CLIMATE DAMAGE IN THE AGRICULTURAL SECTOR

Nigeria

On behalf of:

Federal Ministry
for the Environment, Climate Action,
Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

IKI INTERNATIONAL CLIMATE INITIATIVE

giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn, Germany

Address
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH
Köthener Str. 2
10963, Berlin, Germany
T +49 61 96 79-0
F +49 61 96 79-11 15
E info@giz.de
I www.giz.de/en

Project description
Policy Dialogue and Knowledge Management on
Climate Protection Strategies

Project manager
Anita Richter
anita.richter@giz.de

Author
Dr. Chukwuemeka Emenekwe, Abakaliki

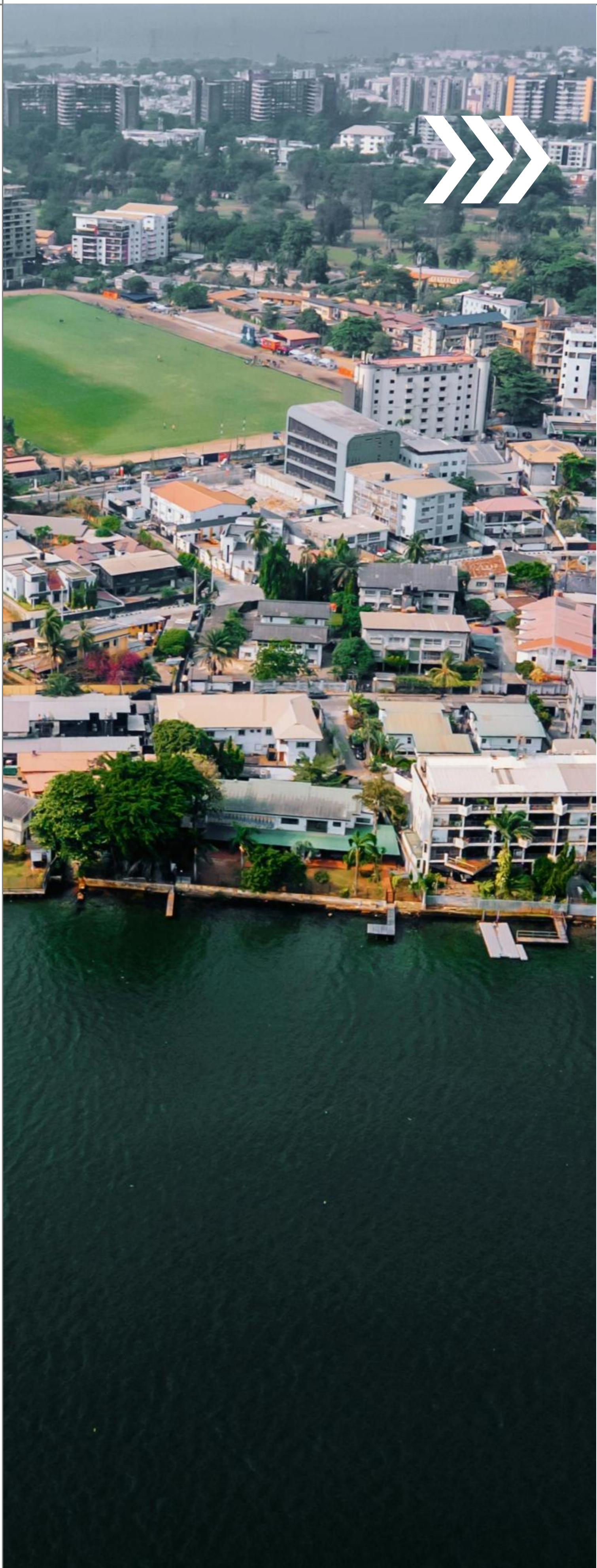
Design and layout
Alvira Yertayeva, Astana

Photo credits/sources
©pexels

This report was elaborated by the expert of the Department of Economics and Development Studies and Centre for Climate Change and Development (CCCD) at the Alex-Ekwueme Federal University Ndufu-Alike (AEFUNAI), within IKI global project "Policy Dialogue and Knowledge Management on Climate Protection Strategies", implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) on behalf of the Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN).

