overall vulnerability of a system to climate change. A highly exposed system with high sensitivity and low adaptive capacity is exceedingly vulnerable to climate change impacts. Conversely, a system with low exposure, low sensitivity, and high adaptive capacity exhibits lower vulnerability. The goal of this assessment is to disentangle these components and provide a spatially explicit understanding of agricultural vulnerability across the target countries.

During the workshops on water policy review that were held in most of the countries, an exercise was carried out with the participants to identify and rank the climate indices most relevant to agriculture in the country. Based on this exercise, a unified map has been developed to characterize the exposure of the agricultural sector in each country to the potential hazards induced by climate change in the future. Two periods of 20 years are considered to evaluate this exposure and presented in this report. The first spans from 2021 to 2040 and the second is between 2081 and 2100. Two climate scenarios are considered for both periods: RCP4.5 considered as an optimistic scenario and RCP8.5 considered as business as usual where the Green House Gaz emissions will continue as in the past few decades. The reference period against which the changes in all indices are calculated is the same one considered by the IPCC in its fifth assessment report (1986-2005).

3.1. Data acquisition and sources: building a robust evidence base

A comprehensive vulnerability assessment hinges on the availability and reliability of climate and socioeconomic data. This assessment draws on data from multiple sources to ensure a robust and representative analysis.

3.1.1. Observed Climate Data: Capturing Historical Trends

Understanding historical climate trends is crucial for establishing a baseline against which future projections can be compared. This assessment utilizes observed climate data from two primary sources:

- **National Weather Stations:** Observed monthly rainfall and temperature data were collected from national weather stations across each country. These stations provide valuable localized information on historical climate variability. However, data availability varies considerably among stations, with many exhibiting missing data points, particularly in recent years. This data sparsity, especially in recent years, poses challenges for accurately capturing long-term climate trends.
- **Climatic Research Unit (CRU) Data:** To address limitations associated with weather station data, gridded data from the CRU at the University of East Anglia were incorporated into the analysis. The CRU TS4.03 dataset (Harris et al., 2014), available online, provides monthly rainfall, average, maximum, and minimum temperature data at a spatial resolution of 0.5 degrees (approximately 50 km x 50 km). This dataset helps overcome spatial gaps in weather station coverage and enhances the representation of historical climate trends.

3.1.2. Projected Climate Data: Anticipating Future Climate Scenarios

Assessing future climate risks necessitates the use of climate projections based on different greenhouse gas emissions scenarios. This assessment relies on projected climate data from the NASA NEX-GDDP Dataset. Projected climate scenarios were obtained from the NASA Center for Climate Simulation's NEX-GDDP dataset, accessible online https://portal.nccs.nasa.gov/datashare/NEXGDDP/BCSD/. This dataset provides daily bias-corrected and downscaled climate data for both historical periods (1950-2005) and two greenhouse gas emissions scenarios, known as Representative Concentration Pathways (RCPs). The two RCPs considered are RCP4.5, representing a moderate emissions scenario, and RCP8.5, representing a high emissions scenario. The data spans the period from 2006 to 2100 at a spatial resolution of 0.25

degrees (approximately 25 km x 25 km). These high-resolution, downscaled projections provide insights into potential future climate changes on a local scale.

3.1.3. Socioeconomic Data: Characterizing Sensitivity and Adaptive Capacity

Socioeconomic data are essential for characterizing the sensitivity and adaptive capacity of agricultural systems to climate change. This data provides insights into the socioeconomic conditions, demographic characteristics, and institutional arrangements that influence vulnerability.

- **Country-Specific Data:** Partners in each country were tasked with providing fine-scale data relevant to the agricultural sector and population characteristics to inform the assessment of sensitivity and adaptive capacity. These data were intended to capture socioeconomic conditions, agricultural practices, and demographic factors at a localized level. However, to date, only Togo and Botswana have provided such data, and even these datasets are incomplete. This data scarcity represents a significant limitation in comprehensively evaluating sensitivity and adaptive capacity across all target countries. Table 2 outlines the indices considered for sensitivity and adaptive capacity assessment and highlights the data availability for Togo and Botswana.

3.2. Climate indices used to evaluate the exposure

To assess the exposure of the agricultural sector to climate change, a suite of climate indices was selected. These indices, developed by the Expert Team on Climate Change Detection and Indices (ETCCDI), are designed to capture changes in temperature and precipitation patterns relevant to agricultural systems. The ETCCDI website http://etccdi.pacificclimate.org/list_27_indices.shtml provides detailed information on these indices. The indices considered in this assessment are grouped into two categories:

3.2.1. Temperature-Related Indices: Assessing Heat Stress

Heat stress can have detrimental effects on crop growth and yields, livestock productivity, and overall agricultural productivity. The following temperature-related indices were used to assess heat stress:

- **Annual mean of daily temperature (tas):** This index represents the average daily temperature over a year and provides a general indication of changes in temperature regimes.
- **Annual mean of daily maximum temperature (tasmax):** This index focuses specifically on the average daily maximum temperature over a year, capturing changes in daytime temperature extremes relevant to heat stress.

- **Annual mean of daily minimum temperature (tasmin):** This index captures the average daily minimum temperature over a year, reflecting changes in nighttime temperatures that can influence crop development and livestock heat stress.
- **Consecutive summer days (csu):** This index measures the number of consecutive days with a maximum temperature exceeding a specific threshold, providing insights into the duration of heat waves that can severely impact agricultural systems.
- **Percentage of days of extremely hot temperature (tx90p):** This index represents the percentage of days in a year with maximum temperatures exceeding the 90th percentile of the historical temperature distribution, indicating the frequency of extreme heat events.

3.2.2. Rainfall-Related Indices: Evaluating Water Availability

Changes in rainfall patterns, including both droughts and floods, can significantly impact agricultural production. The following rainfall-related indices were used to assess changes in water availability:

- **Annual mean of annual rainfall (pr):** This index provides an overall measure of changes in total annual rainfall, reflecting shifts in water availability for agriculture.
- **Consecutive dry days (cdd):** This index quantifies the number of consecutive days with rainfall below a specific threshold (1mm), capturing the duration and severity of droughts that can lead to crop failures and water shortages.
- **Consecutive wet days (cwd):** This index measures the number of consecutive days with rainfall exceeding a specific threshold (1mm), reflecting periods of excessive rainfall that can result in flooding and waterlogging, damaging crops and hindering agricultural operations.
- **Percentage of days with heavy rain (r99p):** This index represents the percentage of days in a year with rainfall exceeding the 99th percentile of the historical rainfall distribution, indicating the frequency of extreme rainfall events that can cause flooding and erosion.
- **Annual mean of maximum one-day rainfall (rx1day):** This index captures the average of the highest daily rainfall amount in a year, reflecting the intensity of rainfall events that can contribute to flooding and soil erosion.

3.2.3. Weighting Climate Indices: Incorporating Expert Knowledge

To account for the varying importance of these indices for agriculture in each country, workshops were conducted with experts in the respective countries. Participants in these workshops were tasked with assigning weights to each climate index, ranging from 0 to 10, based on their perceived impact on the agricultural sector. Higher weights were assigned to indices considered to have a more substantial impact on agricultural production. The results of this participatory weighting process highlighted drought and changes in maximum temperature and annual rainfall as the most critical factors affecting agriculture across the target countries. Table 1 summarizes the weights assigned to each climate index for each country.

Table 1: Climate indices and their importance for agriculture in the targeted countries

	Index	Weights					
		The Gambia	**Sierra Leone**	**Liberia**	**Togo**	**Mozambique**	**Botswana**
Temperature related indices	Annual mean of daily temperature (tas)	10	1	1	5	8	7
	Annual mean of daily maximum temperature (tasmax)	6	7	7	7	10	8
	Annual mean of daily minimum temperature (tasmin)	1	0	0	4	5	7
	Consecutive summer days (csu)	9	6	6	7	7	8
	Percentage of days of extremely hot temperature (tx90p)	5	4	4	2	10	6
Rainfall related indices	Annual mean of annual rainfall (pr)	7	9	9	8	10	5
	Consecutive dry days (cdd)	3	9	9	10	10	8
	Consecutive wet days (cwd)	5	7	7	5	5	5
	Percentage of days with heavy rain (r99p)	10	6	6	4	10	6
	Annual mean of maximum one day rainfall (rx1day)	4	5	5	3	3	6

3.3. Indices for assessing sensitivity and the adaptive capacity: unveiling socioeconomic and institutional factors

Evaluating sensitivity and adaptive capacity requires understanding the socioeconomic and institutional context within which agricultural systems operate. To assess these components, data on a range of socioeconomic indicators related to the agricultural sector and population characteristics were sought from country partners. This data was intended to provide insights into factors that influence the susceptibility and resilience of agricultural systems to climate change impacts.

Table 2 provides a list of the indices considered for sensitivity and adaptive capacity assessment, categorized by the vulnerability component they represent. These indices encompass agricultural structure, socioeconomic indicators, and adaptive capacity indicators. However, data availability for these indices was limited, hindering a comprehensive evaluation of sensitivity and adaptive capacity for all target countries. Only Togo and Botswana provided partial data for some of the indices, as indicated in Table 2. This data scarcity underscores the need for improved data collection and sharing mechanisms to support robust vulnerability assessments.

Table 2: Indices to evaluate agricultural sensitivity to climate change and its adaptive capacity

Vulnerability component	Category of indicators	Indicator	Data availability in Togo	Data availability in Botswana
Sensitivity	Agricultural structure	Percentage of agricultural GDP (department compared to national)	No	No
		Number of crops planted	Yes	No
		Crop yields	No	Yes
		Percentage of small farms	No	Yes
		Percentage of irrigated land	No	Yes
	Socio-economic	Percentage of people working in the agricultural sector	Yes	No
		Population density per department	Yes	No
		Unemployment rate	No	Yes
	water indicators	Percentage of renewable water resources compared to total water resources	No	No
Adaptive capacity	Socio-economic	Percentage of rural population (for each department)	Yes	No
		Percentage of population with access to drinking water	Partial	Yes
		Percentage of population with access to finance system (access to loan)*	No	No
		Percentage of illiterate population	No	Yes
		Percentage of paved roads (% of total roads per department)**	Yes	No
		Number of markets (the weekly markets) per department	Yes	No
		Total area of each department	Yes	Yes
		Percentage of treated waste water reuse (compared to all sources)	No	No
		Percent population with access to climate services	No	Yes
*** Number of bank branches per department**				
**** Length of paved roads per department**				

3.4. Data Standardization and vulnerability mapping

To facilitate comparison and aggregation of the various indices used in the assessment, all indices were standardized to a common scale ranging from 0 to 1. This standardization process ensures that all indices, despite their different units and magnitudes, contribute equally to the overall vulnerability assessment.

For exposure and sensitivity indices, a value of 0 represents a positive condition (low exposure or low sensitivity), while a value of 1 represents a negative condition (high exposure or high sensitivity). For adaptive capacity, the scale is reversed, with 0 representing low adaptive capacity and 1 representing high adaptive capacity. Therefore, prior to aggregation, values must be inverted. This reversal ensures that higher values consistently indicate greater vulnerability across all components.

The following formula was applied for standardization:

$$index\_stand = \frac{\text{index} - \text{min (index)}}{\text{max}(index) - \text{min }(index)}$$

where:

- Index_stand is the standardized value of the index for a specific location.
- index is the original, unstandardized value of the index for that location.
- min(index) is the minimum value of the index across all locations in the spatial domain.
- max(index) is the maximum value of the index across all locations in the spatial domain.

This standardization process transforms the original index values into a comparable scale ranging from 0 to 1, allowing for meaningful comparisons and aggregation.

Vulnerability maps were then generated by combining the standardized indices. These maps provide a spatial representation of vulnerability, enabling the identification of regions facing varying levels of climate change risk. The vulnerability maps classify vulnerability into three categories based on the standardized vulnerability score:

- **Low:** Standardized vulnerability score ranging from 0 to 0.5.
- **Moderate:** Standardized vulnerability score ranging from 0.5 to 0.8.
- **High:** Standardized vulnerability score ranging from 0.8 to 1.

4.Observed and projected climate in Togo

Togo's climate is generally tropical, with average temperatures ranging from 25°C to 29°C on the coast to approximately 26°C to 31°C in the northernmost regions. In the north, temperatures can drop to 19°C in January and December and rise to 38°C in March. Togo also has a dry climate characteristic of a tropical savanna. The southern region has two rainy seasons: one from April to July and another from September to November. The northern regions have a single rainy season between June and September (Figure 4).

4.1. Climate data from the national weather stations

Observed monthly average temperature and rainfall from the weather stations in Togo located all over the country (Figure 2) has been accessed through the KNMI website https://climexp.knmi.nl. Data has been extracted from the Global Historical Climatology Network (GHCN) that is managed by NOAA. Very few stations have complete timeseries. Missing data during the last decade is common between all stations. The period covered for each station is given in table 2.

Figure 2: Weather stations

Table 3: Weather Stations in Togo including available parameters and the number of missing months

Station name	WMO Code	Latitude	Longitude	Period	Parameters	%missing
DAPAONG VILLE	653510	10.90	0.20	1970-2018	RR	54
MANGO (SANSANNE)	653520	10.40	0.50	1905-2018	RR & T	20
BASSAR (BASSARI)	653571	9.30	0.80	1901-1991	RR	14
SOKODE	653610	9.00	1.10	1901-2018	RR & T	18
ATAKPAME	653760	7.60	1.10	1899-2018	RR & T	18
KLOTO (KOUMA KONDA)	653781	7.00	0.60	1890-1997	RR	11
TABLIGBO	653800	6.60	1.50	1961-2018	RR	34
LOME_AERO	653870	6.20	1.30	1892-2018	RR & T	21

4.2. Observed changes in the climate

4.2.1. Precipitation

The average annual total rainfall in Togo is around 1000mm/year. It has increased by 50mm in 50 years and is characterized by a very high interannual variability (Figure 3). Rainfall in Togo varies on both decadal and inter-annual scales. Rainfall decreased to low levels in the late 1970s and early 1980s. The erratic characteristic of rain in Togo put the country under risk of flood, drought and poor distribution of rain. Over the past decade, Togo endured 6 major flood events that caused significant environmental, social, and economic damage. Togo is also prone to drought. Drought events occur most frequently in the Kara and savannah regions. Over the past 60 years, Togo has experienced three major droughts (between 1942-1943, 1976-1977, and 1982-1983) leading to severe famines.

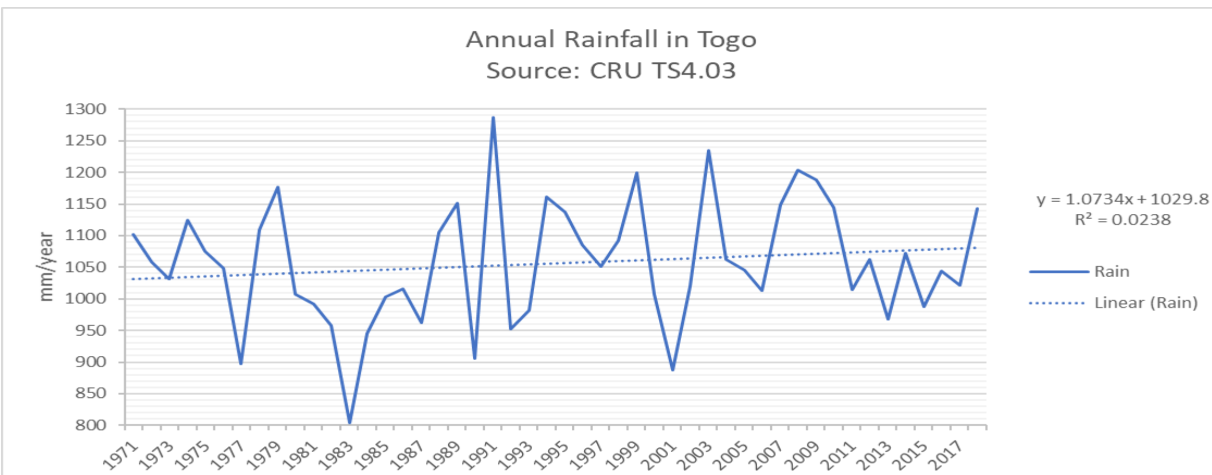


Figure 3: Annual rainfall in Togo for the period 1971-2018 from CRU TS4.03

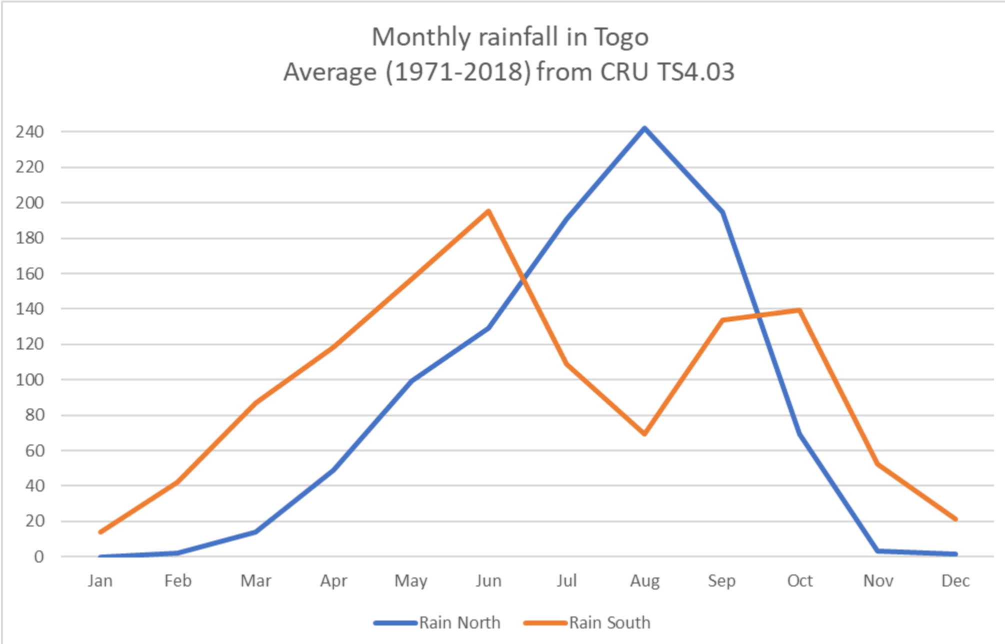


Figure 4: Monthly rainfall in South and North of Togo calculated for the period 1971-2018 from CRU TS4.03

4.2.2. Temperature

Annual average temperature in Togo has increased by 1 degree Celsius in 50 years. Between 1971 and 2018, temperature has shifted from around 33.5 degrees Celsius to almost 34.5 degrees Celsius (Figure 5). At this rate (+2 degrees Celsius per 100 years), the average temperature in Togo will reach 35.5 degrees Celsius around 2070. Daily temperature data indicate that the frequency of hot days and nights has increased significantly in all seasons.

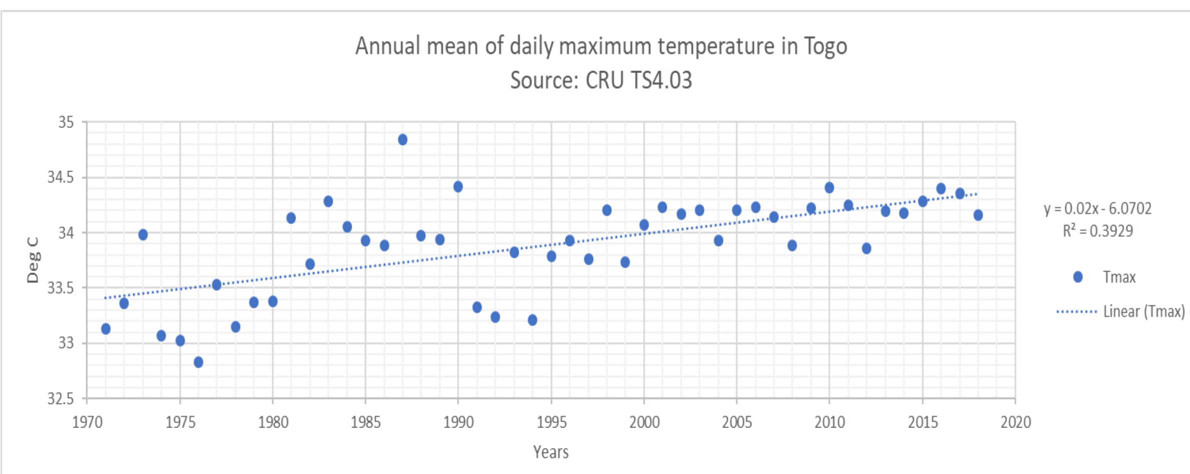


Figure 5: Annual mean of daily maximum temperature in Togo for the period 1971-2018 from CRU TS4.03

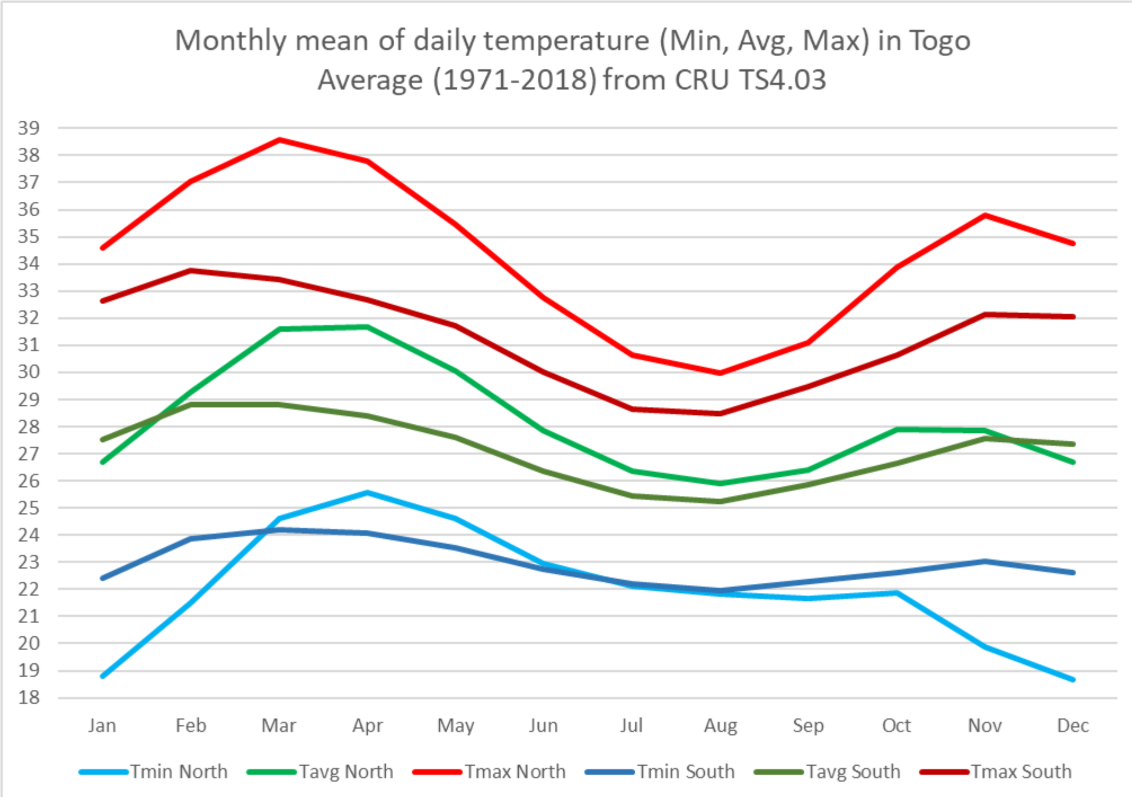


Figure 6: Monthly mean of daily average, maximum and minimum temperature in South and North of Togo calculated for the period 1971-2018 from CRU TS4.03

4.3. Projected changes in the climate

4.3.1. Precipitation

Considering the 21 models, the trend in annual rainfall is not significant. The inter-annual variability will continue to be high under both scenarios (Figure 7). It is noted that most models agreed on a positive signal of changes in rainfall over Togo especially in the south-west part of the Plateaus region where the increase is predicted to reach around 100mm per year (Figure 8). This increase is not always beneficial to agriculture as analyses of extreme events such as floods and drought show that these phenomena will increase in both magnitude and frequency in the future under both scenarios putting the agriculture and other sectors at risk.

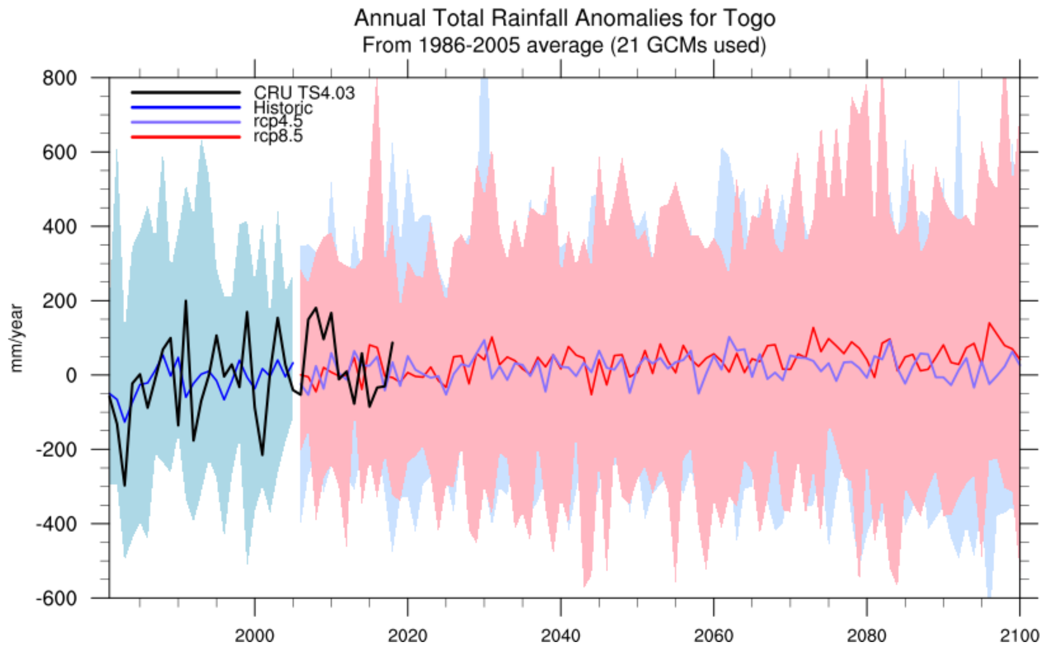


Figure 7: Changes in annual total rainfall in Togo for RCP4.5 and RCP8.5. Departures are calculated from 1986-2005 reference period. Black line represents observed change in annual total rainfall from CRU TS4.03

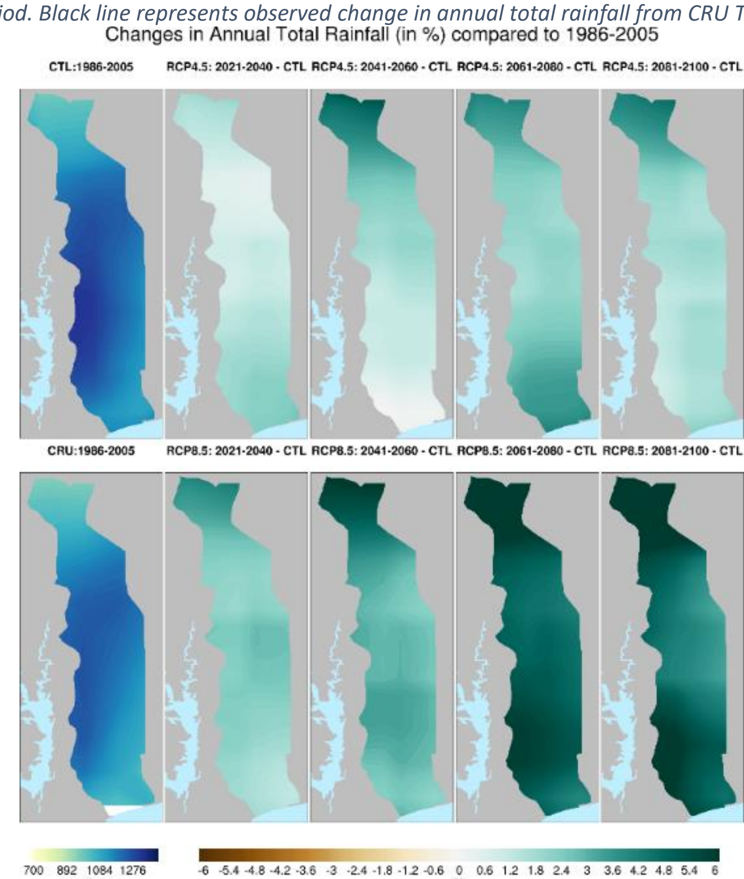


Figure 8: Percentage changes in annual total rainfall for RCP4.5 and RCP8.5 over Togo. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the average of annual total rainfall from 21 models (top left) and (CRU) is the average annual total rainfall from CRU TS4.03 (bottom left).

4.3.2. Temperature

By the end of this century, the maximum and minimum temperatures will likely increase in Togo by +5 degrees Celsius for the RCP8.5 scenario and by +2 degrees Celsius for the RCP4.5 scenario (Figure 9 and 10). This increase in temperature will induce an increase in water demand by evapotranspiration and put the cropping systems at risk. It will also impact the growing season of many crops in Togo.

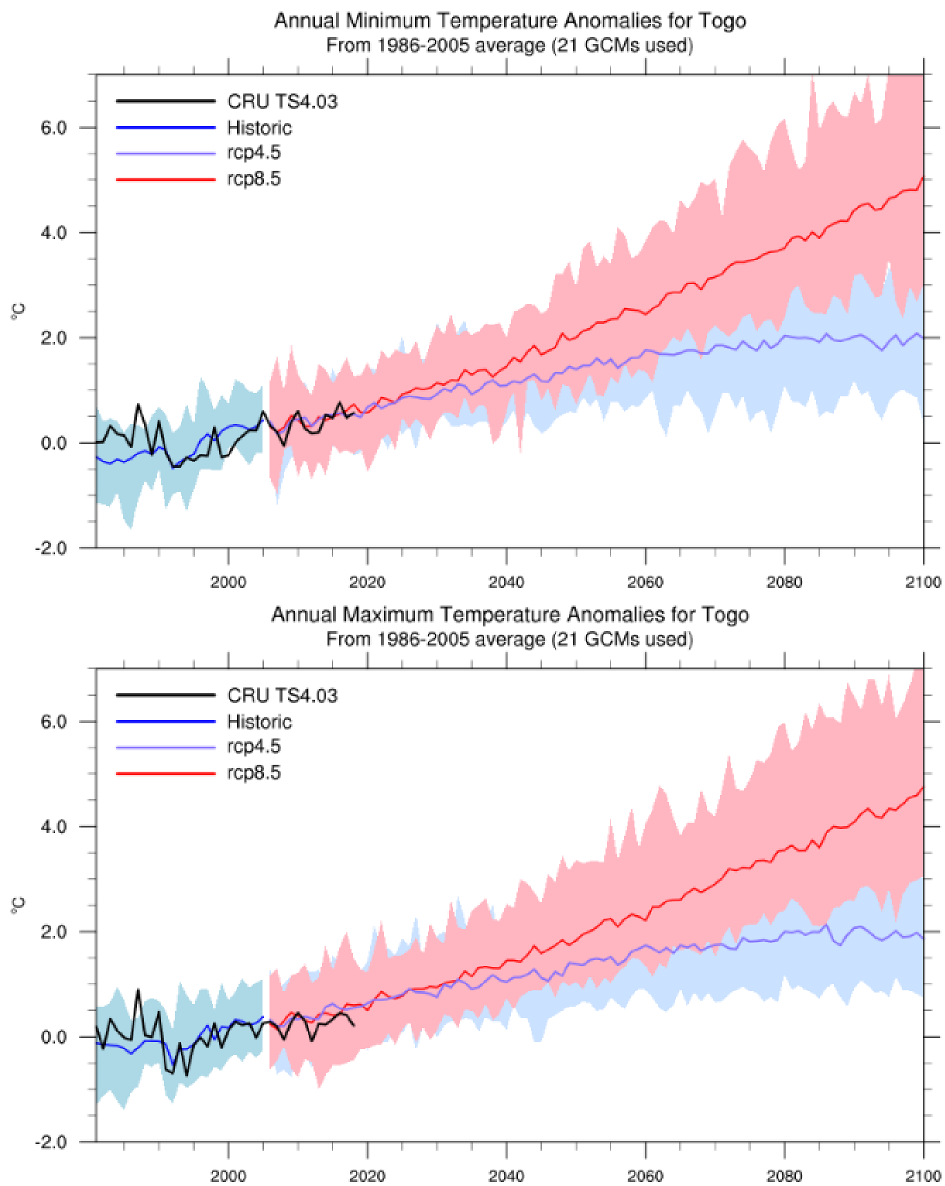


Figure 9: Changes in maximum and minimum temperatures for RCP4.5 and RCP8.5 compared to 1986-2005 reference period. Black line represents observed change in annual average of daily maximum and minimum temperatures from CRU TS4.03

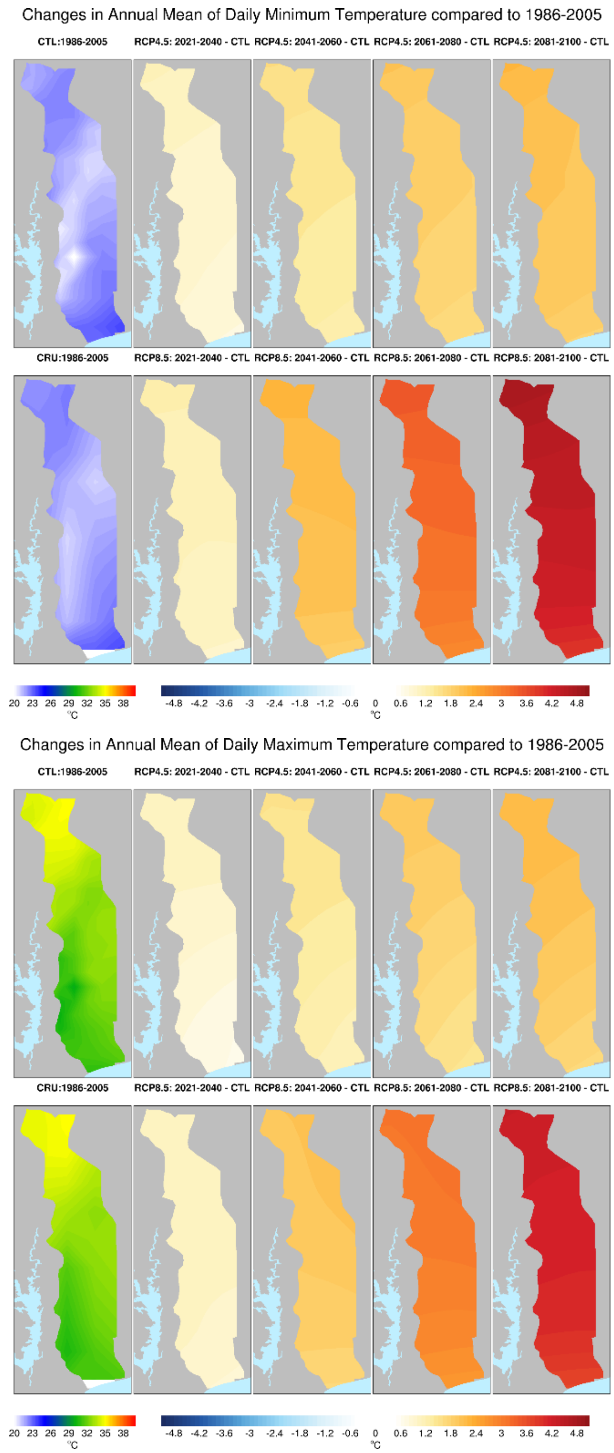


Figure 10: Changes in annual average of daily minimum (top panel) and maximum (bottom panel) temperatures for RCP4.5 and RCP8.5 over Togo. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the annual average of daily minimum and maximum temperature from 21 models (top left in both panels) and (CRU) is the annual average of daily minimum and maximum temperature from CRU TS4.03 (bottom left in both panels).

5. Observed and projected climate in The Gambia

The climate in The Gambia is generally sub-tropical with average temperatures ranging from 25 to 32 degrees Celsius in the eastern part of the country and between 24 and 28 degrees Celsius in the western part (Figure 15). Difference between minimum and maximum temperatures is high during the months of March, April and May (dry season). Minimum temperature can be as low as 16 degrees Celsius in January and December and as high as 40 degrees Celsius in April. The Gambia also has a dry climate and characteristics of a tropical savanna. There is one rainy season in The Gambia that takes place between June and October (Figure 13).

5.1. Climate data from the national weather stations

Observed monthly average temperature and rainfall from two weather stations in The Gambia located in Banjul (west) and Georgetown (east) (Figure 11) has been accessed through the KNMI website https://climexp.knmi.nl. Data has been extracted from the Global Historical Climatology Network (GHCN) that is managed by NOAA. Missing data during the last decade is common between the two stations. The period covered for each station is given in table 4.

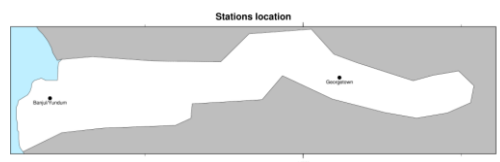


Figure 11: Weather stations

Table 4: Weather Stations in The Gambia including available parameters and the number of missing months

Station name	WMO Code	Latitude	Longitude	Period	Parameters	%missing
Banjul/Yundum	617010	13.40	-16.70	1931-2019 & 1884-2015	RR & T	35 & 17
Georgetown	617210	13.53	-14.77	1961-1990	T	3

5.2. Observed changes in the climate

5.2.1. Precipitation

The average annual total rainfall in The Gambia is around 900mm/year. It has increased by 170mm in 50 years and is characterized by a very high interannual variability (Figure 12). Rainfall in The Gambia varies on both decadal and inter-annual scales. Rainfall decreased to low levels in the late 1970s and early 1980s. The erratic characteristic of rain in The Gambia put the country under risk of drought, floods and storms. Over the past 30 years, The Gambia has experienced three major droughts (between 1990-1991, 2002-

2003, and 2011-2012). More than 520,000 people were affected in 2011-2012. Droughts have affected the greatest number of people by far followed by floods.

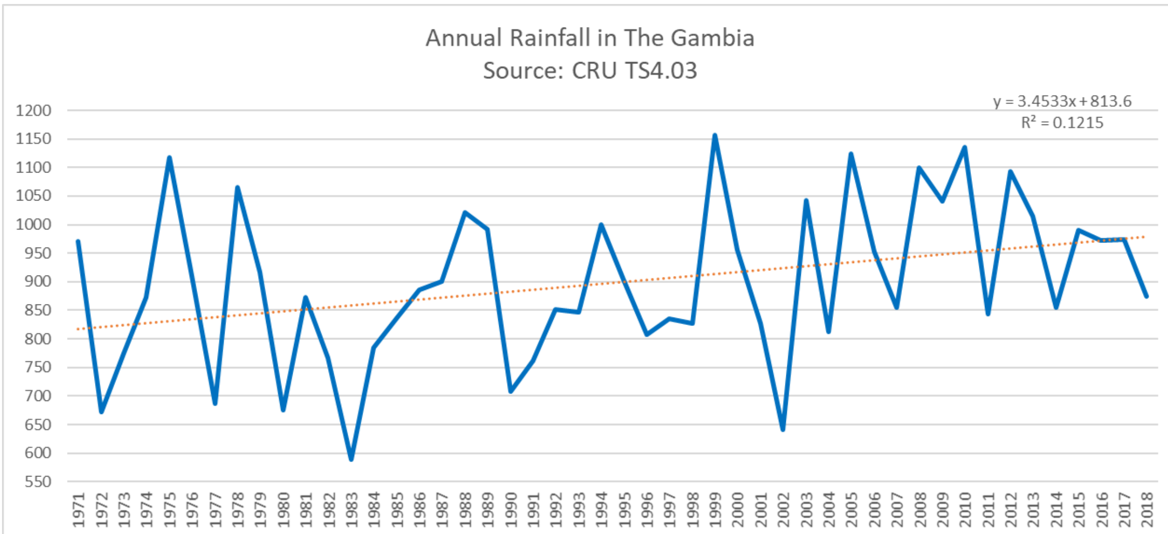


Figure 12: Annual rainfall in The Gambia for the period 1971-2018 from CRU TS4.03

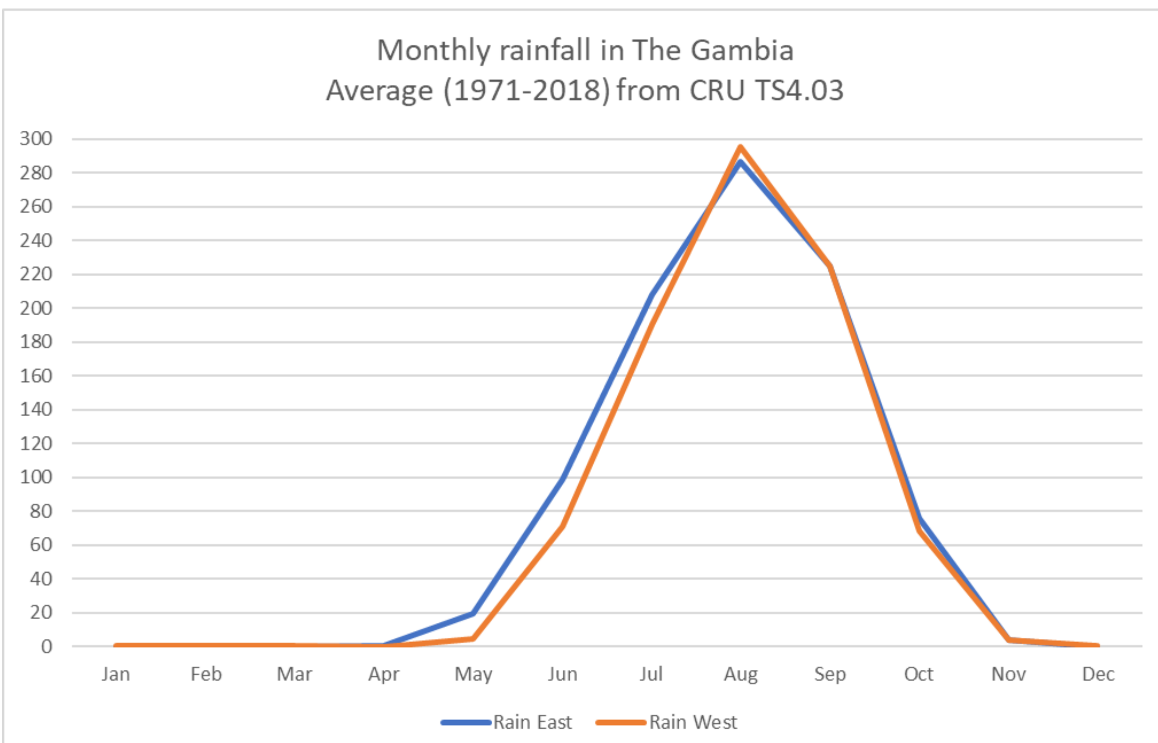


Figure 13: Monthly rainfall in South and North of Togo calculated for the period 1971-2018 from CRU TS4.03

5.2.2. Temperature

Annual maximum temperature in The Gambia has increased by 1.5 degree Celsius in 50 years. Between 1971 and 2018, it has shifted from around 34 degrees Celsius to almost 35.5 degrees Celsius. While minimum temperature has increased by 1.2 degree Celsius in 50 years. Between 1971 and 2018, it has shifted from around 20.2 degrees Celsius to 21.4 degrees Celsius (Figure 14). At this rate (+3 degrees Celsius per 100 years), the daily maximum temperature in The Gambia will reach 37 degrees Celsius around 2070. Daily temperature data indicate that the frequency of hot days and nights has increased significantly in all seasons.

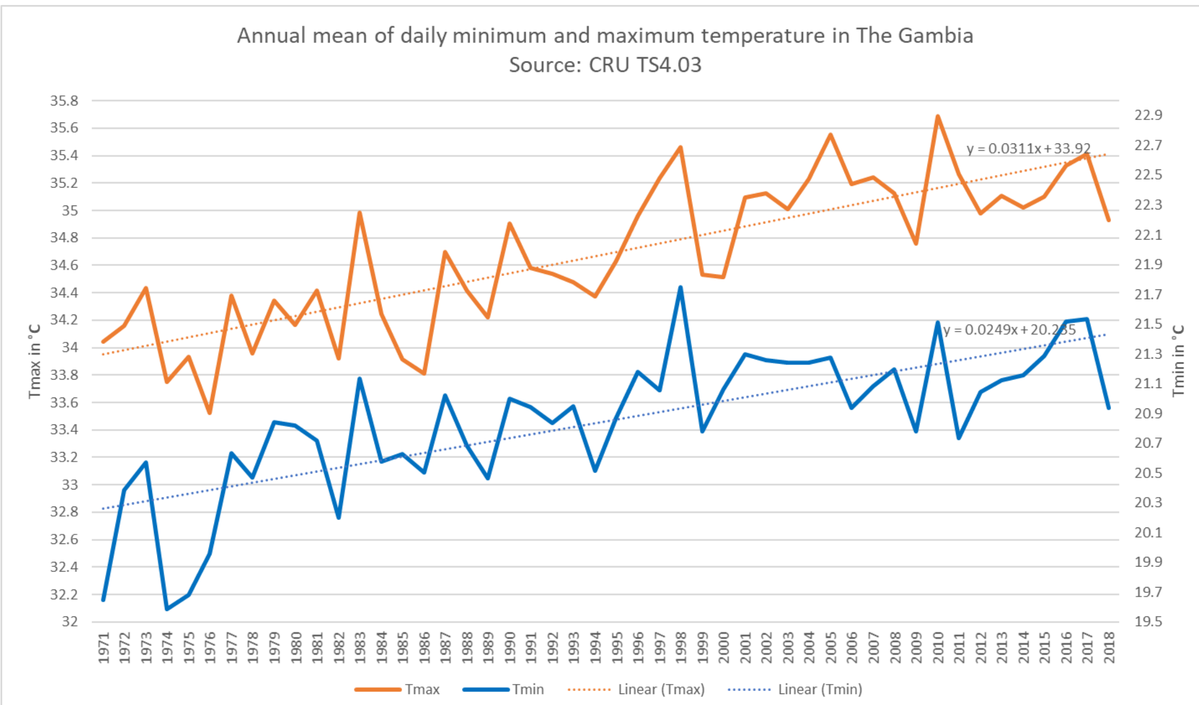


Figure 14: Annual mean of daily minimum and maximum temperature in The Gambia for the period 1971-2018 from CRU TS4.03

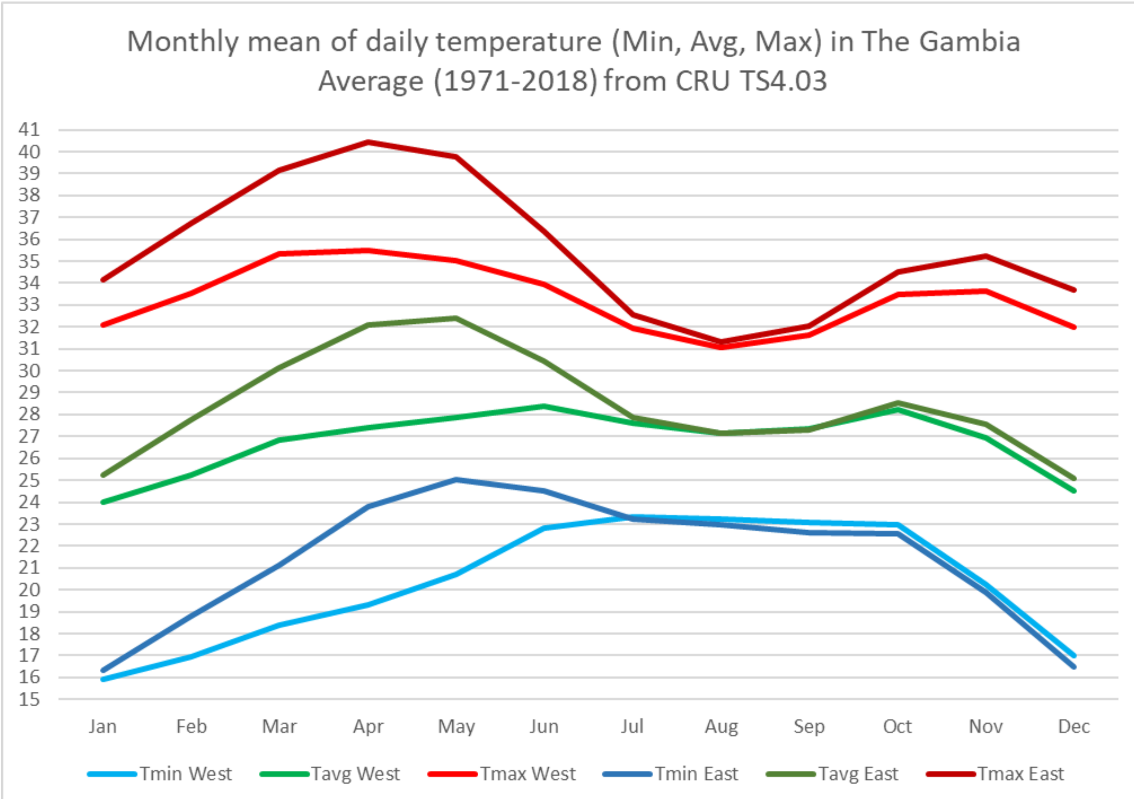


Figure 15: Monthly mean of daily average, maximum and minimum temperature in West and East of The Gambia calculated for the period 1971-2018 from CRU TS4.03

5.3. Projected changes in the climate

5.3.1. Precipitation

Considering the 21 models, the trend in annual rainfall is not significant. The inter-annual variability will continue to be high under both scenarios (Figure 16). It is noted that most models agreed on a negative signal of changes in rainfall over The Gambia especially in the east part of the country where the decrease is predicted to reach around -150mm per year for the RCP8.5 by the end of this century (Figure 17). This trend in rainfall in The Gambia will increase drought risk in the future.

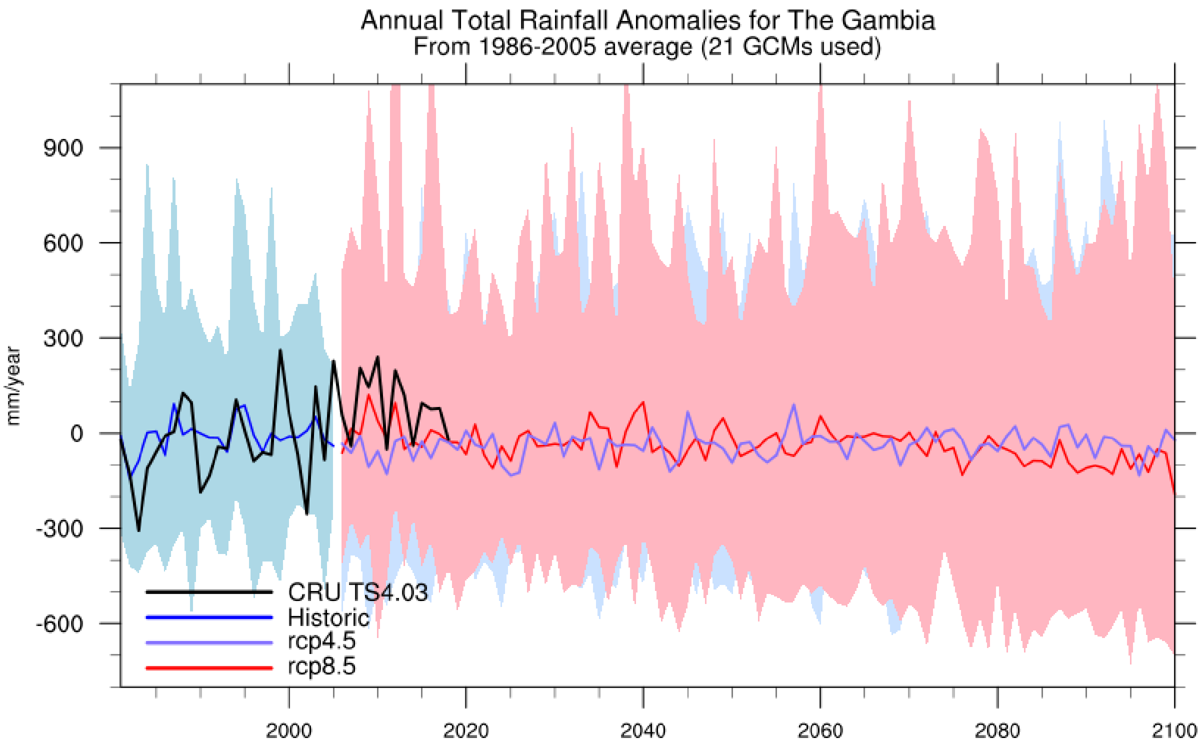


Figure 16: Changes in annual total rainfall in The Gambia for RCP4.5 and RCP8.5. Departures are calculated from 1986-2005 reference period. Black line represents observed change in annual total rainfall from CRU TS4.03

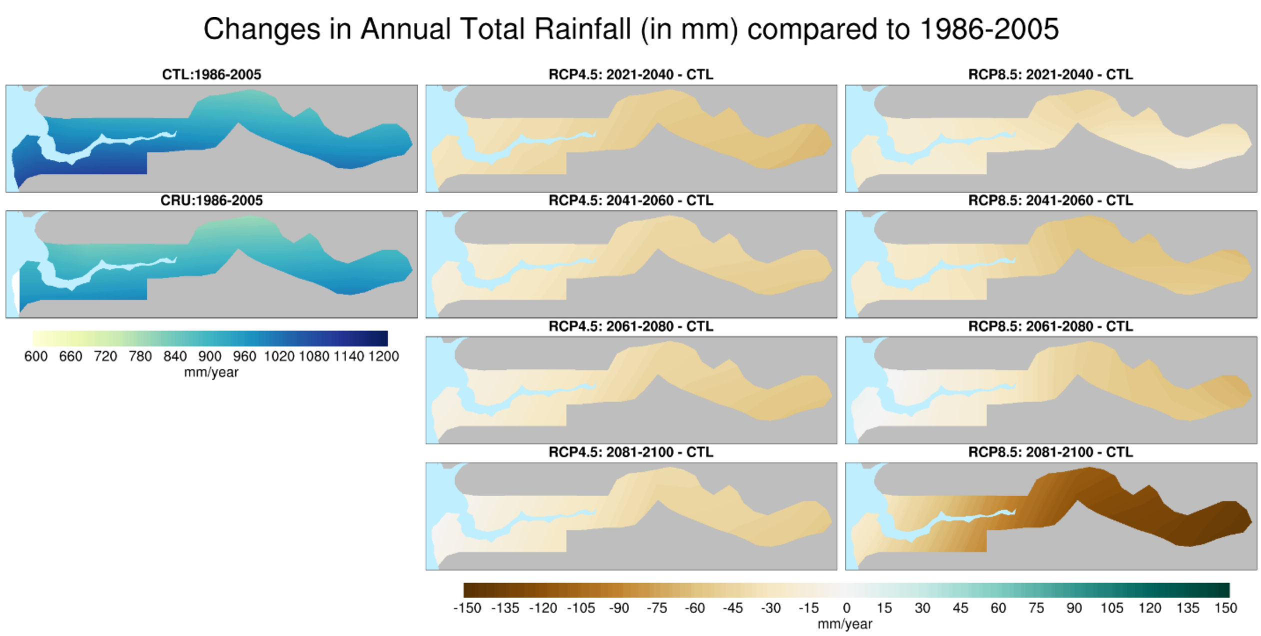


Figure 17: Changes in annual total rainfall for RCP4.5 and RCP8.5 over The Gambia. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the average of annual total rainfall from 21 models (top left) and (CRU) is the average annual total rainfall from CRU TS4.03 (bottom left).

5.3.2. Temperature

By the end of this century, the maximum and minimum temperatures will likely increase in The Gambia by +4.5 degrees Celsius for the RCP8.5 scenario and by +2 degrees Celsius for the RCP4.5 scenario (Figure 18 and 19). This increase in temperature will induce an increase in water demand by evapotranspiration and put the cropping systems at risk. Combined with the decrease in the annual rainfall, this will also impact negatively the growing season of many crops in The Gambia.

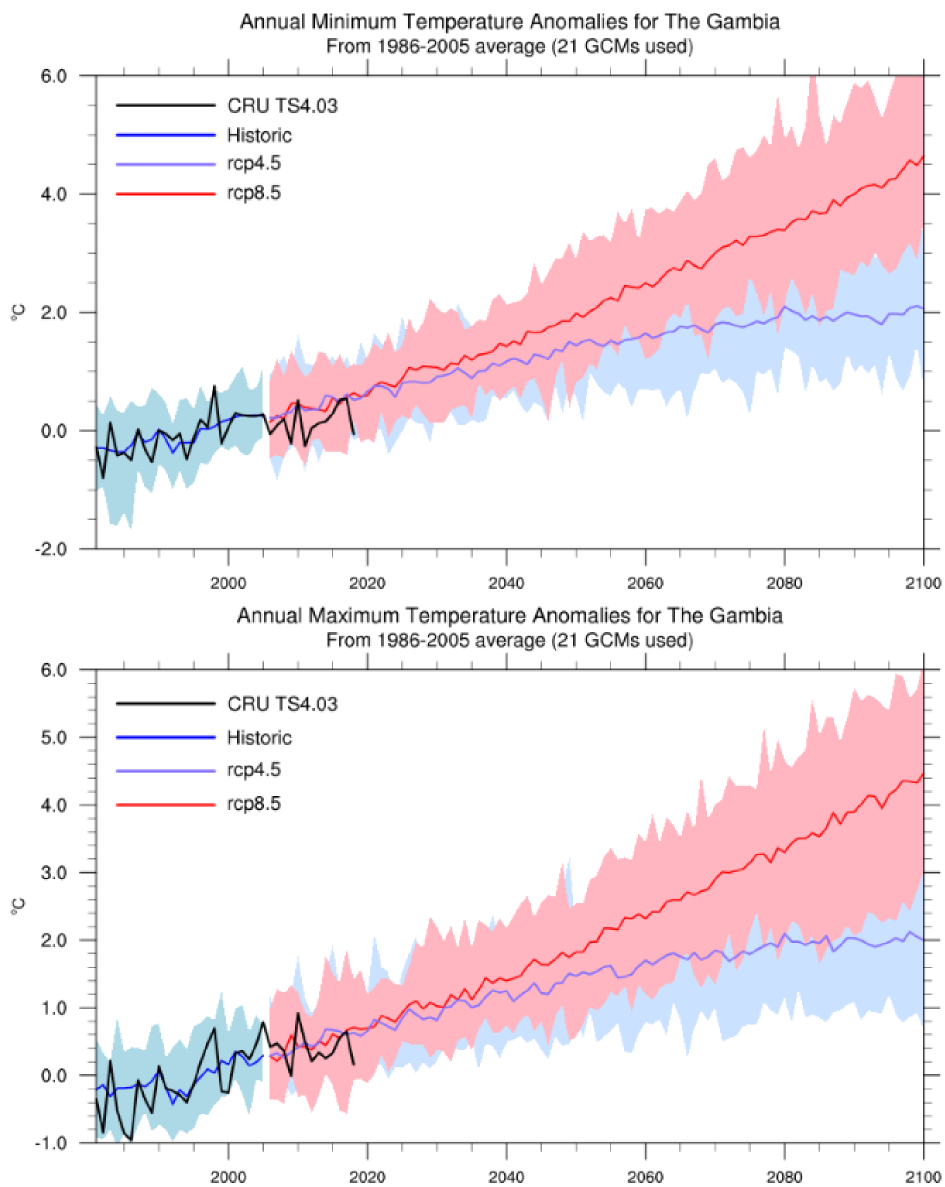


Figure 18: Changes in maximum and minimum temperatures for RCP4.5 and RCP8.5 compared to 1986-2005 reference period. Black line represents observed change in annual average of daily maximum and minimum temperatures from CRU TS4.03

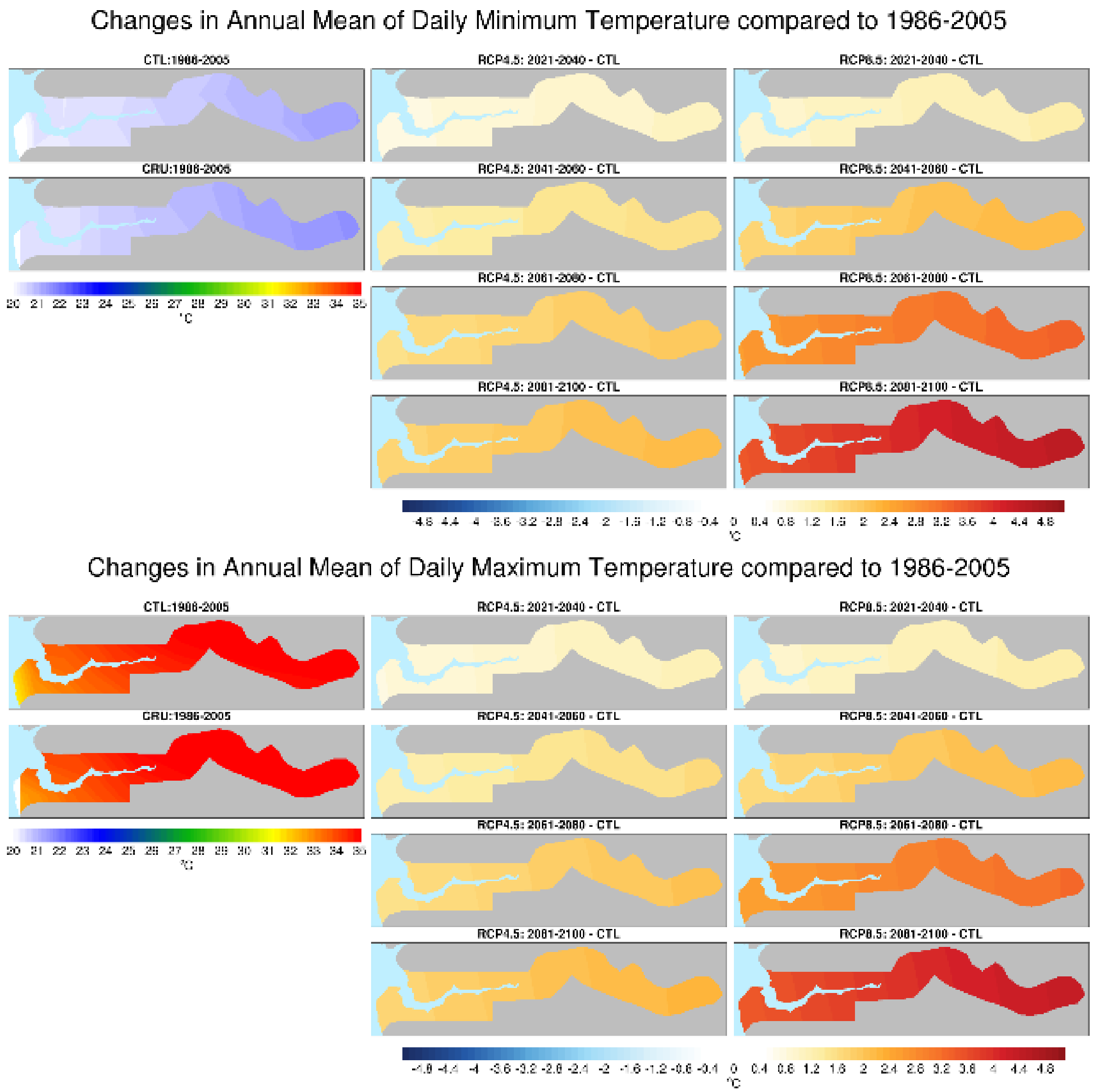


Figure 19: Changes in annual average of daily minimum (top panel) and maximum (bottom panel) temperatures for RCP4.5 and RCP8.5 over The Gambia. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the annual average of daily minimum and maximum temperature from 21 models (top left in both panels) and (CRU) is the annual average of daily minimum and maximum temperature from CRU TS4.03 (bottom left in both panels).

6. Observed and projected climate in Sierra Leone and Liberia

The climate in Sierra Leone and Liberia is tropical, hot and humid all year round with average temperatures ranging from 24 to 27 degrees Celsius (Figure 24). Temperature in Sierra Leone and Liberia can be as low as 18 degrees Celsius in January and December and as high as 34 degrees Celsius in March. The rainy season in Sierra Leone and Liberia spans from April to October followed by a very short dry period from December to February (Figure 22).

6.1. Climate data from the national weather stations

Observed daily temperature and rainfall from one weather station in Liberia and one in Sierra Leone (Figure 20) have been accessed through this website https://en.tutiempo.net/. This data has not been checked for consistency and quality. The period covered for these stations is given in table 5.

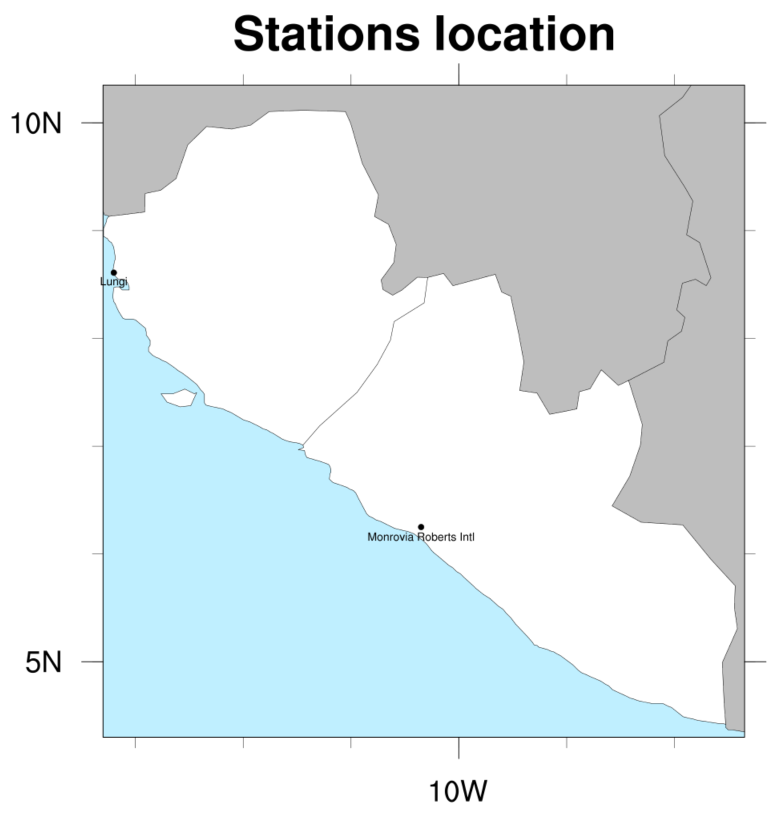


Figure 20: Weather stations

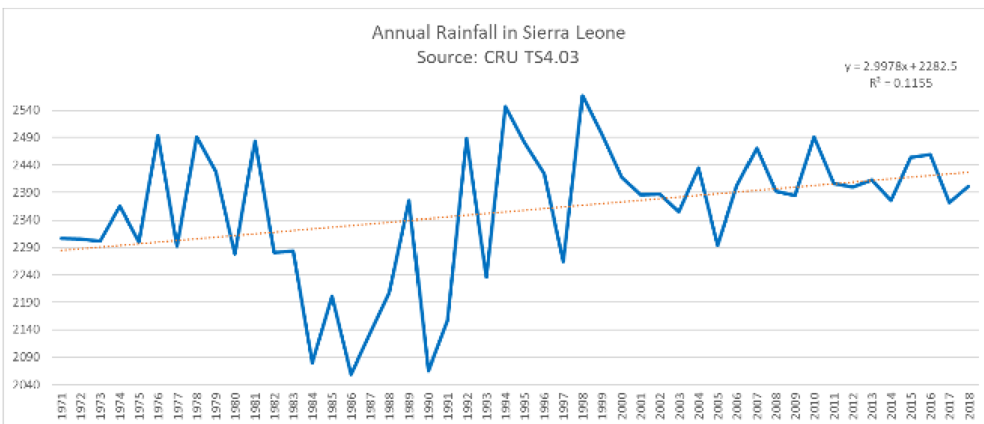
Table 5: Weather Stations in Sierra Leone and Liberia including available parameters and the number of missing values

Station name	WMO Code	Latitude	Longitude	Period	Parameters	%missing
Monrovia Roberts Intl	65660	6.25	-10.35	1971-2018	RR & T	36
Lungi	61856	8.61	-13.2	1973-2018	RR & T	31

6.2. Observed changes in the climate

6.2.1. Precipitation

The average annual total rainfall is around 2300mm/year and 2100mm/year in Sierra Leone and Liberia respectively. It has increased by 150mm and 170mm in 50 years in Sierra Leone and Liberia respectively and is characterized by a very high interannual variability (Figure 21). Rainfall in both countries varies on both decadal and inter-annual scales. Rainfall decreased to low levels in both countries during 1980s and increased significantly in 1990s. The main risk in both countries related to rainfall is floods and heavy single rainfall events.



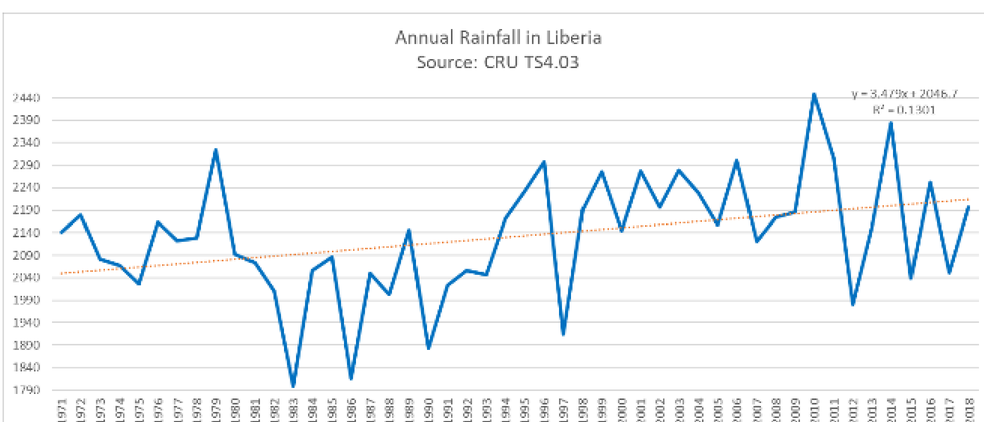
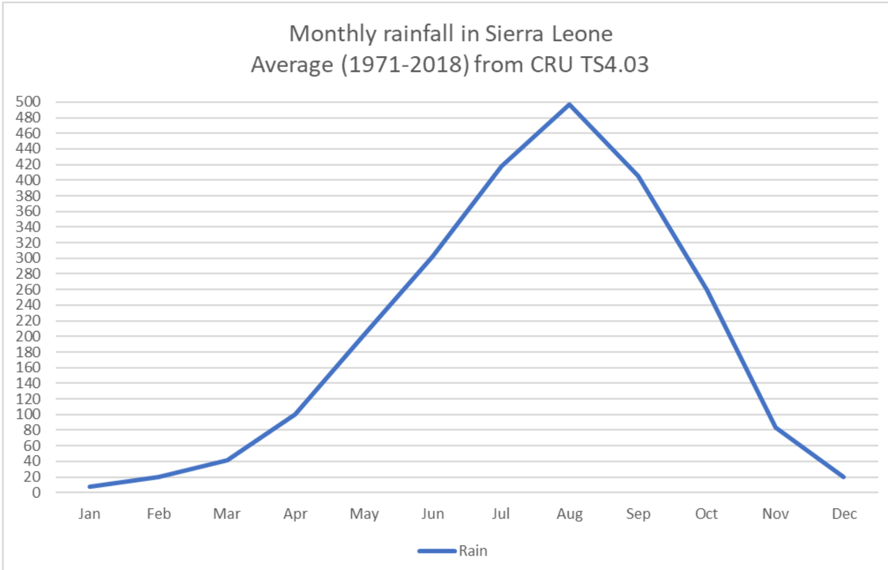


Figure 21: Annual rainfall in Sierra Leone (top) and Liberia (bottom) for the period 1971-2018 from CRU TS4.03



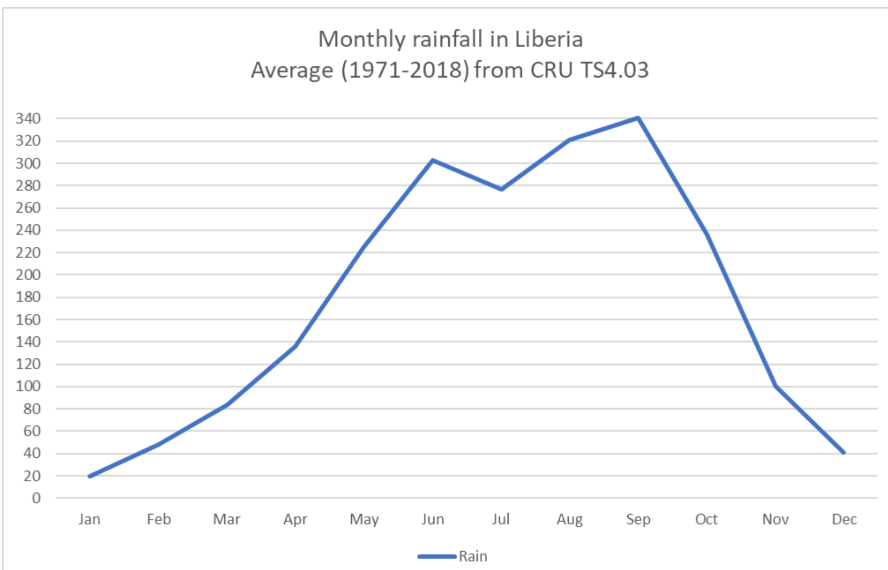
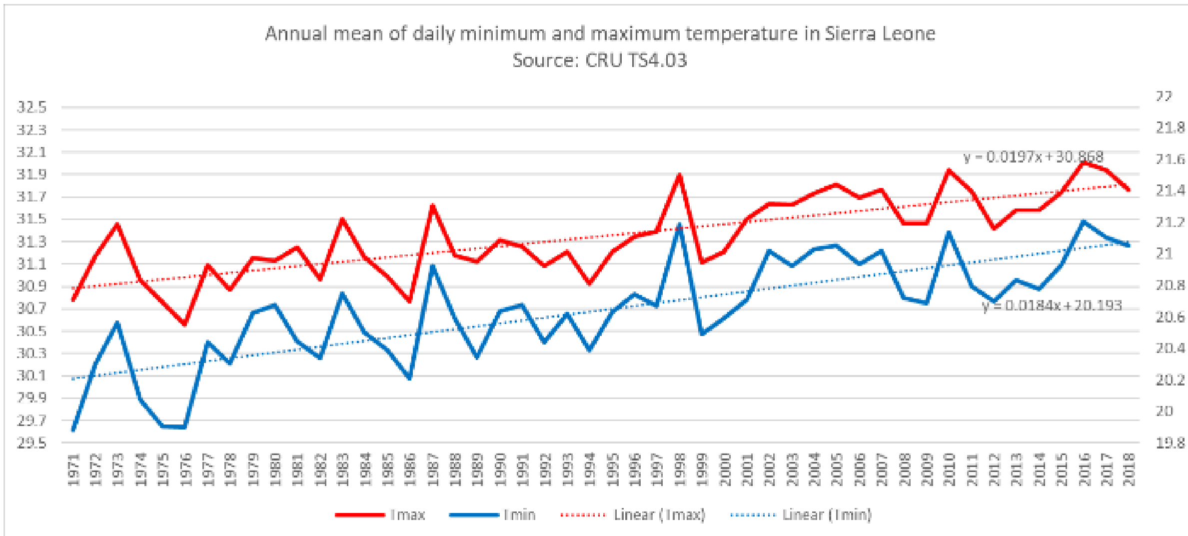


Figure 22: Monthly rainfall in Sierra Leone (top) and Liberia (bottom) calculated for the period 1971-2018 from CRU TS4.03

6.2.2. Temperature

Annual average temperature in Togo has increased by 1 degree Celsius in 50 years. Between 1971 and 2018, temperature has shifted from around 33.5 degrees Celsius to almost 34.5 degrees Celsius (Figure 23). At this rate (+2 degrees Celsius per 100 years), the average temperature in Togo will reach 35.5 degrees Celsius around 2070. Daily temperature data indicate that the frequency of hot days and nights has increased significantly in all seasons.



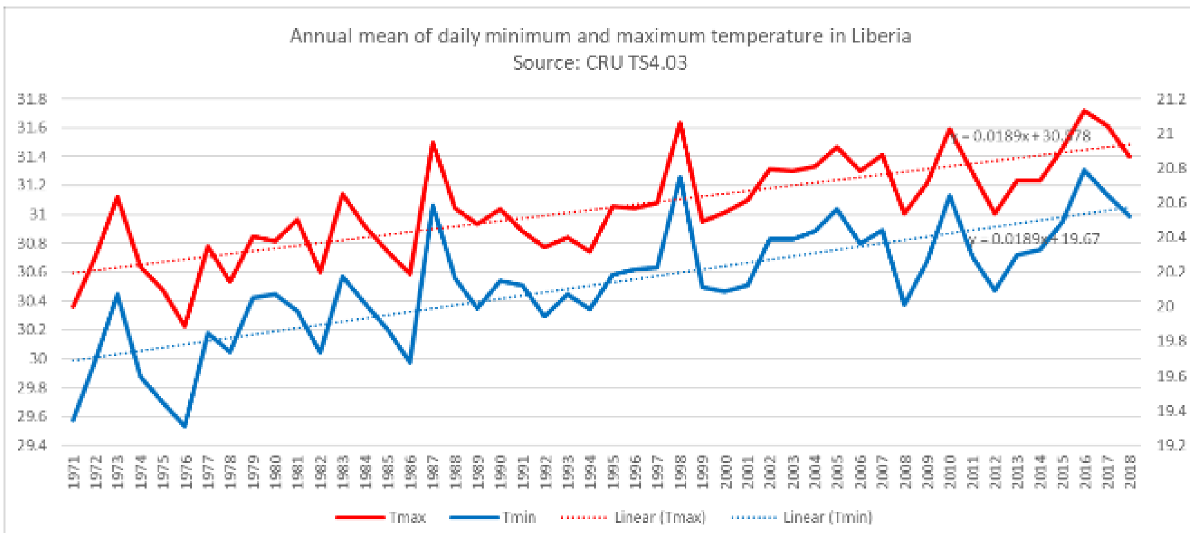
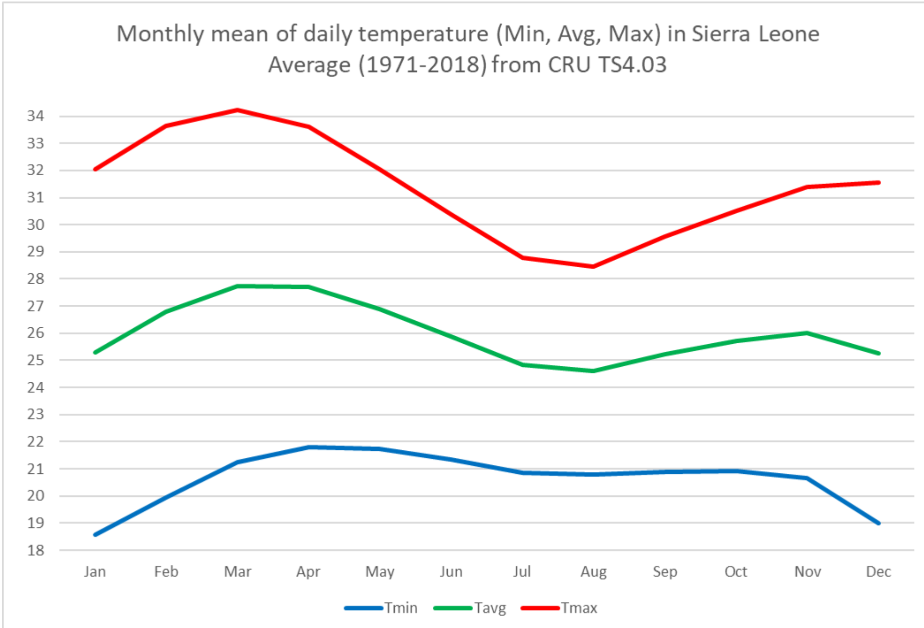


Figure 23: Annual mean of daily minimum and maximum temperature in Sierra Leone (top) and Liberia (bottom) for the period 1971-2018 from CRU TS4.03



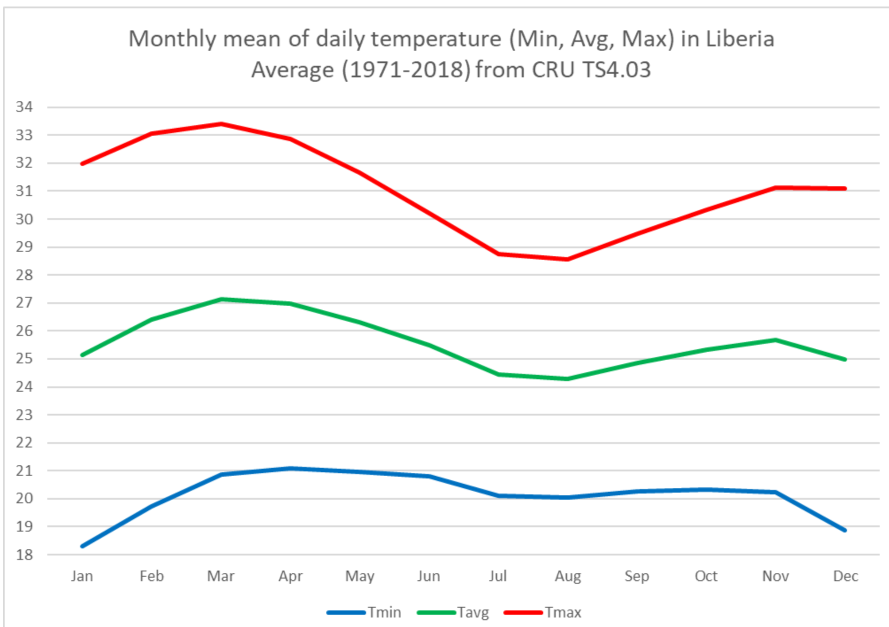


Figure 24: Monthly mean of daily average, maximum and minimum temperature in Sierra Leone (top) and Liberia (bottom) calculated for the period 1971-2018 from CRU TS4.03

6.3. Projected changes in the climate

6.3.1. Precipitation

Considering the 21 models, the trend in annual rainfall is not significant in both countries. The inter-annual variability will continue to be high under both scenarios (Figure 25). It is noted that most models agreed on a positive signal of changes in rainfall over Sierra Leone and Liberia. the increase is predicted to reach around 100mm per year (Figure 26). This increase is not always beneficial to agriculture as analyses of extreme events such as floods and drought show that these phenomena will increase in both magnitude and frequency in the future under both scenarios putting the agriculture and other sectors at risk.

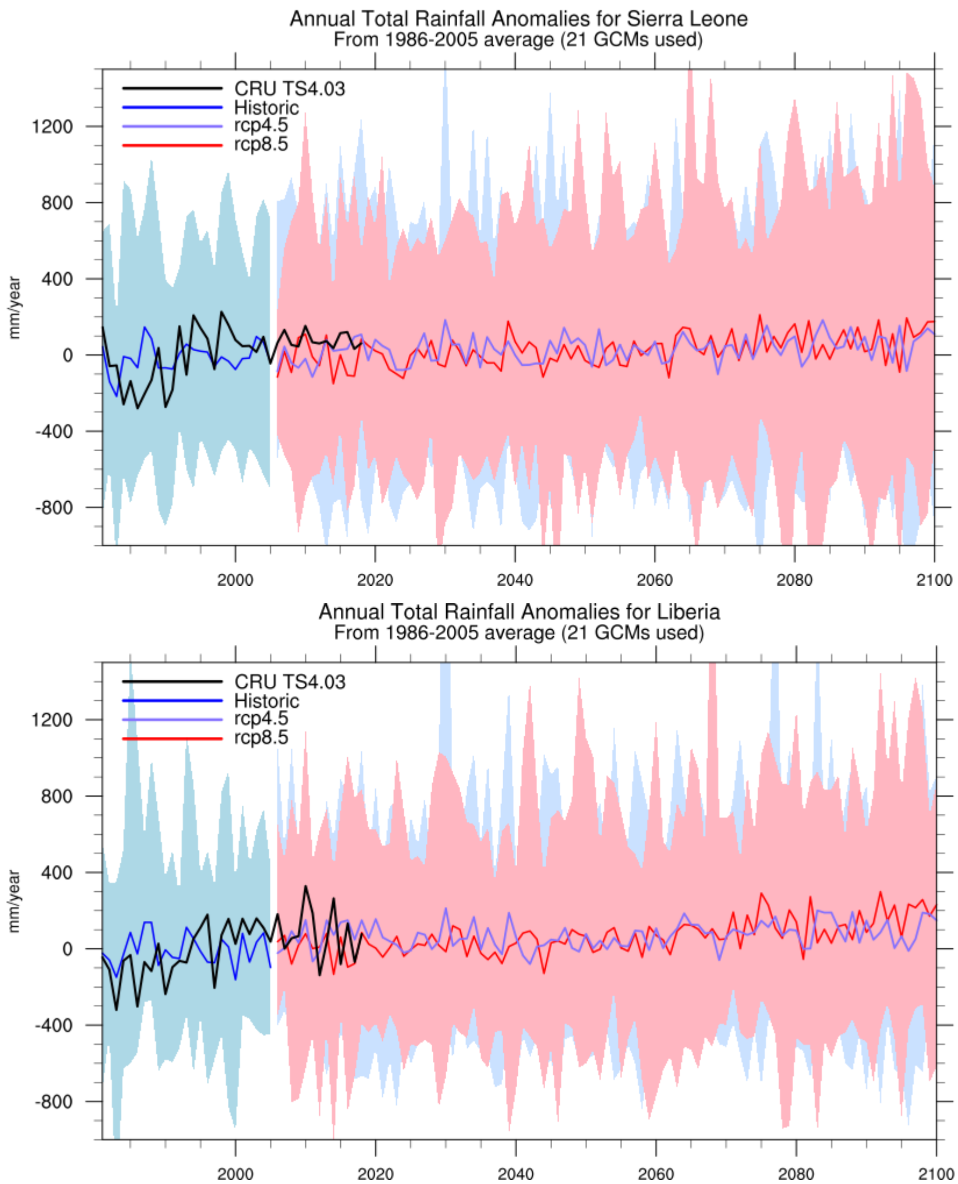


Figure 25: Changes in annual total rainfall in Sierra Leone (top) and Liberia (bottom) for RCP4.5 and RCP8.5. Departures are calculated from 1986-2005 reference period. Black line represents observed change in annual total rainfall from CRU TS4.03

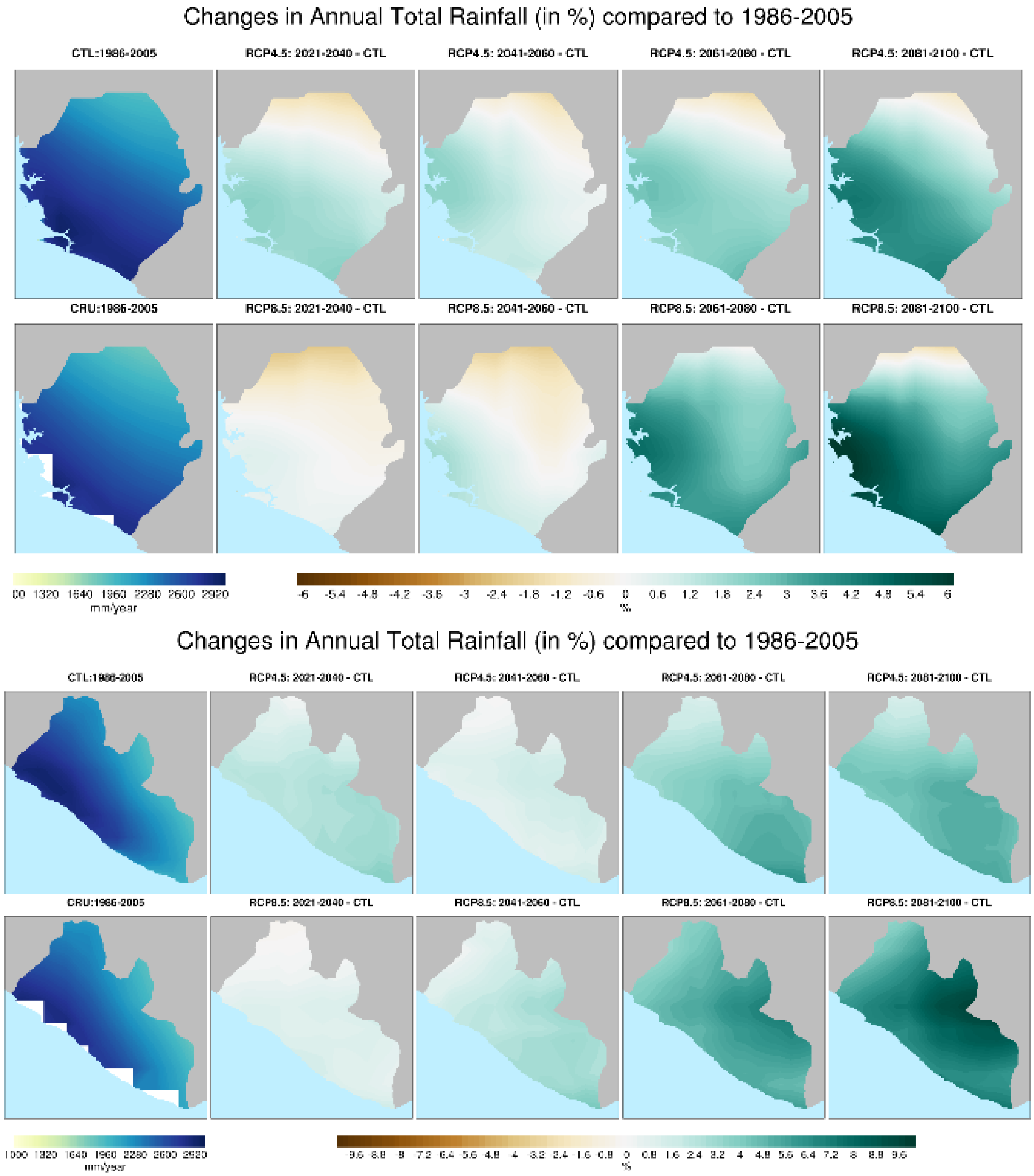


Figure 26: Percentage changes in annual total rainfall for RCP4.5 and RCP8.5 over Sierra Leone (top) and Liberia (bottom). Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the average of annual total rainfall from 21 models (top left) and (CRU) is the average annual total rainfall from CRU TS4.03 (bottom left).

6.3.2. Temperature

By the end of this century, the maximum and minimum temperatures will likely increase in both countries by +4.5 degrees Celsius for the RCP8.5 scenario and by +2 degrees Celsius for the RCP4.5 scenario (Figure 27, 28-a and 28-b). This increase in temperature will induce an increase in water demand by evapotranspiration and put the cropping systems at risk. It will also impact the growing season of many crops in both countries.

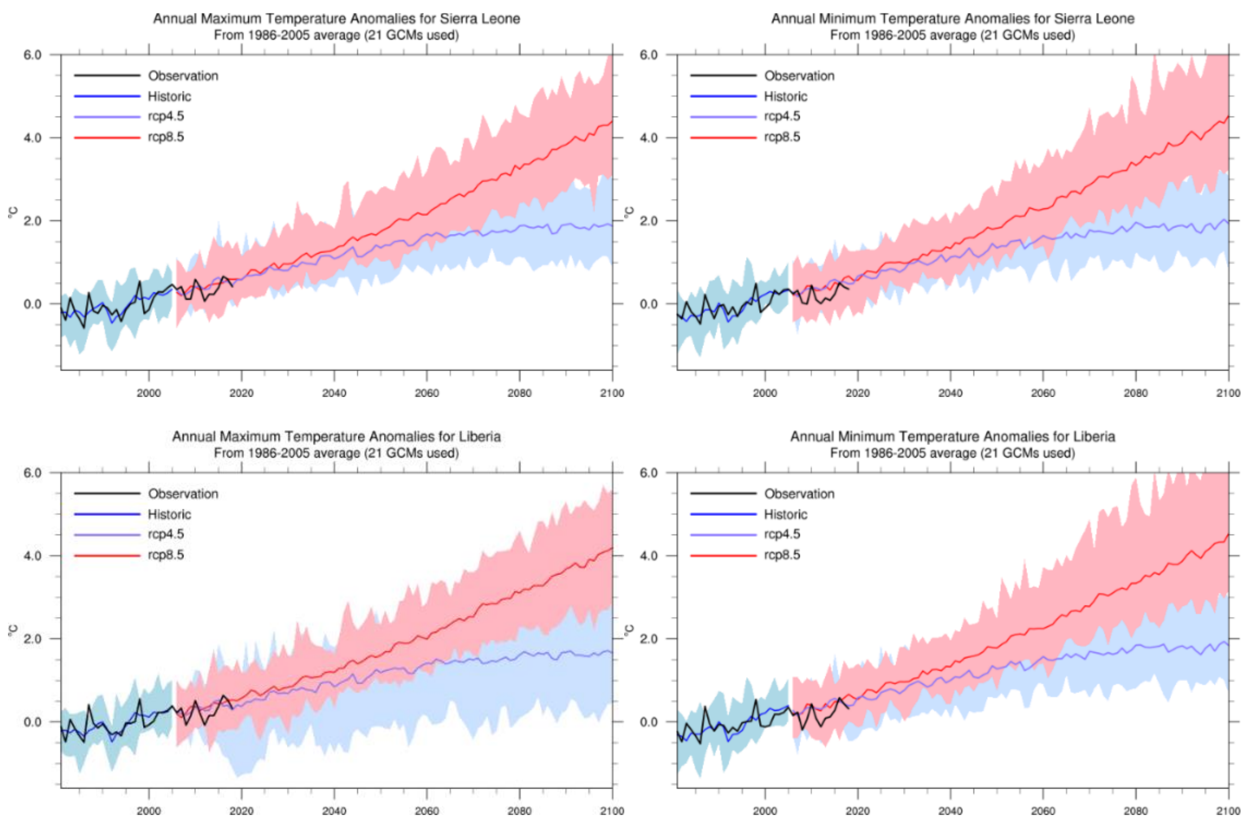
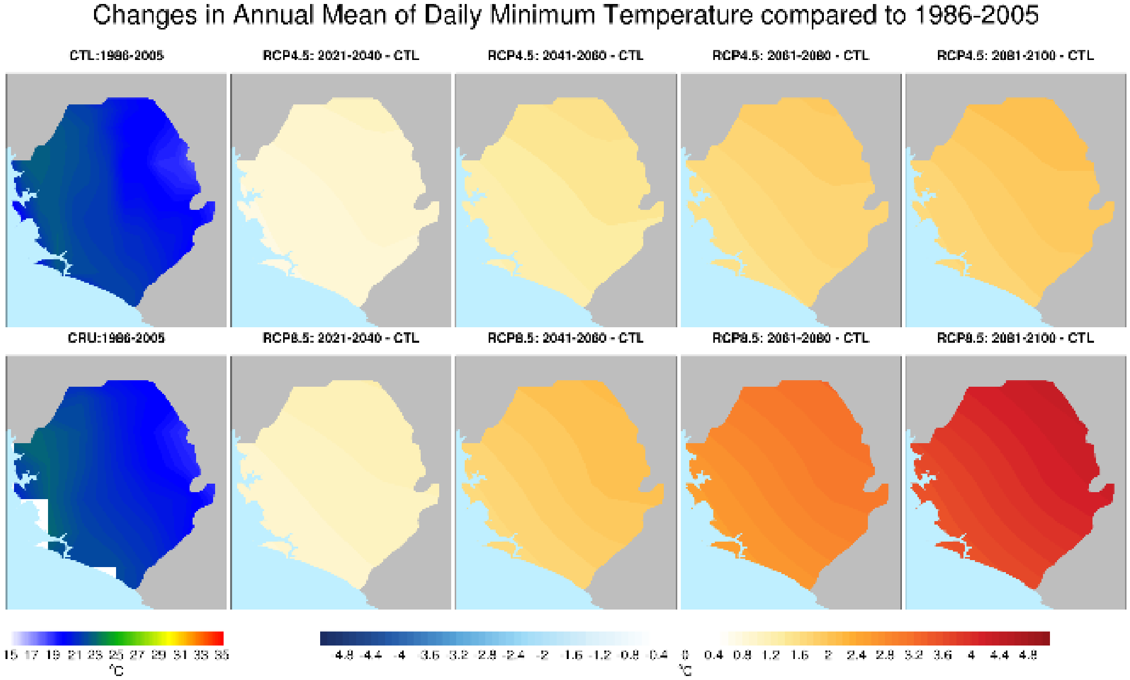


Figure 27: Changes in maximum and minimum temperatures in Sierra Leone (top) and Liberia (bottom) for RCP4.5 and RCP8.5 compared to 1986-2005 reference period. Black line represents observed change in annual average of daily maximum and minimum temperatures from CRU TS4.03



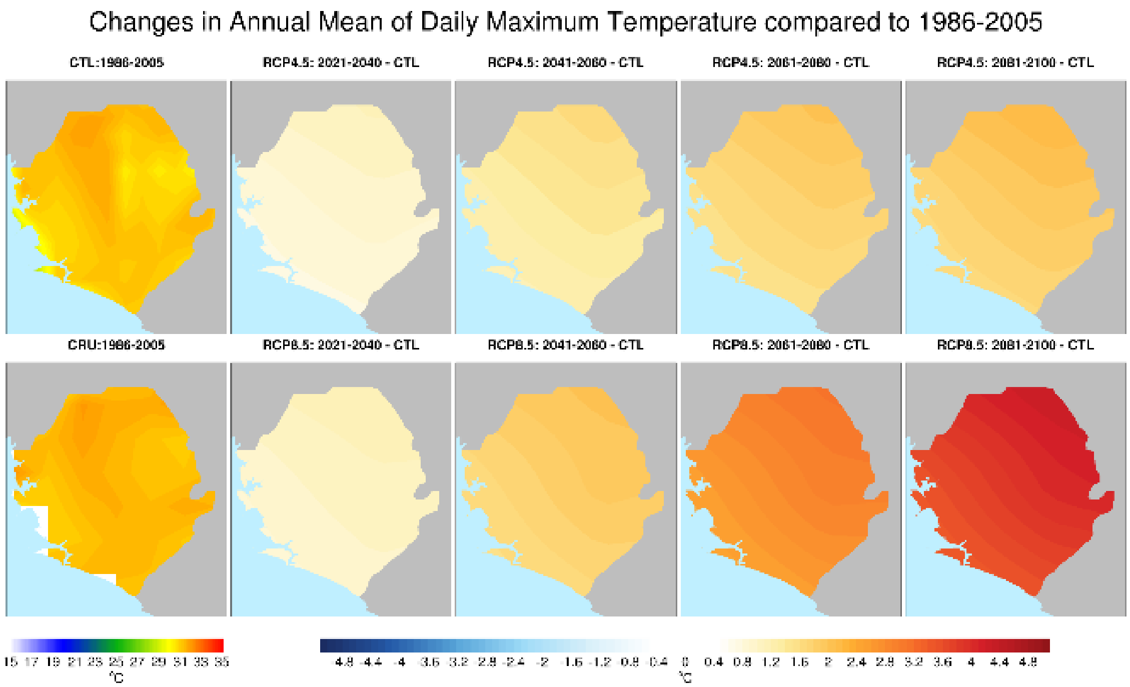


Figure 28-a: Changes in annual average of daily minimum and maximum temperatures for RCP4.5 and RCP8.5 over Sierra Leone. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the annual average of daily minimum and maximum temperature from 21 models (top left) and (CRU) is the annual average of daily minimum and maximum temperature from CRU TS4.03 (bottom left).

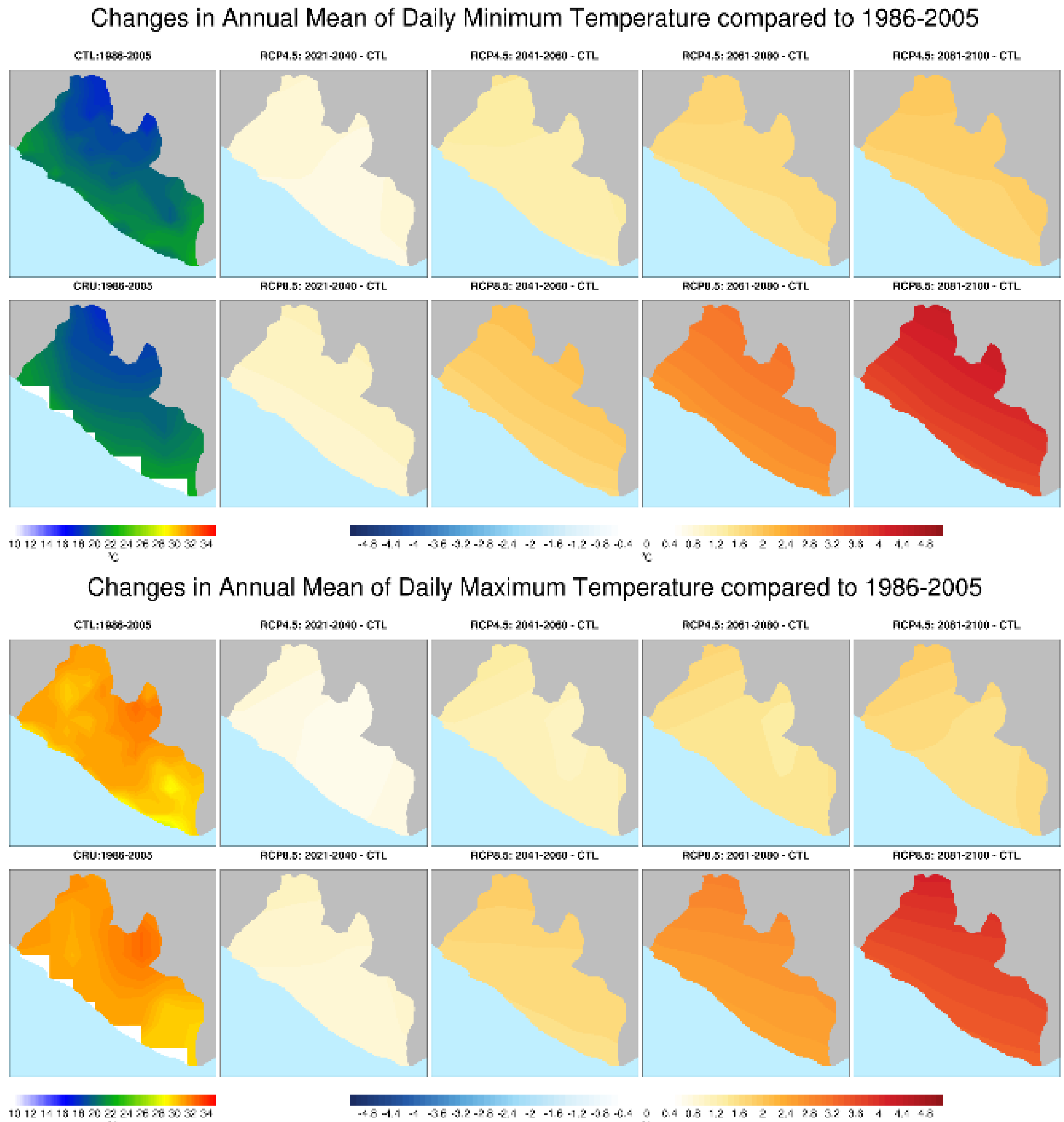


Figure 29-b: Changes in annual average of daily minimum and maximum temperatures for RCP4.5 and RCP8.5 over Liberia. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the annual average of daily minimum and maximum temperature from 21 models (top left) and (CRU) is the annual average of daily minimum and maximum temperature from CRU TS4.03 (bottom left).

7. Observed and projected climate in Mozambique

Mozambique is largely dominated by tropical climate except in the highland in the north and west and the coastline is subject to the regular seasonal influence of the Indian Ocean monsoon rains. The monsoon influence is strongest in the northeast and is impacting less the climate in the south. The average temperatures ranging from 17 to 24 degrees Celsius in the center to about 19 to 27 degrees Celsius in the southern most regions (Figure 33). Temperature in the Center can be as low as 11 degrees Celsius in July and as high as 32 degrees Celsius in October and November. Mozambique also has a dry climate in the South and characteristics of a tropical savanna in the North. The rainy season in Mozambique takes place from November to April (Figure 31).

7.1. Climate data from the national weather stations

Observed monthly average temperature and rainfall from the weather stations in Mozambique located all over the country (Figure 29) has been accessed through the KNMI website https://climexp.knmi.nl. Data has been extracted from the Global Historical Climatology Network (GHCN) that is managed by NOAA. Very few stations have complete timeseries. Missing data during the last decade is common between all stations. The period covered for each station is given in table 6.

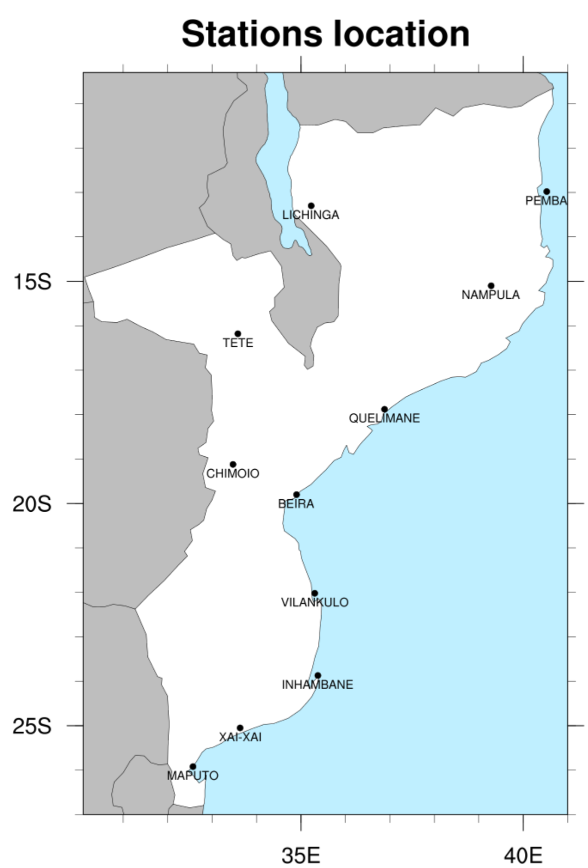


Figure 30: Weather stations

Table 6: Weather Stations in Mozambique including available parameters and the percentage of missing days

Station name	WMO Code	Latitude	Longitude	Period	Parameters	%missing
PEMBA	672150	-12.98	40.53	1973-2018	RR & T	77
LICHINGA	672170	-13.30	35.23	1951-2018	RR & T	35
NAMPULA	672370	-15.10	39.28	1956-2019	RR & T	35
TETE	672610	-16.18	33.58	1952-2019	RR & T	45
QUELIMANE	672830	-17.88	36.88	1951-2018	RR & T	30
CHIMOIO	672955	-19.12	33.47	1951-2018	RR & T	38
BEIRA	672970	-19.80	34.90	1951-2018	RR & T	38
VILANKULO	673150	-22.02	35.31	1973-2018	RR	88
INHAMBANE	673230	-23.87	35.38	1951-2018	RR & T	34
XAI-XAI	673350	-25.05	33.63	1951-2018	RR & T	35
MAPUTO	673410	-25.92	32.57	1973-2018	RR & T	59

7.2. Observed changes in the climate

7.2.1. Precipitation

The average annual total rainfall in Mozambique is around 1100mm/year, 850mm/year and 750mm/year in the North, Center and South respectively. It has decreased by 130mm in 50 years in the South and did not change a lot in the North over the last 50 years. The rainfall in Mozambique is characterized by a very high interannual variability (Figure 30). Rainfall in Mozambique varies on both decadal and inter-annual scales. The erratic characteristic of rain in Mozambique put the country under risk of drought and river/coastal storm surge flooding. Increased frequency and severity of intense storms, droughts and floods are likely to jeopardize the development efforts in the country. For example, El Niño conditions in 2015–2016 caused the worst drought in 35 years, reducing food availability by 15%. Food insecurity caused by the drought worsened in 2017 with Cyclone Dineo, which damaged crops and destroyed infrastructure.

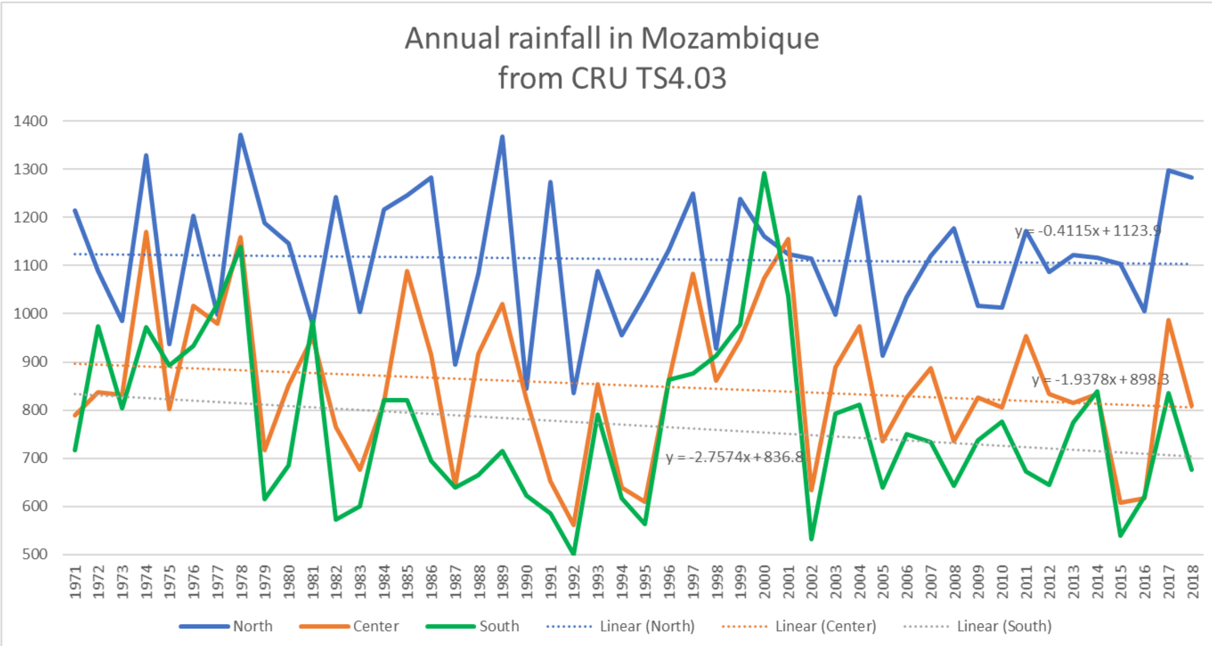


Figure 31: Annual rainfall in Mozambique for the period 1971-2018 from CRU TS4.03

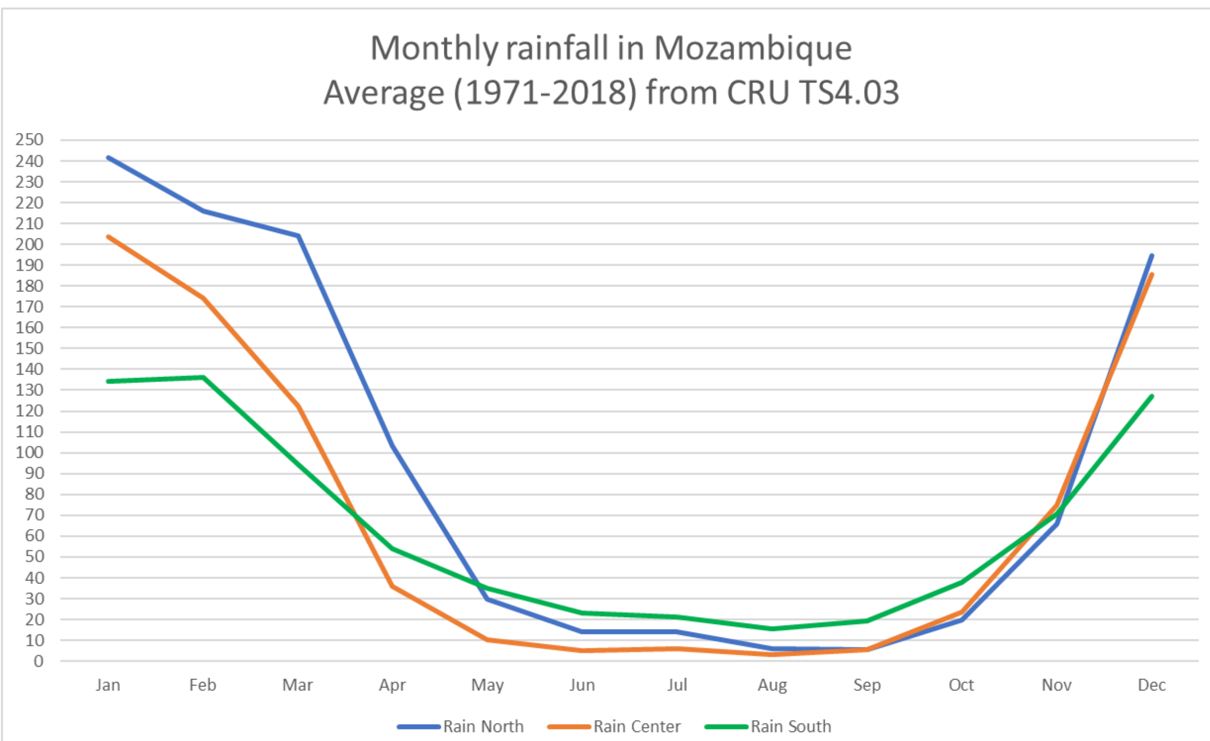


Figure 32: Monthly rainfall in South, Center and North of Mozambique calculated for the period 1971-2018 from CRU TS4.03

7.2.2. Temperature

Annual average temperature in northern part of Mozambique has increased by 1 degree Celsius in 50 years and by 1.3 to 1.4 degrees Celsius in 50 years in the central and southern parts respectively. Between 1971 and 2018, temperature has shifted from around 23.5 degrees Celsius to almost 24.5 degrees Celsius in the North and from 23 degrees Celsius to almost 24.4 in the South and from 21.8 to 23.1 degrees Celsius in the Center of the country (Figure 32). Daily temperature data indicate that the frequency of hot days and nights has increased significantly in all seasons.

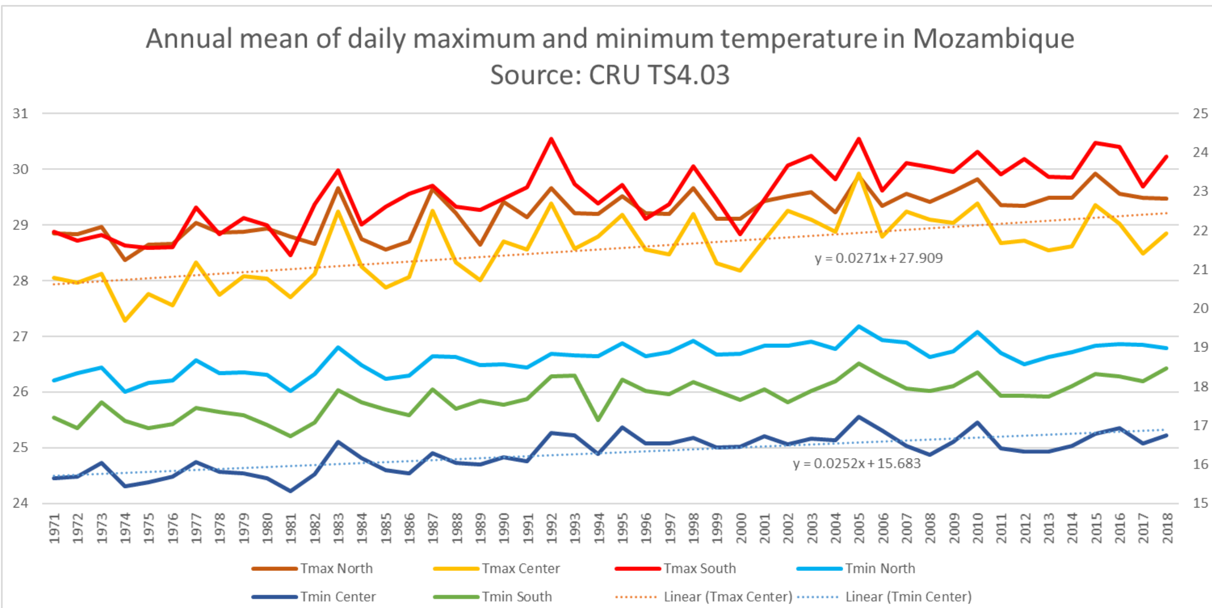


Figure 33: Annual mean of daily maximum temperature in Togo for the period 1971-2018 from CRU TS4.03

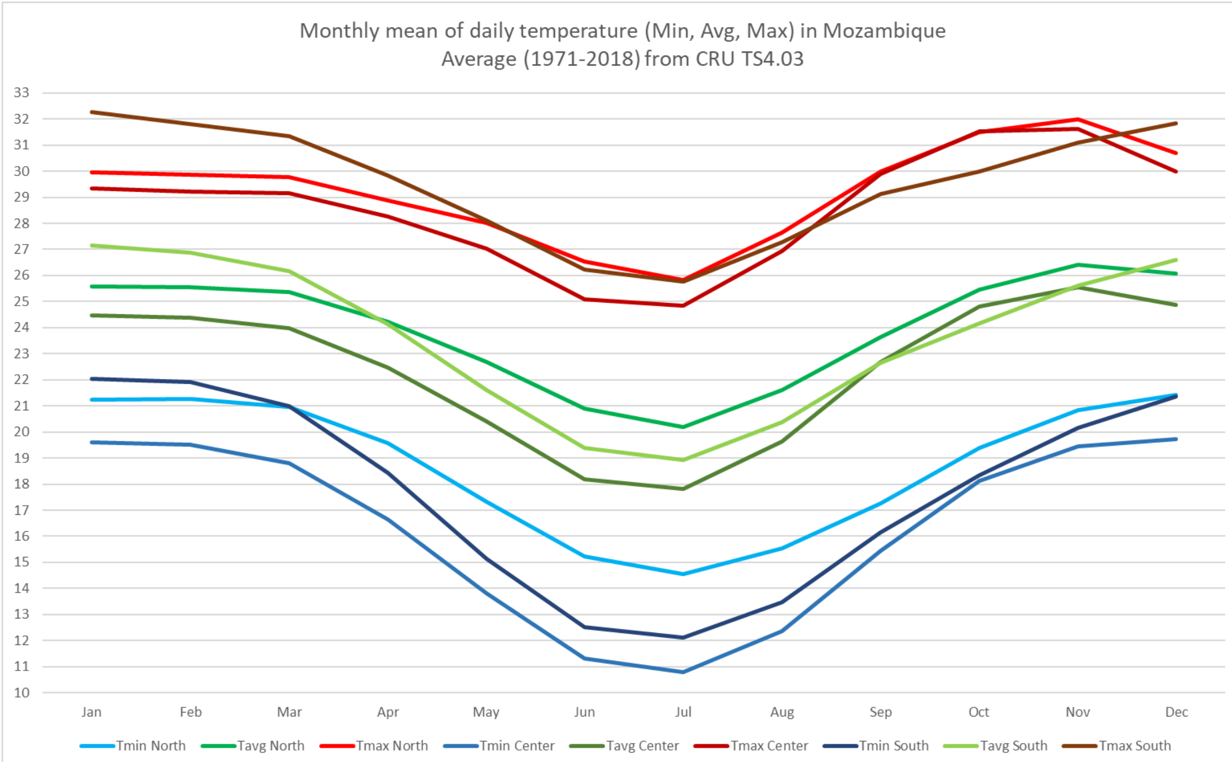


Figure 34: Monthly mean of daily average, maximum and minimum temperature in South, Center and North of Mozambique calculated for the period 1971-2018 from CRU TS4.03

7.3. Projected changes in the climate

7.3.1. Precipitation

Considering the 21 models, the trend in annual rainfall is not significant. The inter-annual variability will continue to be high under both scenarios (Figure 34). It is noted that most models agreed on a positive signal of changes in rainfall over the northern and central parts of country and a negative trend in the south (Figure 35). This increase in rainfall in the North and will likely increase the risk of floods and to the South, the decrease in annual rainfall will likely exacerbate the drought risk.

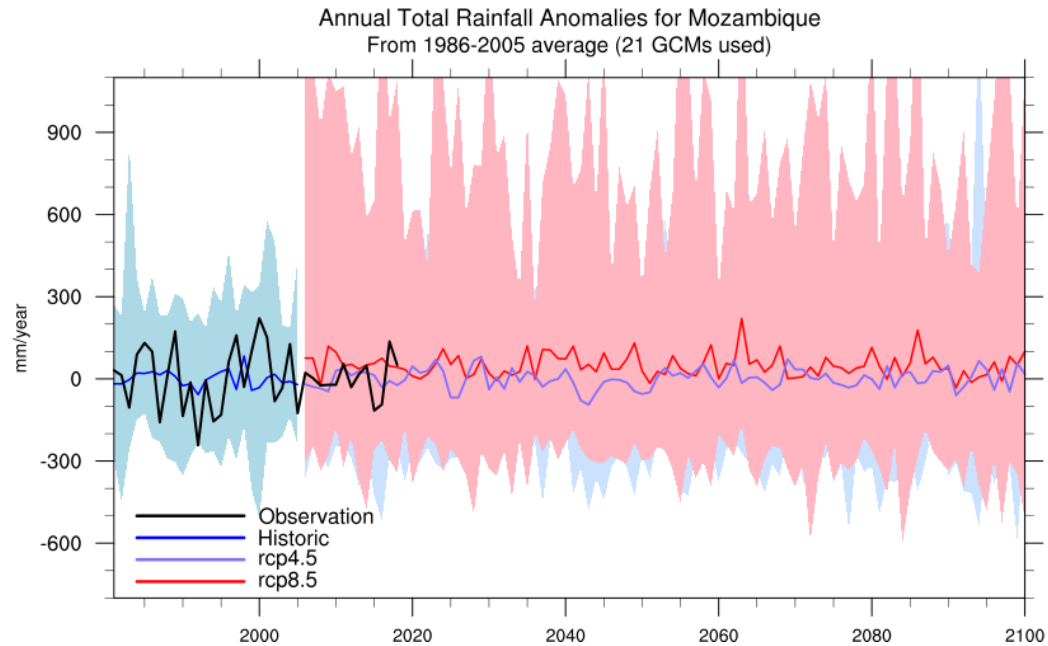


Figure 35: Changes in annual total rainfall in Mozambique for RCP4.5 and RCP8.5. Departures are calculated from 1986-2005 reference period. Black line represents observed change in annual total rainfall from CRU TS4.03

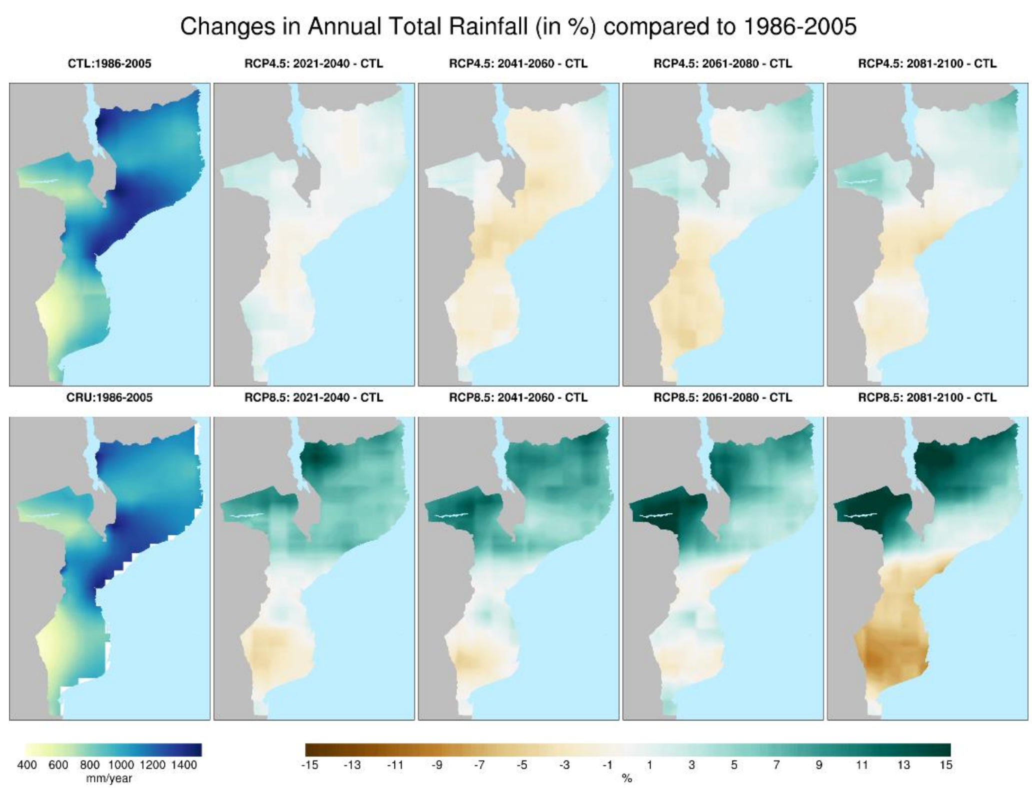


Figure 36: Percentage changes in annual total rainfall for RCP4.5 and RCP8.5 over Mozambique. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the average of annual total rainfall from 21 models (top left) and (CRU) is the average annual total rainfall from CRU TS4.03 (bottom left).

7.3.2. Temperature

By the end of this century, the maximum and minimum temperatures will likely increase in Mozambique by +5 degrees Celsius for the RCP8.5 scenario and by +2 degrees Celsius for the RCP4.5 scenario (Figure 36 and 37). This increase in temperature will induce an increase in water demand by evapotranspiration and put the cropping systems at risk. It will also impact the growing season of many crops in Mozambique.

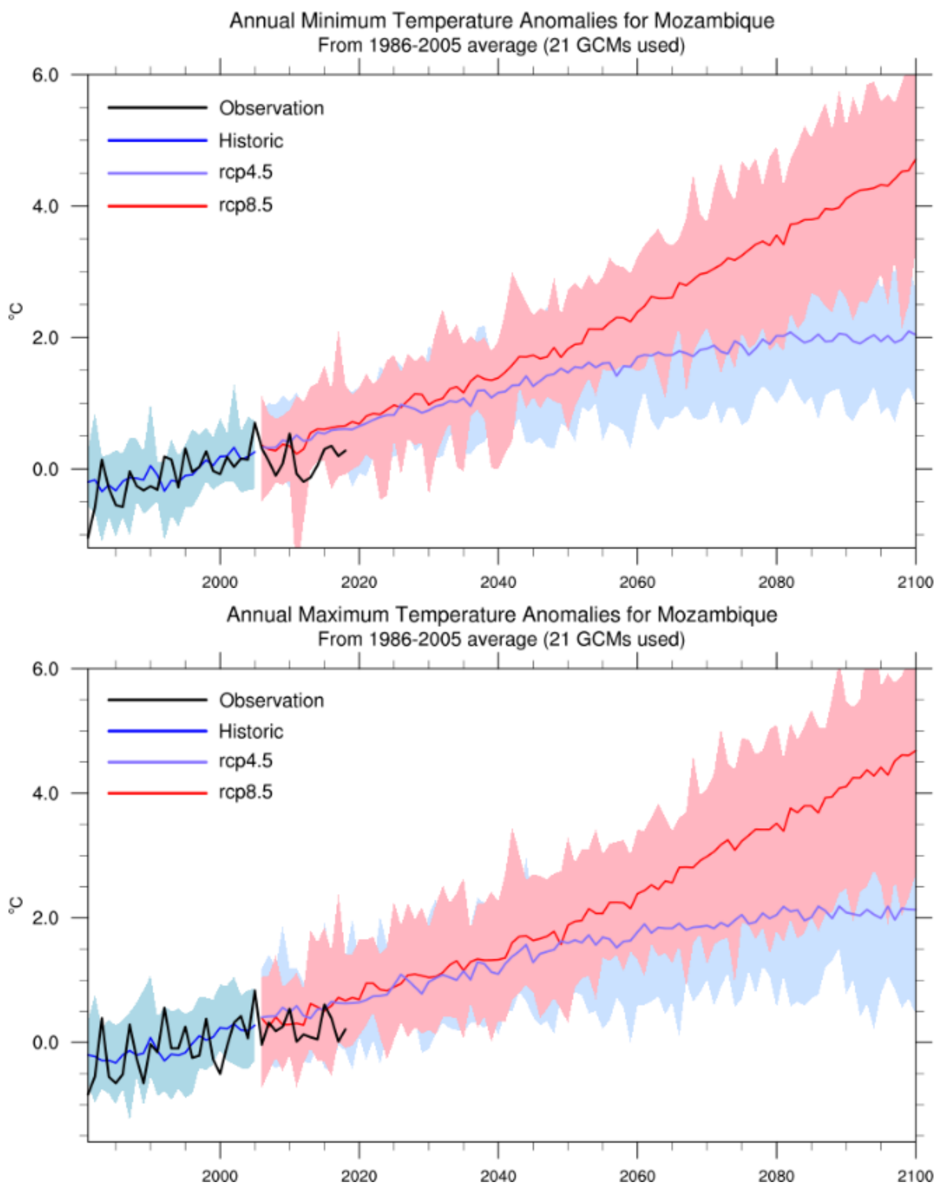


Figure 37: Changes in maximum (top) and minimum (bottom) temperatures for RCP4.5 and RCP8.5 compared to 1986-2005 reference period. Black line represents observed change in annual average of daily maximum and minimum temperatures from CRU TS4.03

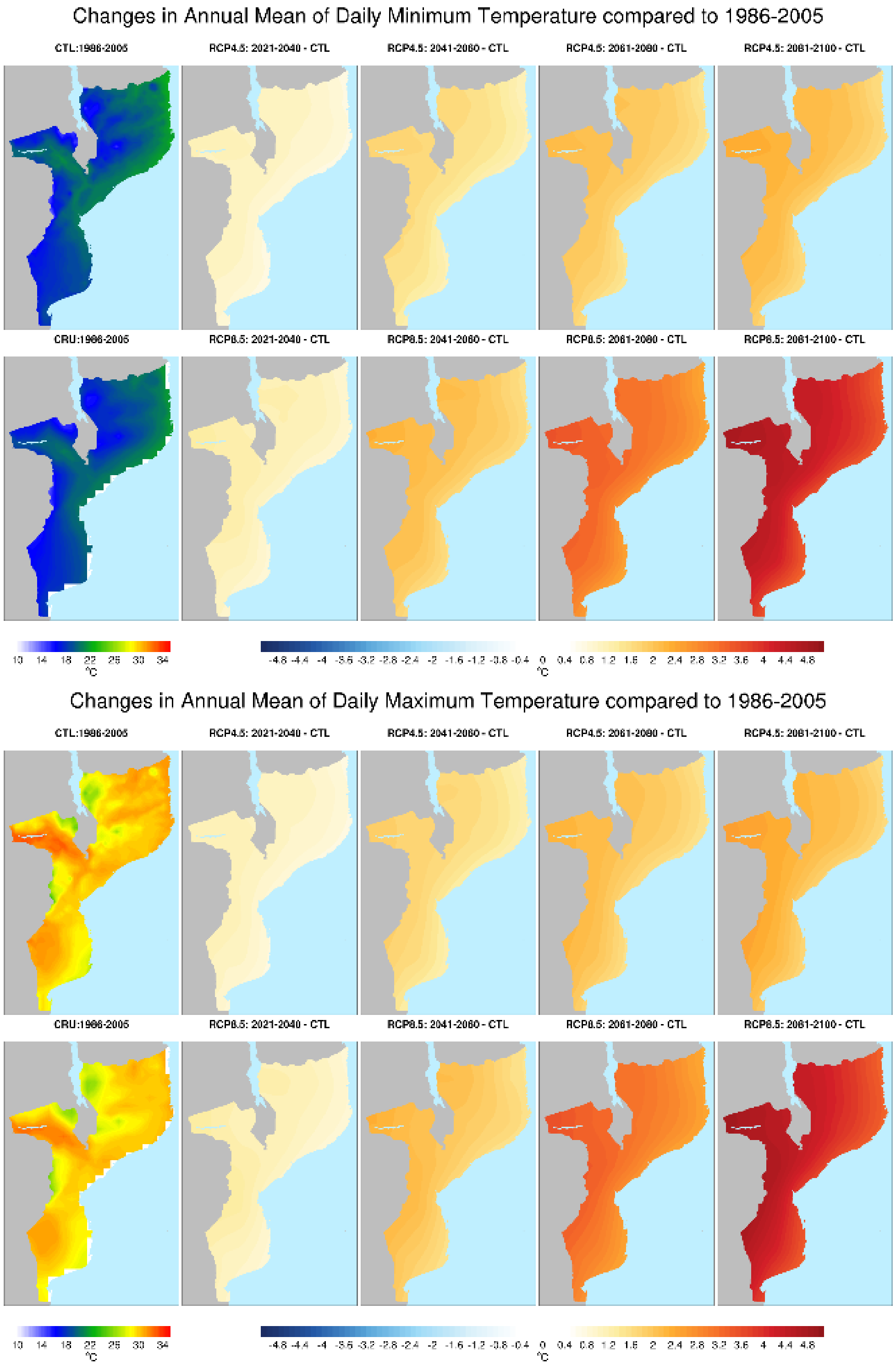


Figure 38: Changes in annual average of daily minimum (left panel) and maximum (right panel) temperatures for RCP4.5 and RCP8.5 over Mozambique. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the annual average of daily minimum and maximum temperature from 21 models (top left in both panels) and (CRU) is the annual average of daily minimum and maximum temperature from CRU TS4.03 (bottom left in both panels).

8. Observed and projected climate in Botswana

Botswana has a semi-arid climate, characterized by hot summers and mild winters. The country experiences a distinct dry season from May to September, with cooler temperatures ranging from 5°C to 25°C. During the hot, wet season, from October to April, temperatures can soar between 20°C and 40°C, particularly in the northern and central regions. Rainfall is highly variable, with most of the annual precipitation occurring during the wet season (October to April). The northern regions receive between 500 to 650 mm of rainfall, while the southern and western parts, which are more arid, typically receive less than 250 mm per year. Droughts are common, contributing to Botswana's overall dry conditions.

8.1. Climate data from the national weather stations

Observed monthly rainfall from the weather stations in Botswana located mainly in the South and the East of the country (Figure 38) has been provided by NARDI. Very few stations have incomplete time series. The period covered for each station is given in table 7.

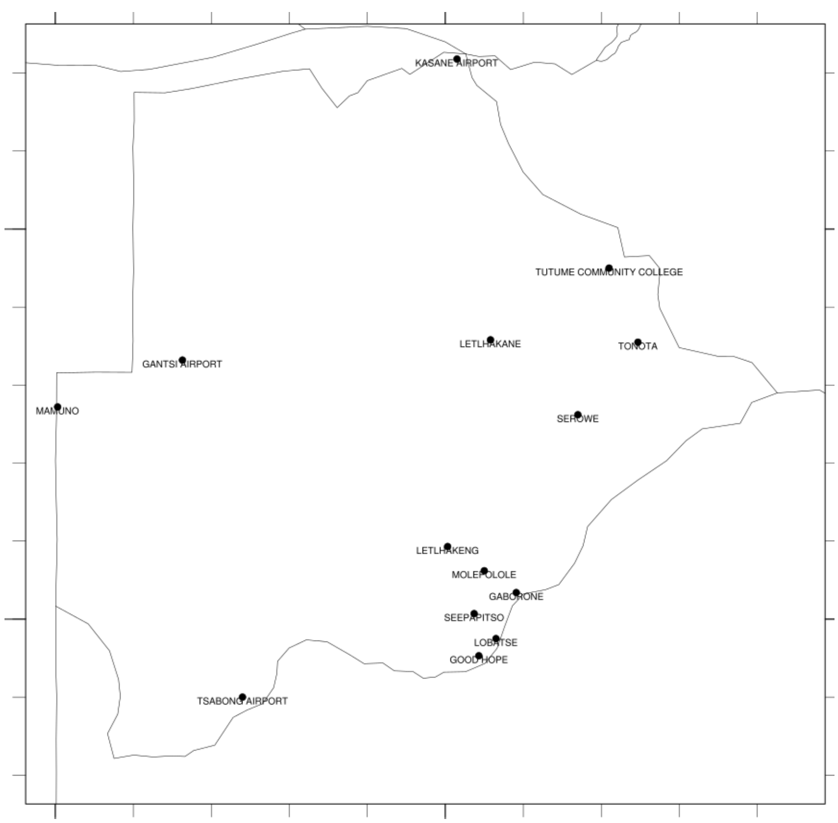


Figure 39: Weather stations in Botswana from where rainfall data was collected

Table 7: Weather Stations in Botswana including available rainfall data and the percentage of missing months

Station name	Latitude	Longitude	Period	%missing months
GABORONE	-24.66	25.91	1980-2021	0
LOBATSE	-25.25	25.65	1971-2019	0
GOOD HOPE	-25.47	25.43	1979-2019	1
GANTSI AIRPORT	-21.68	21.63	1971-2020	0
MAMUNO	-22.28	20.03	1971-2021	14
LETLHAKENG	-24.07	25.03	1979-2015	9
TONOTA	-21.45	27.47	1971-2019	1
KASANE AIRPORT	-17.82	25.15	1979-2020	0
TSABONG AIRPORT	-26.00	22.40	1979-2022	5
SEEPAPITSO	-24.93	25.37	1990-2015	12
TUTUME COMMUNITY COLLEGE	-20.50	27.10	1994-2021	4
MOLEPOLOLE	-24.38	25.50	1979-2020	0
LETLHAKANE	-21.42	25.58	1991-2021	0
SEROWE	-22.38	26.70	1991-2019	0

8.2. Observed changes in the climate.

8.2.1. Precipitation

The average annual total rainfall in Botswana is around 500mm/year to 650mm/year in the north and less than 250mm/year in the south. The rainy season spans from October to April (Figure 39). The overall annual rainfall in Botswana has decreased by 50mm in 50 years and is characterized by a very high interannual variability (Figure 40). Rainfall decreased to low levels in the beginning of 1990s. The erratic characteristic of rain in Botswana put the country under risk of drought and increased aridity. Since 1990, Botswana endured 3 major drought events that caused significant environmental, social, and economic damage. **1991-1992:** during this time, Botswana was part of a Southern African regional drought, affecting nearly half a million people in the country. The government declared it a national disaster. **2005-2006**: another significant drought occurred, severely affecting the agricultural sector, with crop failures reported across the country. It also put pressure on water supplies in both urban and rural areas. **2015-2016**: Botswana faced another major drought event, driven by the El Niño weather phenomenon. This drought led to a severe reduction in rainfall, affecting water resources, agriculture, and hydroelectric power generation. The government declared a national drought disaster, affecting nearly 1.5 million people. Cattle deaths reached over 400,000 due to a lack of water and grazing land, and the country had to import food.

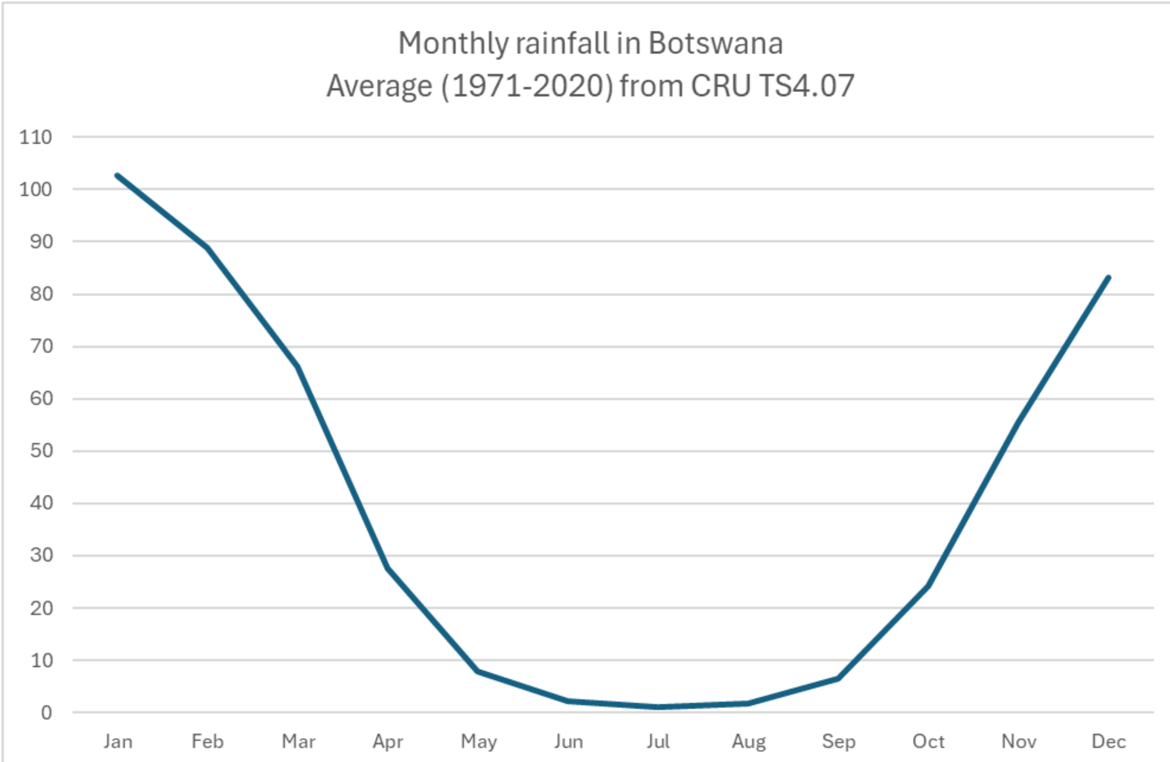


Figure 40: Monthly rainfall in Botswana calculated for the period 1971-2020 from CRU TS4.07

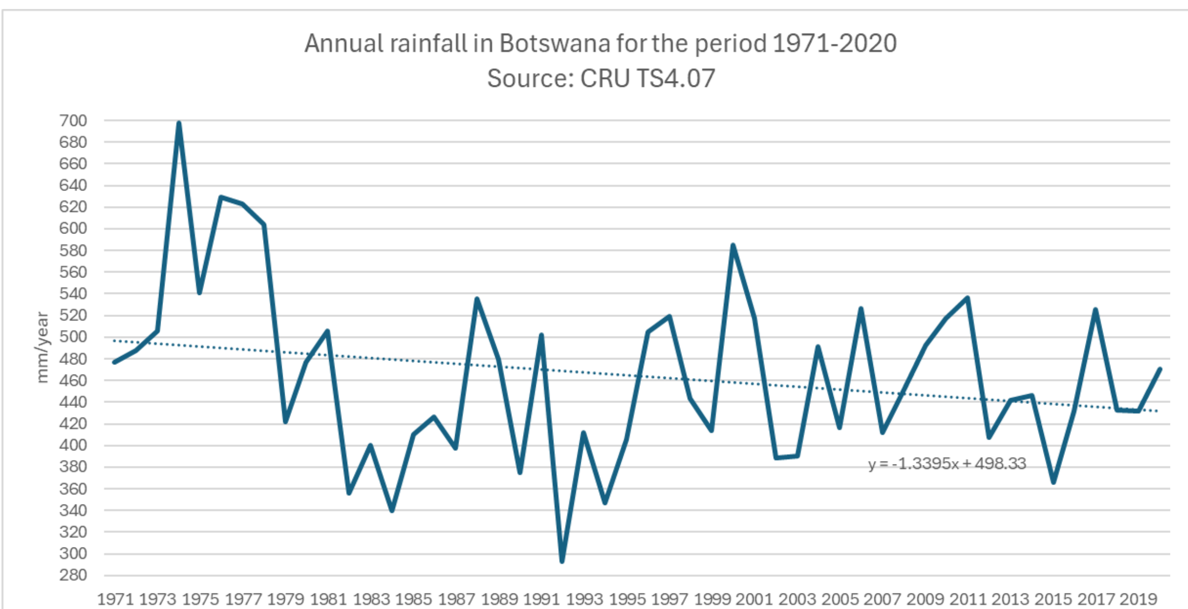


Figure 41: Annual rainfall in Botswana for the period 1971-2020 from CRU TS4.07

8.2.2. Temperature

Annual average temperature in Botswana has increased by 1.4 degree Celsius in 50 years. Between 1971 and 2020, temperature has shifted from around 20.4 degrees Celsius to 21.8 degrees Celsius (Figure 41). At this rate (+2.8 degrees Celsius per 100 years), the average temperature in Botswana will reach 23.2 degrees Celsius around 2070. Daily temperature data indicate that the frequency of hot days and nights has increased significantly in all seasons. Dry season in Botswana is characterized by cold temperature reaching zero degree during the nights in July and the wet season is warm with monthly maximum temperature above 30 degrees (Figure 42).

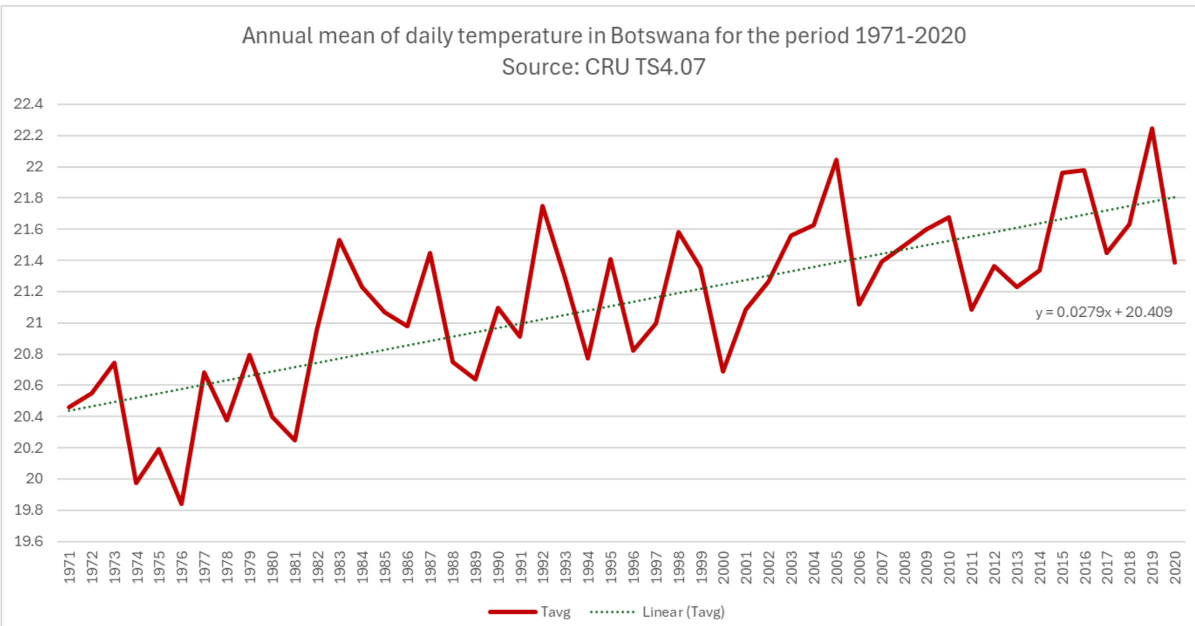


Figure 42: Annual mean of daily temperature in Botswana for the period 1971-2020 from CRU TS4.07

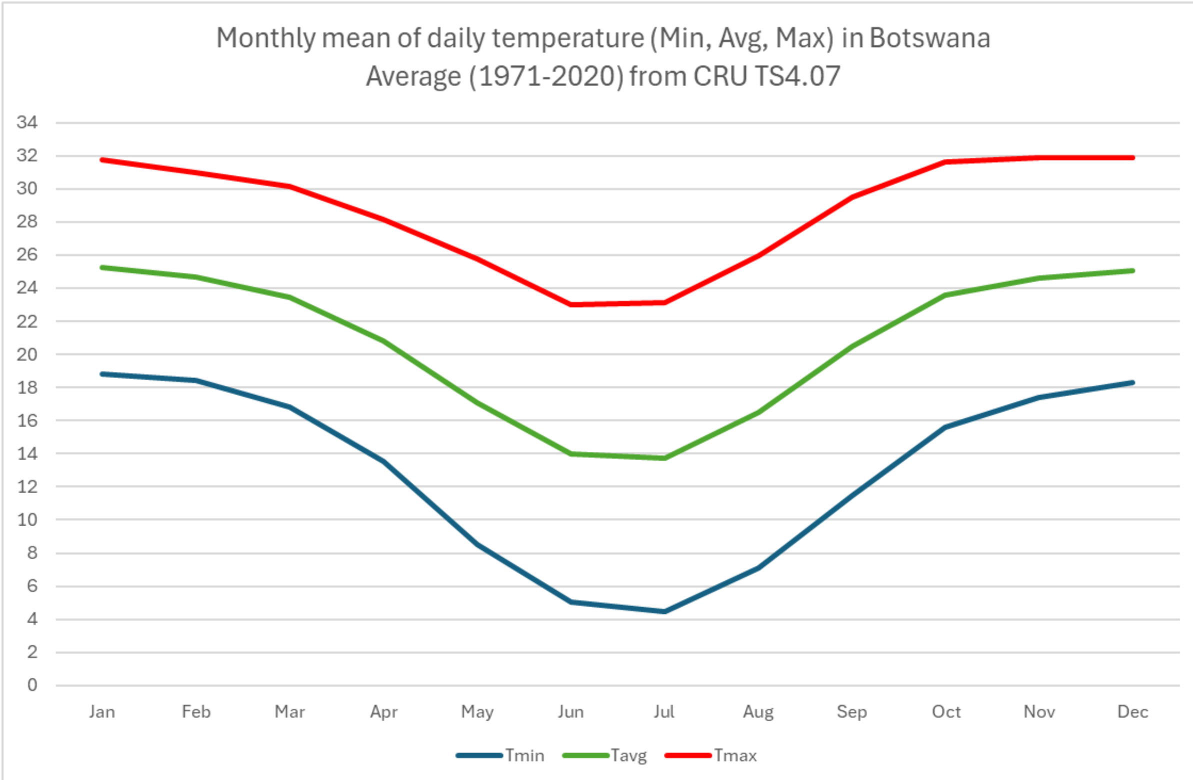


Figure 43: Monthly mean of daily average, maximum and minimum temperature in Botswana calculated for the period 1971-2020 from CRU TS4.07

8.3. Projected changes in the climate

8.3.1. Precipitation

Considering the 21 models, the trend in annual rainfall is not significant. The inter-annual variability will continue to be high under both scenarios (Figure 43). It is noted that most models agreed on a negative signal of changes in rainfall over Botswana especially under the high emission scenario (RCP8.5) where the decrease is predicted to reach around 100mm by the end of this century (Figure 44). This decrease in total rainfall in the future under both scenarios will likely put the agriculture and other sectors at risk of extreme drought.

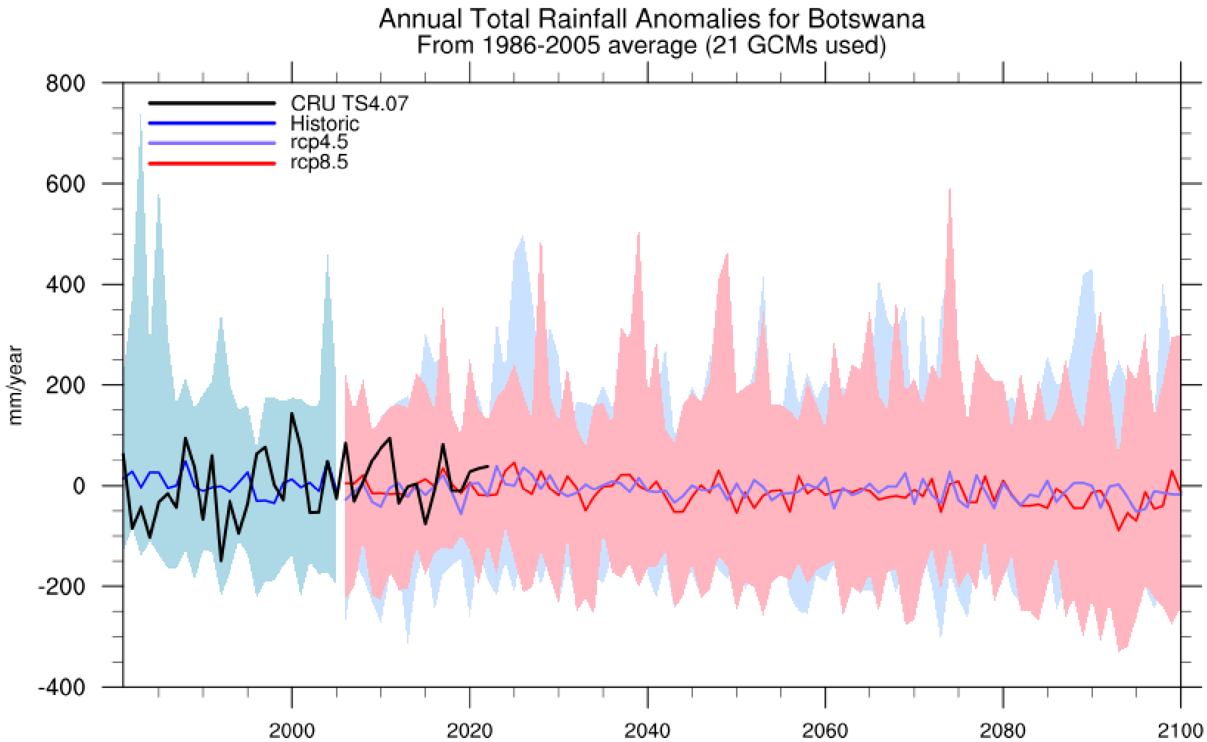


Figure 44: Changes in annual total rainfall in Botswana for RCP4.5 and RCP8.5. Departures are calculated from 1986-2005 reference period. Black line represents observed change in annual total rainfall from CRU TS4.07

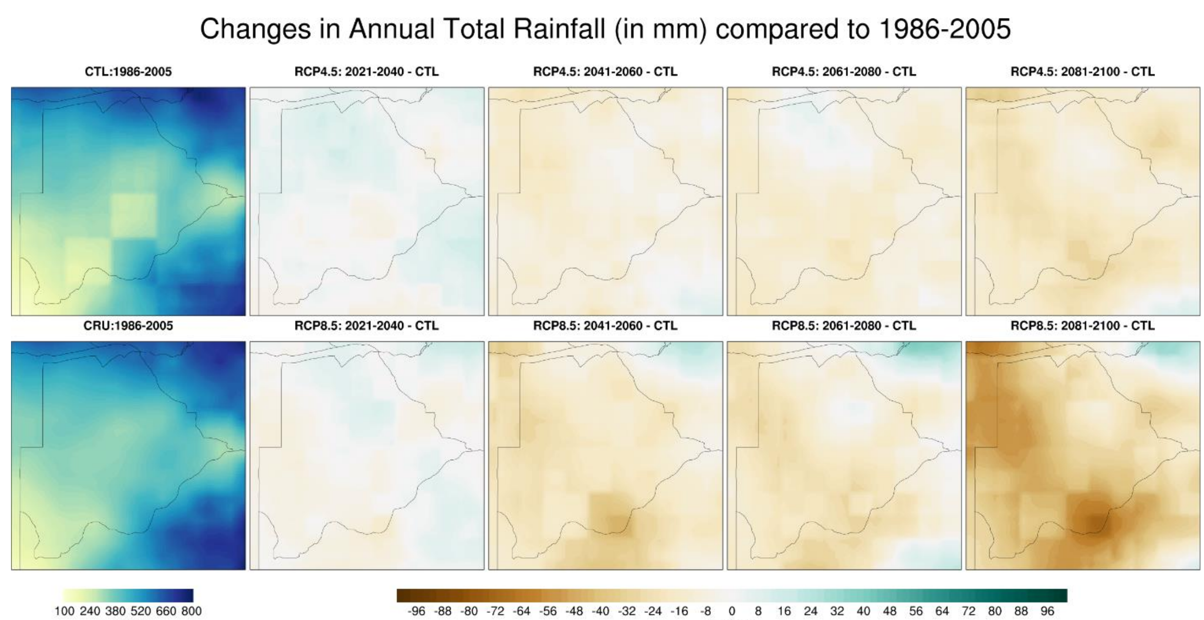


Figure 45: Changes in annual total rainfall for RCP4.5 and RCP8.5 over Botswana. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the average of annual total rainfall from 21 models (top left) and (CRU) is the average annual total rainfall from CRU TS4.07 (bottom left).

8.3.2. Temperature

By the end of this century, the maximum and minimum temperatures will likely increase in Botswana by +6 degrees Celsius for the RCP8.5 scenario and by +2 to +3 degrees Celsius for the RCP4.5 scenario (Figure 45, 46, and 47). This increase in temperature will induce an increase in water demand by evapotranspiration and put the cropping systems at risk. It will also impact the growing season of many crops in Botswana and increase the aridity in the south.

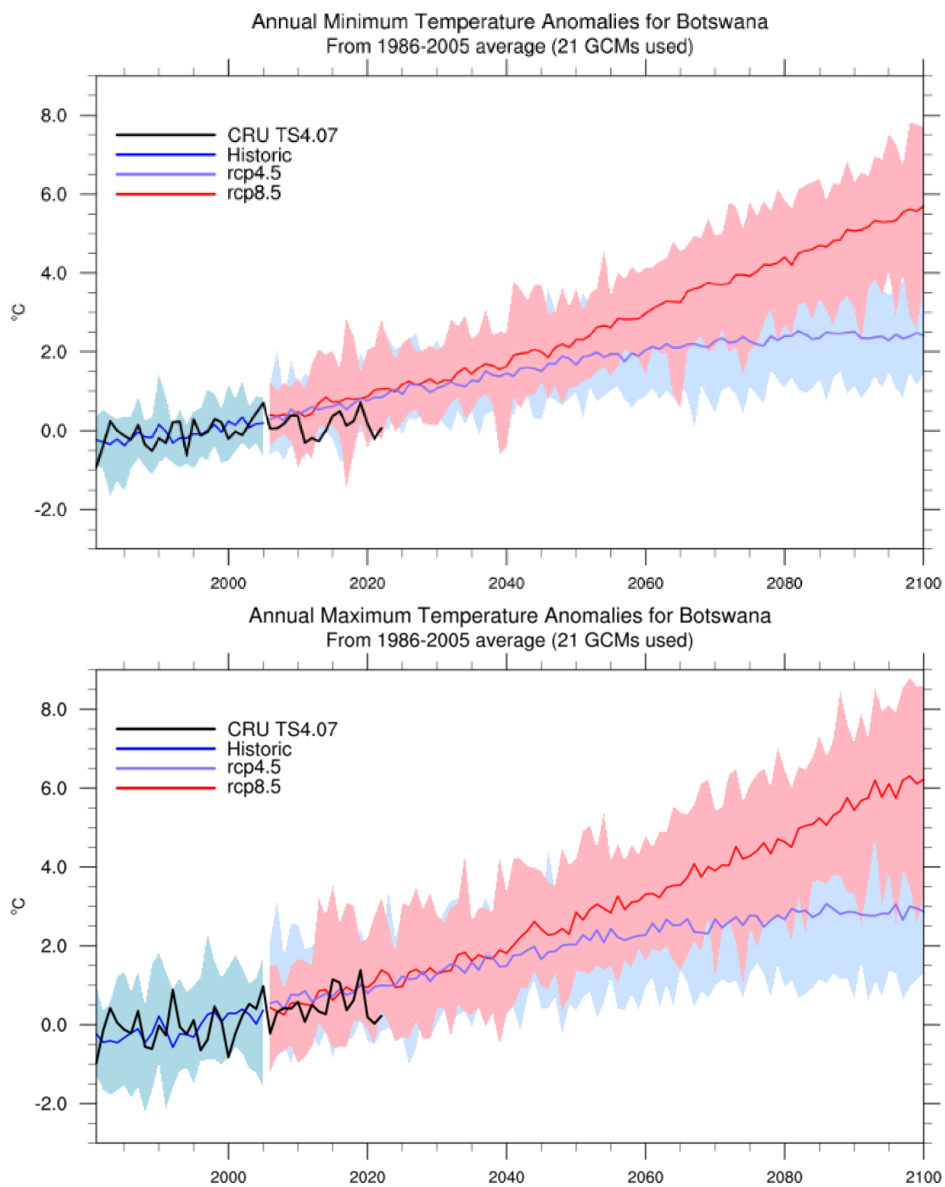


Figure 46: Changes in maximum and minimum temperatures for RCP4.5 and RCP8.5 compared to 1986-2005 reference period. Black line represents observed change in annual average of daily maximum and minimum temperatures from CRU TS4.07

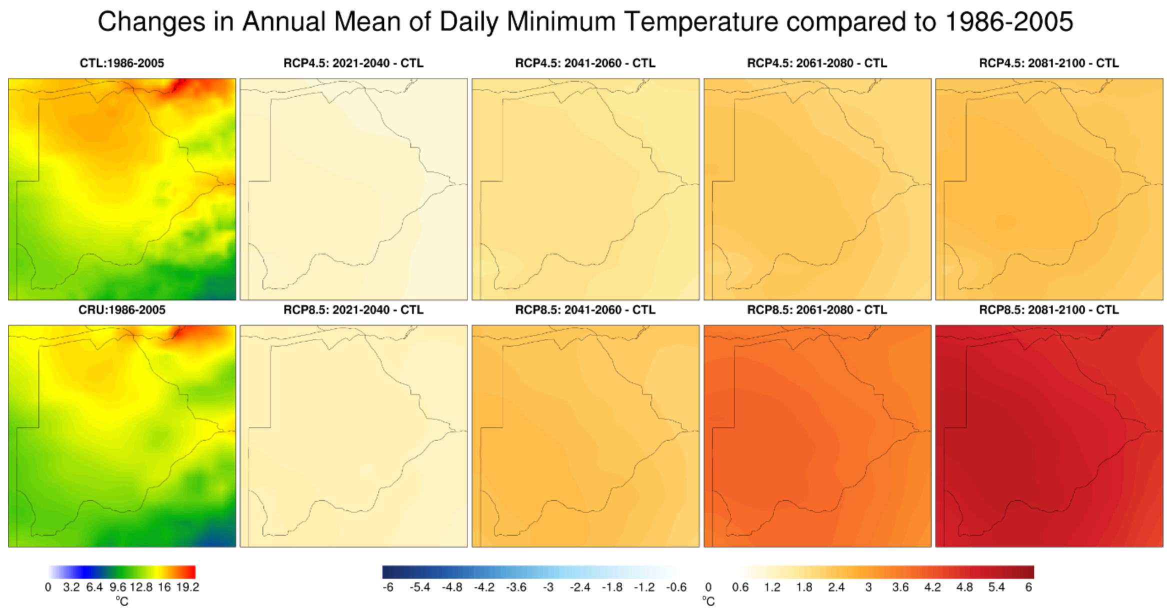


Figure 47: Changes in annual average of daily minimum temperature for RCP4.5 and RCP8.5 over Botswana. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the annual average of daily minimum temperature from 21 models (top left) and (CRU) is the annual average of daily minimum temperature from CRU TS4.07 (bottom left).

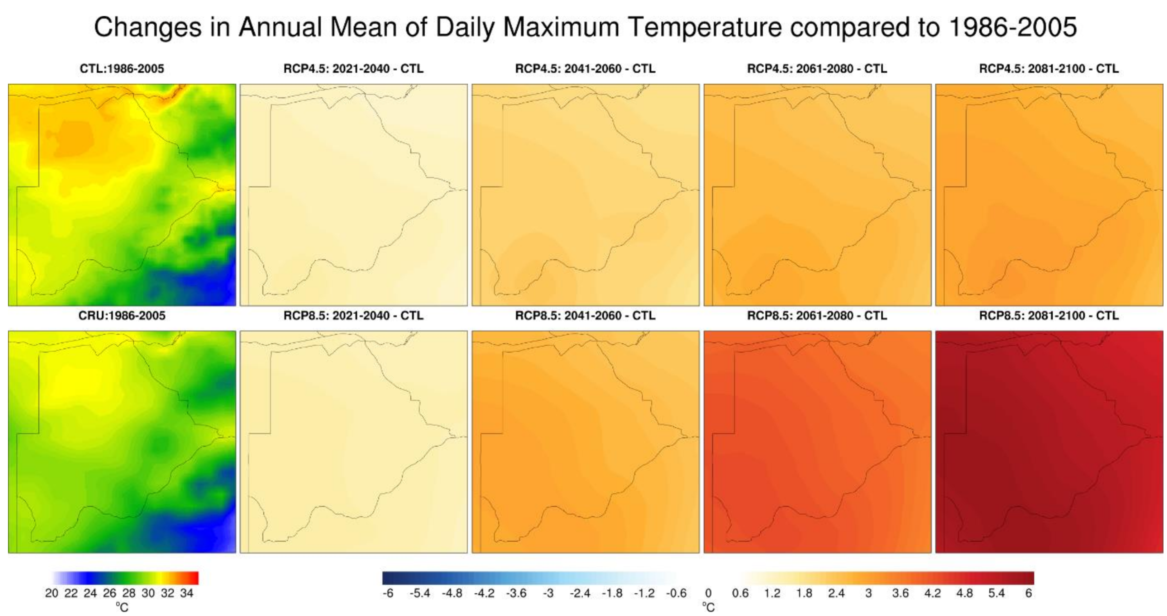


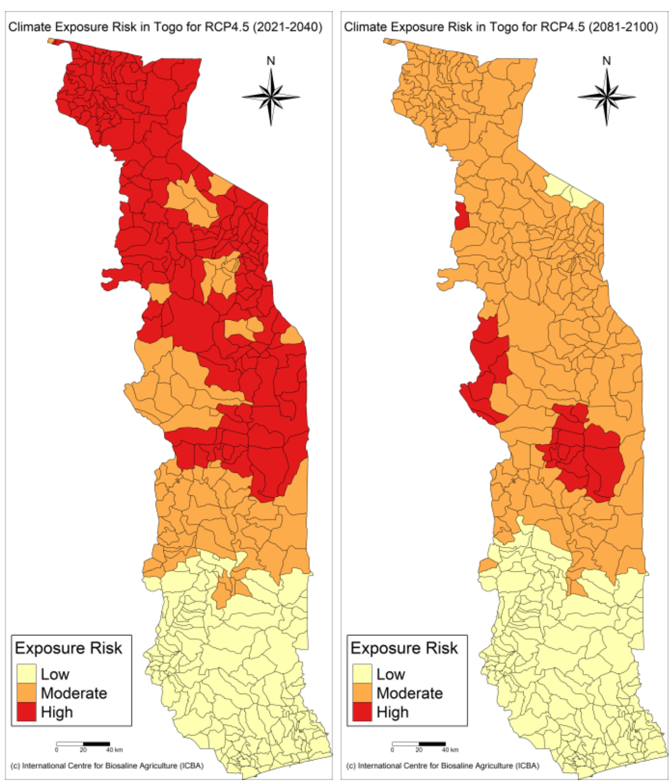
Figure 48: Changes in annual average of daily maximum temperature for RCP4.5 and RCP8.5 over Botswana. Different periods of 20 years compared to 1986-2005 reference period are presented. The reference period (CTL) is the annual average of daily maximum temperature from 21 models (top left) and (CRU) is the annual average of daily maximum temperature from CRU TS4.07 (bottom left).

9. Vulnerability maps

The exposure maps have been produced following the weights suggested by the experts from each country. The final exposure maps for all countries are given below along with the sensitivity and adaptive capacity maps for Togo. The exposure maps are calculated for 2 climate scenarios (RCP4.5 and RCP8.5) and for two periods in the future (2021-2040 and 2081-2100), while the final vulnerability maps are only generated for the near future (2021-2040) because projections of socio-economic conditions in the distant future are not available.

9.1. Vulnerability to climate change in Togo

The overall exposure to climate risk in Togo calculated from individual indices related to heat and drought stresses (Figure 48) shows that the agricultural sector in central and northern regions will be exposed more to the climate risks than the southern regions. For near future (2021-2040), most of regions in the center and north of the country will be at higher risk under RCP4.5 than RCP8.5 scenario. This result was expected as there is no significant difference between the two scenarios up to 2040 (Figures 7-10). After this period, the temperature will increase more under RCP8.5.



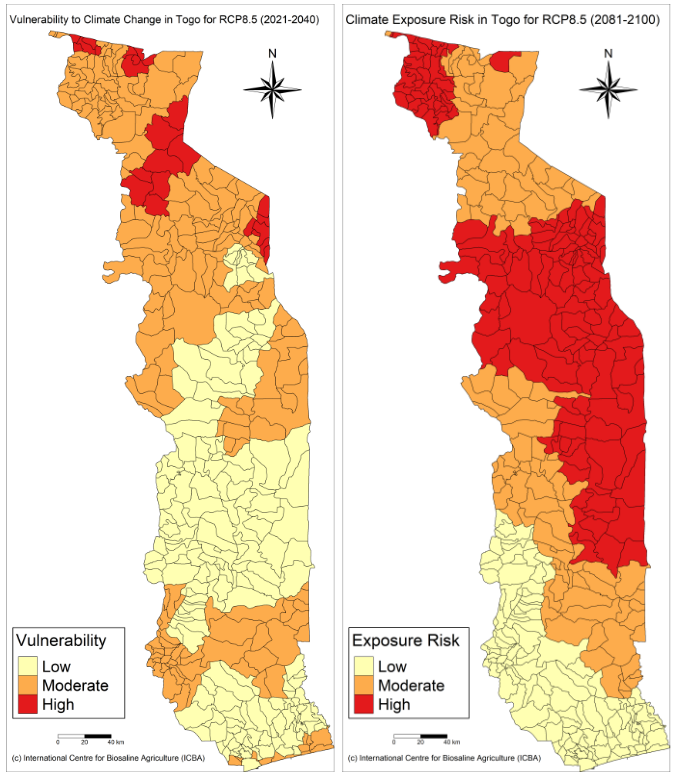


Figure 49: Overall exposure index in Togo for RCP4.5 (top panel) and RCP8.5(bottom panel) for the periods 2021-2040 and 2081-2100.

The sensitivity to climate change impacts has been calculated from the available data provided by ITRA at department level. This includes the population density, the rural population working in the agricultural sector and the number of crops being cultivated in each department. We assumed that the higher the numbers are the more sensitive is the concerned department. The sensitivity map (Figure 49, left panel) shows that most regions in Togo are sensitive to climate impacts, especially the areas in the south-west, center, and extreme north with high number of households relying on agriculture as source of income.

The combination of the exposure and the sensitivity indices for the near future (2021-2040) gives an idea of the potential impacts of climate change on the agricultural sector under both scenarios (RCP4.5 and RCP8.5). Figure 49 (central and right panels) shows that the impacts of climate change on agricultural production will be moderate to high in the center and north of the country, while in the south, the impacts will be low.

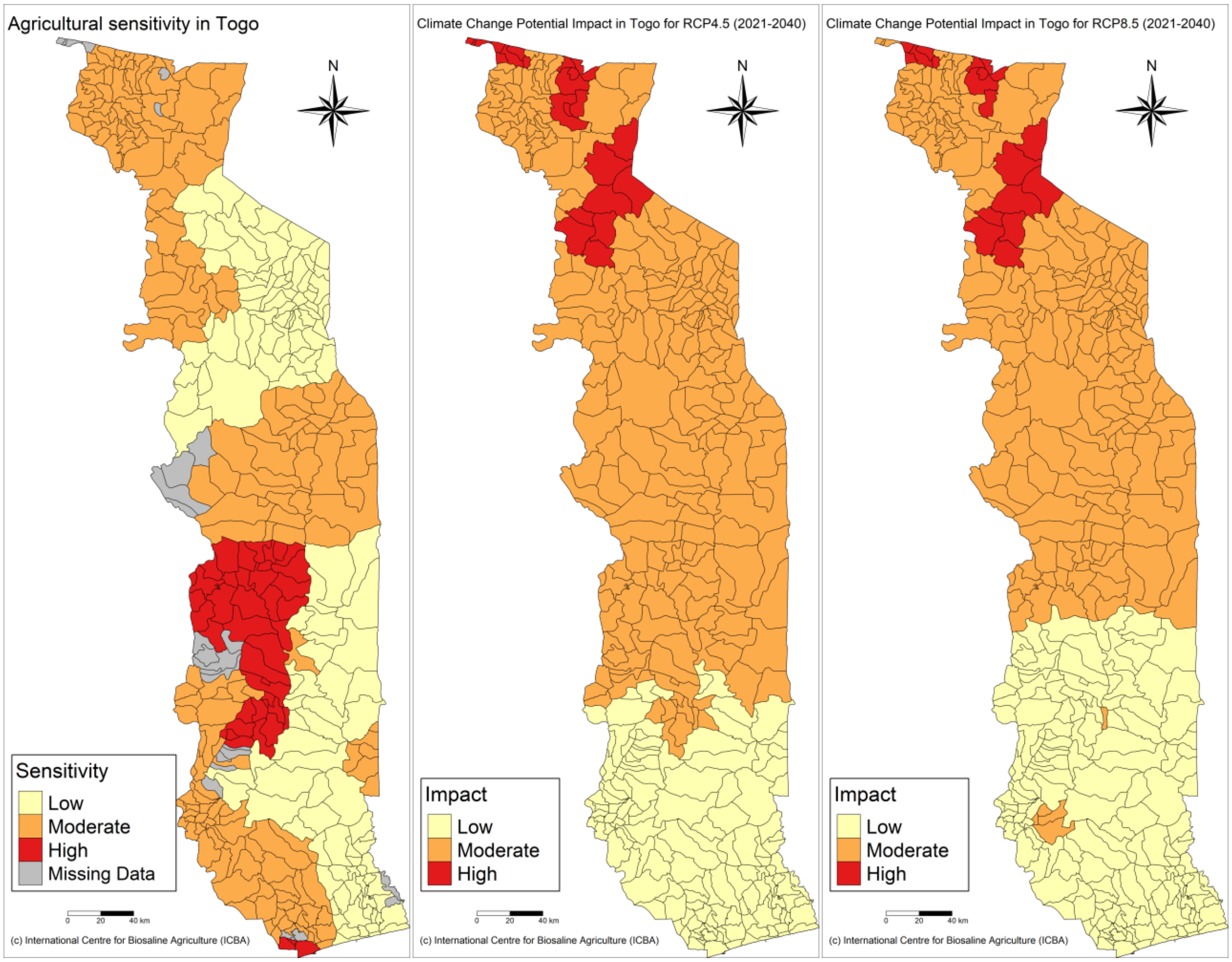


Figure 50: Sensitivity index in Togo (left panel) and potential impacts for RCP4.5 and RCP8.5 for the period 2021-2040 (central and right panels).

The adaptive capacity index has been calculated from the available data provided by ITRA at department level. This includes the rural population, access to markets and the roads infrastructure in each department. We assumed that the higher the numbers are the higher the adaptive capacity of the concerned department. The adaptive capacity map (Figure 50, left panel) shows that the regions with relatively dense roads network and markets in the center and south are less susceptible to climate shocks.

The combination of the potential impact and the adaptive capacity indices for the near future (2021-2040) gives an idea on the overall vulnerability of the agricultural sector to climate change under both scenarios (RCP4.5 and RCP8.5). Figure 50 (central and right panels) shows that the northern part of the country (Savanes and Kara regions) is more vulnerable to climate change than the southern part. The southern part of the Plateaux region, the extreme south of the Maritime region, and the east part of the Centre region are showing moderate vulnerability to climate change. Most of the Maritime and northern part of Plateaux regions are less vulnerable.

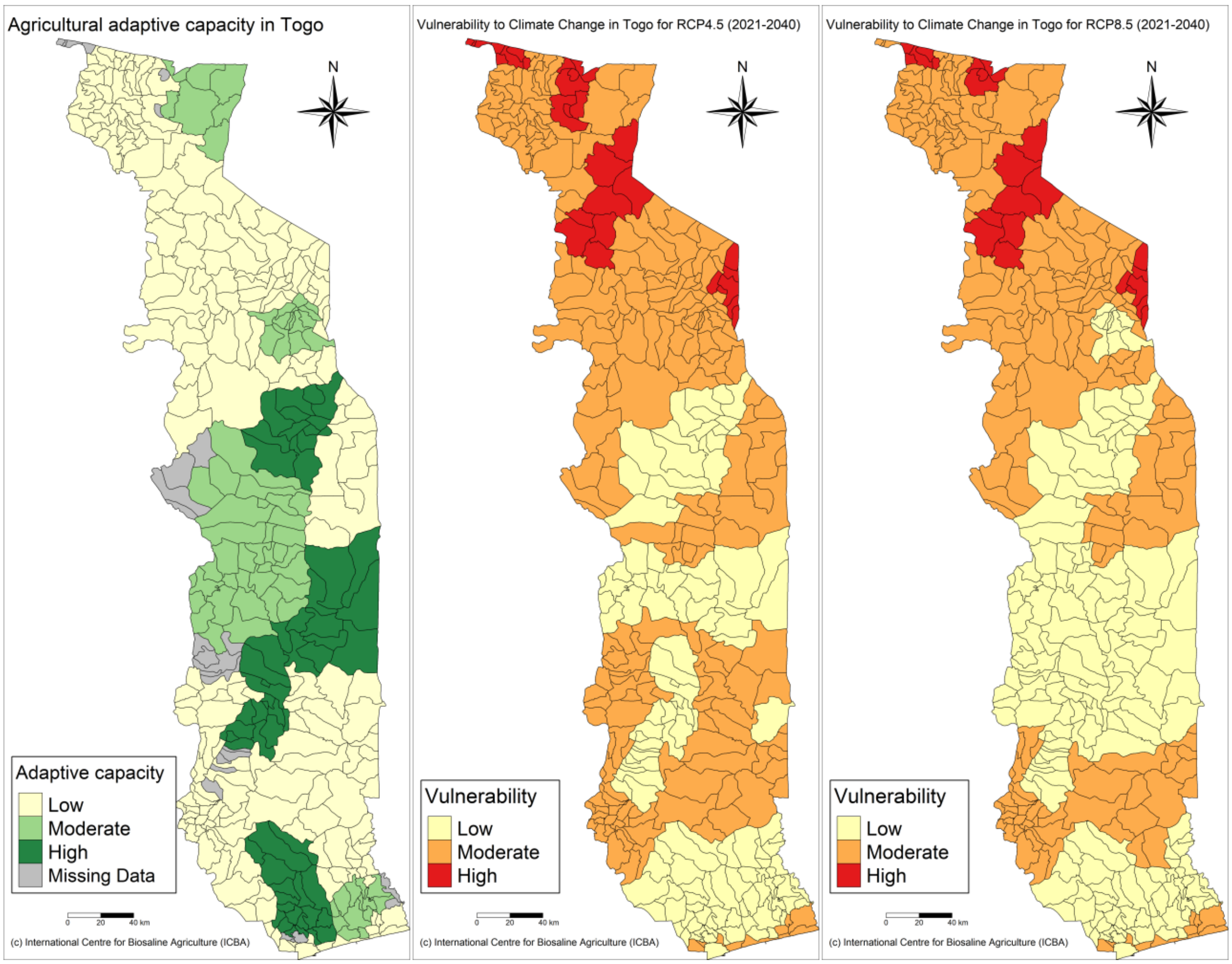


Figure 51: Adaptive capacity index in Togo (left panel) and vulnerability to climate change for RCP4.5 and RCP8.5 for the period 2021-2040 (central and right panels).

9.2. Vulnerability to climate change in The Gambia

Only exposure component was possible to calculate for The Gambia as no data was available at fine scale to describe the sensitivity to climate change and the adaptive capacity of the agricultural sector to the potental impacts of such change in the future. Figure 51 shows the overall exposure to climate risks for the periods 2021-2040 and 2081-2100 under two climate scenarios (RCP4.5 and RCP8.5). The eastern part of country will be exposed to higher climate risks than the coastal zone driven by the high increase in temperature in that part of the country compared to the coastal region. The central part of the country will be under moderate climate exposure risk across periods and scenarios, while lower exposure risks will be observed in the coastal region.

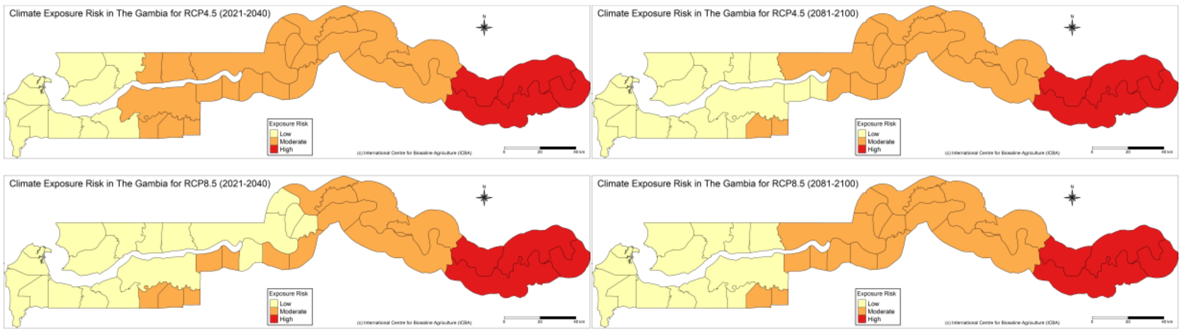


Figure 52: Overall exposure index in The Gambia for RCP4.5 (top row) and RCP8.5 (bottom row) for the periods 2021-2040 (left column) and 2081-2100 (right column).

9.3. Vulnerability to climate change in Sierra Leone

Only exposure component was possible to calculate for Sierra Leone as no data was available at fine scale to describe the sensitivity to climate change and the adaptive capacity of the agricultural sector to the potental impacts of such change in the future. The exposure component weights were copied from the Liberia as the climate conditions in both countries are similar and the weights were not provided by the experts from this country. Figure 52 shows the overall exposure to climate risks for the periods 2021-2040 and 2081-2100 under two climate scenarios (RCP4.5 and RCP8.5). The northern part of country will be exposed to higher climate risks than the southern zone driven by the high increase in temperature in that part of the country compared to the central and southern regions.

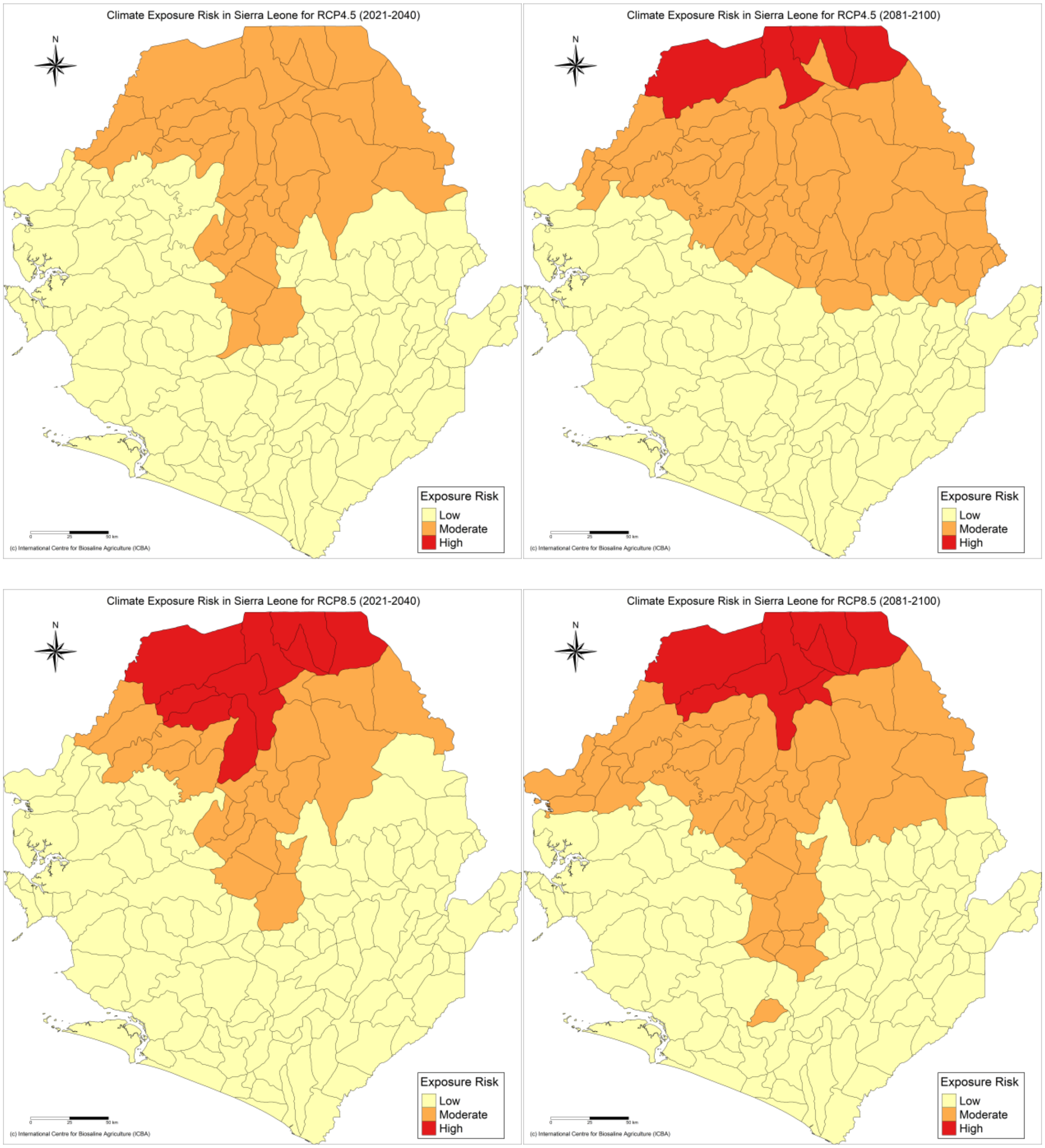


Figure 53: Overall exposure index in Sierra Leone for RCP4.5 (top row) and RCP8.5 (bottom row) for the periods 2021-2040 (left column) and 2081-2100 (right column).

9.4. Vulnerability to climate change in Liberia

Only exposure component was possible to calculate for Liberia as no data was available at fine scale to describe the sensitivity to climate change and the adaptive capacity of the agricultural sector to the potental impacts of such change in the future. Figure 53 shows the overall exposure to climate risks for the periods 2021-2040 and 2081-2100 under two climate scenarios (RCP4.5 and RCP8.5). Smiliraly to Sierra Leone, the northern part of Liberia will be exposed to higher climate risks than the southern zone driven by the high increase in temperature in that part of the country compared to the central and southern regions.

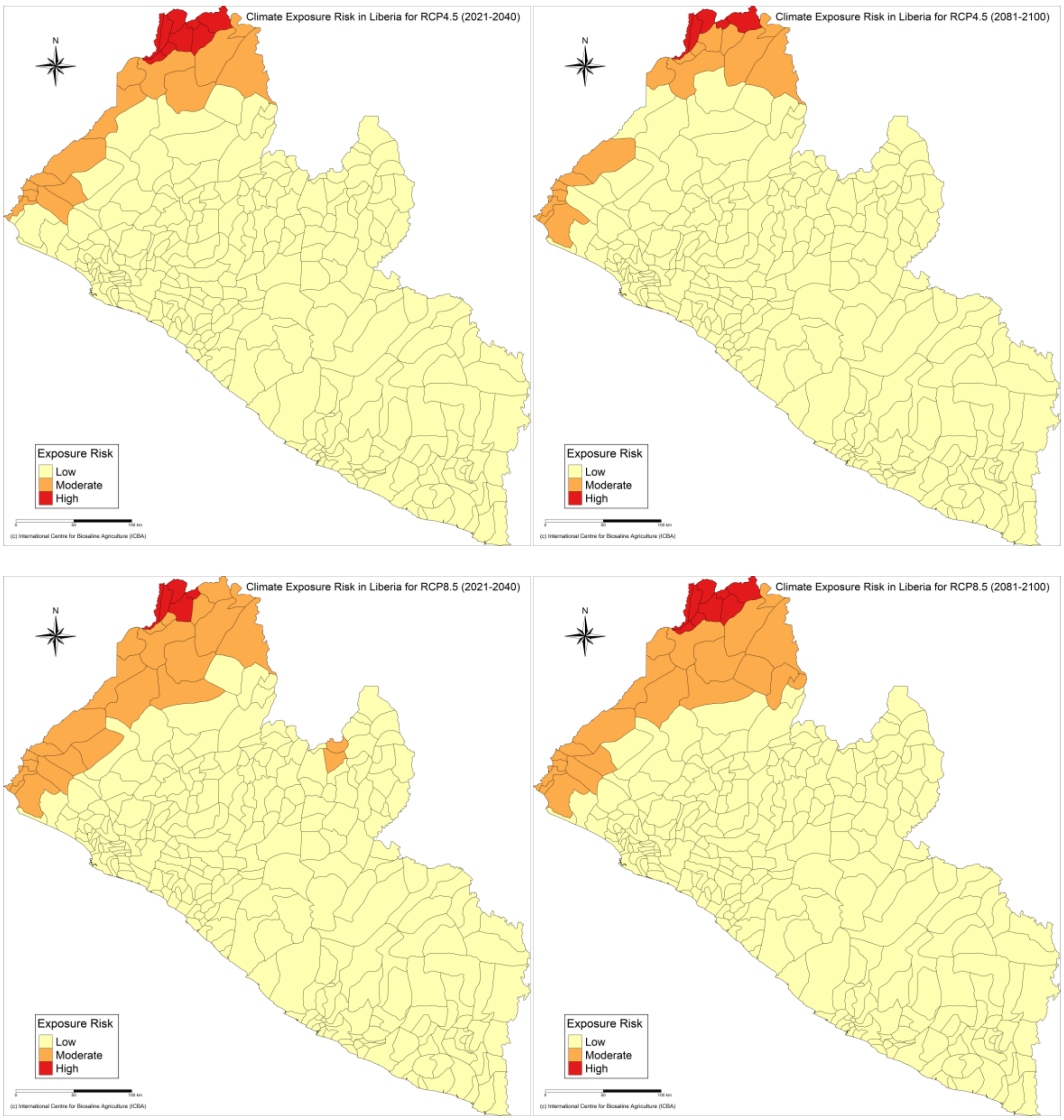
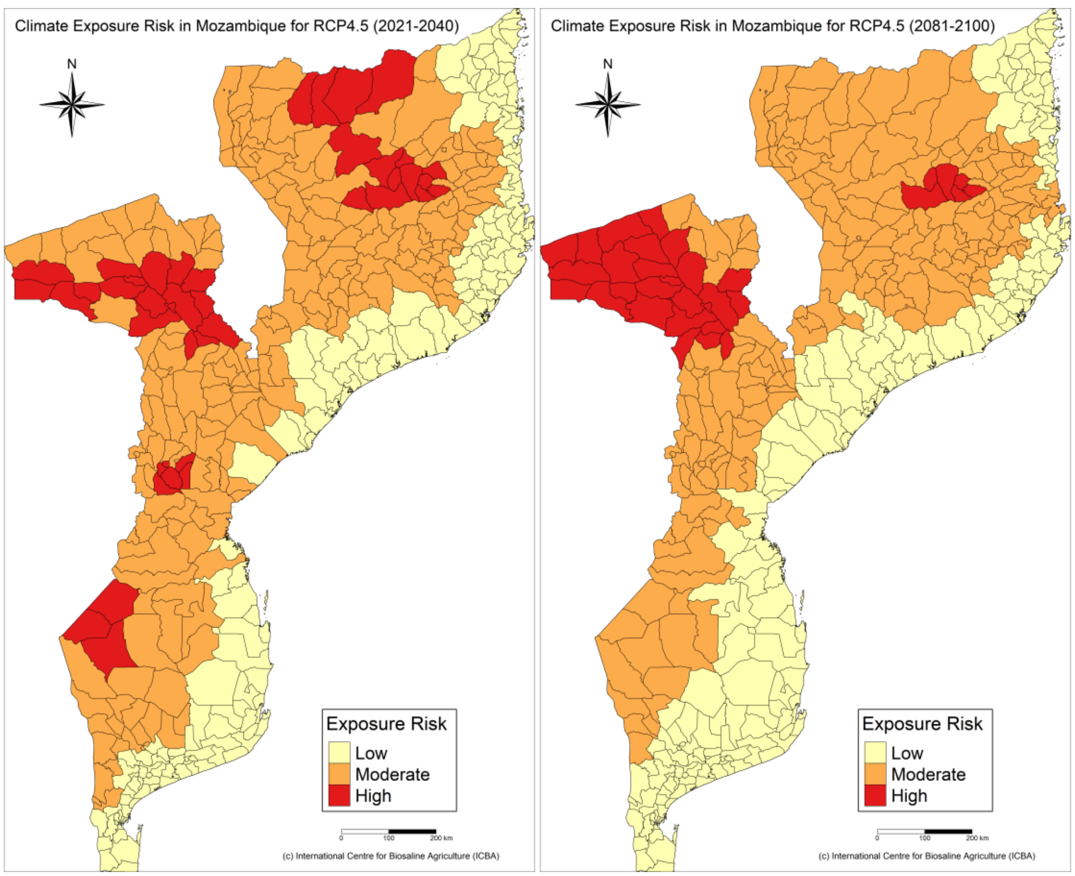


Figure 54: Overall exposure index in Liberia for RCP4.5 (top row) and RCP8.5 (bottom row) for the periods 2021-2040 (left column) and 2081-2100 (right column).

9.5. Vulnerability to climate change in Mozambique

Only exposure component was possible to calculate for Mozambique as no data was available at fine scale to describe the sensitivity to climate change and the adaptive capacity of the agricultural sector to the potental impacts of such change in the future. Figure 54 shows the overall exposure to climate risks for the periods 2021-2040 and 2081-2100 under two climate scenarios (RCP4.5 and RCP8.5). The coastal zone will be exposed to low climate risks compared to the inland zone driven by the high increase in temperature inside the country (Figure 37). Tete and north of Gaza regions seems will likely be exposed to higher climate risks than the other regions. Manhica, Niassa, west of Zambezia and Nampula are likely to be exposed to moderate risks while the rest of the regions will be exposed to low risk, especially the coastal regions.



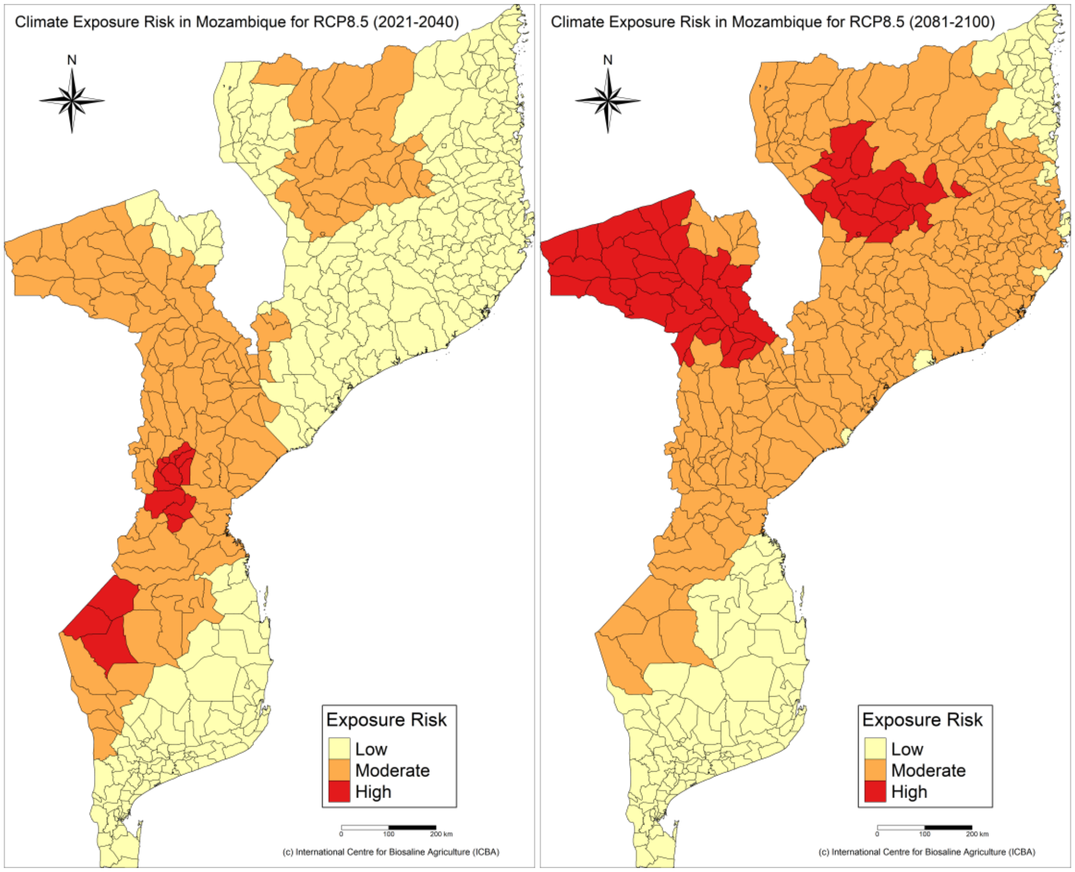


Figure 55: Overall exposure index in Mozambique for RCP4.5 (top row) and RCP8.5 (bottom row) for the periods 2021-2040 (left column) and 2081-2100 (right column).

9.6. Vulnerability to climate change in Botswana

The overall exposure to climate risk in Botswana, as calculated from individual indices related to heat and drought stresses (as illustrated in Figure 55), reveals a pronounced geographical disparity. In particular, the agricultural sector in the western regions of the country will face significantly higher exposure to climate-related risks compared to the eastern regions. This vulnerability is especially critical because these western areas are already characterized by arid and semi-arid climates, which are more susceptible to extreme heat and prolonged drought conditions.

In the near future, spanning from 2021 to 2040, climate projections under the high emission scenario (RCP8.5) indicate a sharp increase in these risks. Under this scenario, where greenhouse gas emissions continue to rise unabated, much of the western part of Botswana is expected to experience more frequent and intense heatwaves, along with decreased rainfall. These factors will exacerbate water scarcity, further stressing the agricultural systems that depend on consistent precipitation and moderate temperatures.

By contrast, the eastern regions, which benefit from relatively more favorable climatic conditions and greater access to water resources, will likely remain at lower risk during this period. However, even these areas are not immune to the long-term effects of climate change and could still experience gradual shifts in weather patterns over time. In sum, the western part of Botswana, especially under a high-emission future, is poised to endure more acute agricultural challenges, posing a significant threat to food security and rural livelihoods.

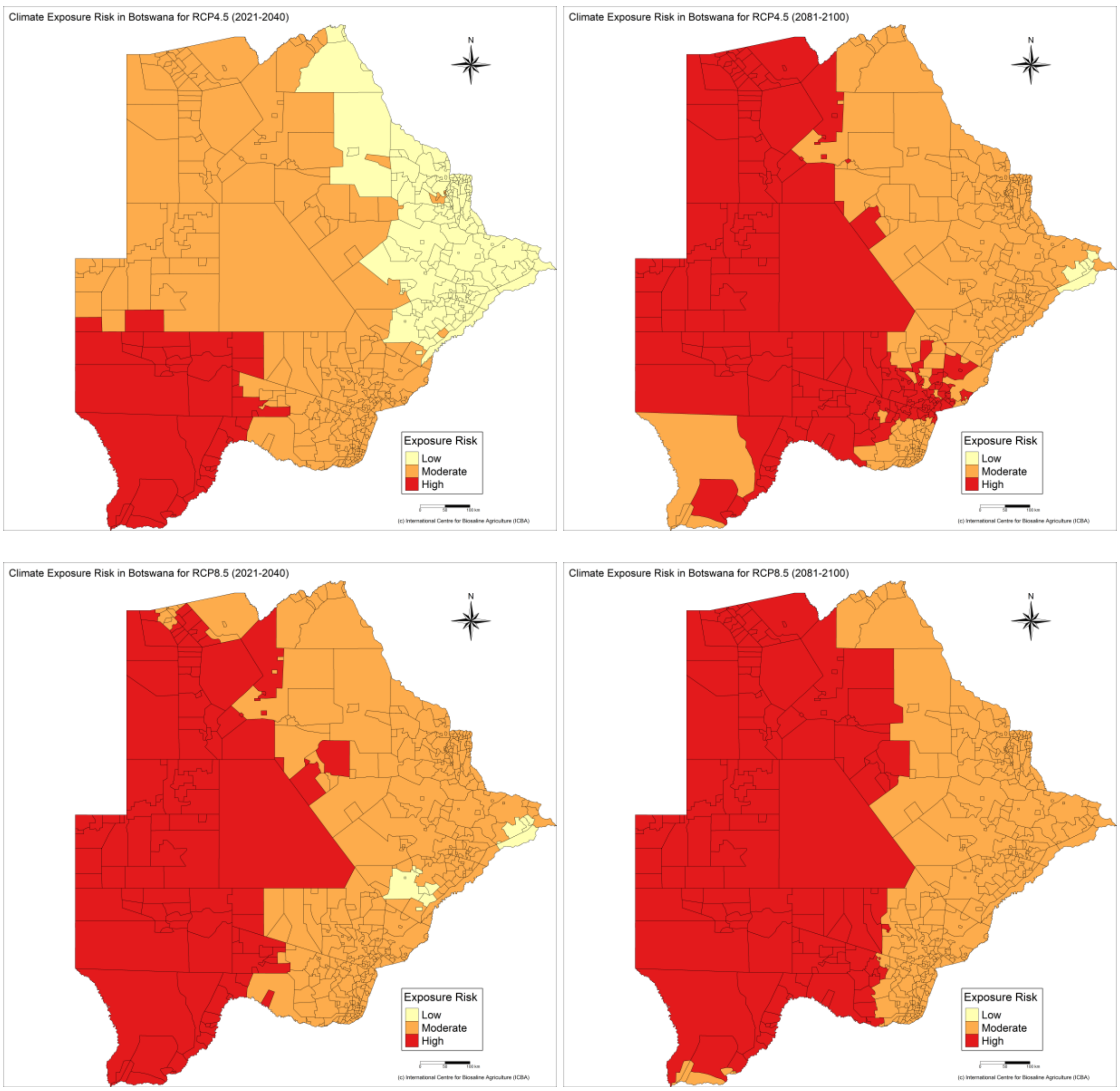


Figure 56: Overall exposure index in Botswana for RCP4.5 (upper row) and RCP8.5 (lower row) for the periods 2021-2040 (left column) and 2081-2100 (right column).

10. Conclusion and recommendations

The agricultural sector across the countries examined faces a future marked by heightened exposure to climate change impacts, particularly those related to heat and drought stress. This exposure translates into tangible risks for agricultural production, threatening the livelihoods of those dependent on this sector. There is a consensus agreement on the projected increase in temperatures across all regions, a trend expected to disrupt growing seasons, increase water demand through evapotranspiration, and potentially lead to crop failures.

The projected changes in rainfall patterns vary considerably across regions. While some areas may experience an increase in total rainfall, this does not necessarily mitigate the risk of drought, as the temporal distribution and intensity of rainfall events can play a significant role in agricultural productivity. In regions facing a projected decrease in rainfall, the risk of drought is even more pronounced, potentially leading to water scarcity and further exacerbating the negative impacts of rising temperatures on crop yields.

The project team acknowledges the inherent limitations in assessing sensitivity and adaptive capacity, particularly due to data availability constraints. While the analysis for Togo provides some insights into these factors, the incomplete and less detailed nature of the data necessitates cautious interpretation. Nevertheless, the available data underscores the importance of considering factors such as population density, access to markets, and road infrastructure when evaluating a region's vulnerability to climate change. Regions with greater access to these resources are likely to be better equipped to cope with the adverse impacts of climate change, highlighting the need for targeted interventions to enhance adaptive capacity in more vulnerable regions.

Building upon these findings, we strongly recommend that the next phase of the project prioritize regions identified as highly vulnerable or facing elevated climate risks. This strategic approach will enable the effective allocation of resources and the implementation of targeted interventions, such as the establishment of a second Best Practice Hub (BPH). The BPH can serve as a focal point for knowledge dissemination, technology transfer, and capacity building, empowering local communities to adapt to the challenges posed by climate change and build resilience within the agricultural sector.

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