On behalf of
Federal Ministry for the Environment, Climate Action, Nature
Conservation and Nuclear Safety (BMUKN)

Germany 2025



CLIMATE DAMAGE IN THE AGRICULTURAL SECTOR OF NIGERIA

Author

Dr. Chukwuemeka Emenekwe

Department of Economics and Development Studies Centre for Climate Change and Development
Alex-Ekwueme Federal University Ndufu-Alike (AEFUNAI)

Ebonyi State, Nigeria
E emenekwe.c@gmail.com;
chukwuemeka.emenekwe@funai.edu.ng
T +234(0)8143003703

CENTRE FOR CLIMATE CHANGE & DEVELOPMENT

CONTENTS

List of Tables ... v
List of Figures ... vi
1. INTRODUCTION ... 1
2. METHODS ... 2
    2.1. Data collection ... 2
3. LOSS AND DAMAGE FROM THE 2012 FLOODS IN NIGERIA ... 2
    3.1. Effects on the Agricultural Sector ... 3
    3.2. Estimates of Damage and Losses in the Agricultural Sector ... 4
    3.2.1 Crop ... 5
    3.3. Livestock ... 5
    3.4. Fishery ... 6
4. CLIMATE PROJECTIONS FOR NIGERIA ... 6
    4.1. Historical Context (1950–2014) ... 6
    4.2. Projected Changes (2019–2060) and Anomalies ... 8
5. CLIMATE DAMAGE ASSESSMENTS ... 8
    5.1. Statistical Analyses of Historical Performance ... 9
    5.2. Future Modelling Studies ... 10
    5.3. Heat and labour productivity ... 19
    5.4. Sea Level Rise and Land Loss ... 22
    5.5. Damage for Priority Crops in Nigeria ... 23
References ... 25

List of Tables

Table 1. Impact of the flood disaster on employment and income in the agricultural sector ... 4

Table 2. Anomalies of key climate variables in Nigeria across scenarios ... 8

Table 3. Hasegawa et al. (2022) average of climate impacts on Nigerian staple crops ... 13

Table 4. Roson and Sartori (2016) estimates of climate impacts on major crops in Nigeria's agricultural sector ... 14

Table 5. Roson and Sartori (2016) estimates of percentage variation in multi-factor productivity for Nigeria's broad agricultural sector ... 15

Table 6. Jägermeyr et al. (2024) projected crop yield and yield changes in Nigeria ... 16

Table 7. Cervigni et al. (2013) aggregate percent change in crop yields by major crops – 2050 ... 17

Table 8. Roson and Sartori (2016) Heat impacts on agricultural sector labour productivity in Nigeria ... 20

Table 9. ILO (2019) estimates of working hours lost to heat stress, by sector in Nigeria and Western Africa, 1995 and 2030 (projections) ... 21

Table 10. Sea level rise: percentage losses of land ... 23

Table 11. Base year (2019) – Crop and Livestock Statistics for Nigeria ... 23

Table 12. Base year (2019) – Crop Statistics for Nigeria ... 24

List of Figures

Figure 1. Literature Search 2

Figure 2. Map Showing the Most-Affected States 3

Figure 3. Agricultural sector disaster effects from 2012 nationwide flood in Nigeria 4

Figure 4. Estimated production losses of crops 5

Figure 5. Number of drowned animals due to the 2012 floods 5

Figure 6. Fishery production losses due to the 2012 floods 6

Figure 7. Nigeria Annual Precipitation; historical, SSP245 and SSP585 (1950-2100) 6

Figure 8. Nigeria Average Mean Surface Air Temperature; historical, SSP245 and SSP585 (1950-2100) 7

Figure 9. Nigeria Annual SPEI Drought Index; historical, SSP245 and SSP585 (1950-2100) 7

Figure 10. Projected yield changes for major staple crops in Africa due to climate change (compared to 2005 yield levels) 11

Figure 11. ILO (2019) estimate of incidence of heat stress during the hottest month in Africa, 1995 and 2030 (projections) 20

Figure 12. Percentage of GDP lost to heat stress under a 1.5°C global warming scenario, ten most affected countries in Africa, 1995 and 2030 (projections) 22

1. INTRODUCTION

There is significant concern about the impacts of climate change on agricultural production in Nigeria. Issues of food security feature prominently among the human activities and ecosystem services threatened by anthropogenic alterations to Earth's climate. Nigeria is particularly interested in potential damages—and, in limited cases, benefits—that may emerge over the coming decades, not only due to direct domestic challenges but also because global climate change can affect international trade, resource allocation, regional planning, and ultimately the welfare of its people.

Recent research suggests that crops may respond positively to elevated CO_2 concentrations if all other conditions remain stable. However, altered temperature regimes, shifts in rainfall patterns, and increased frequency of extreme events (e.g., droughts and floods) are expected to combine to reduce yields and increase production risks. A broad consensus identifies Nigeria—a developing country—as especially vulnerable to climate change (ND-GAIN Vulnerability Ranking[1]). This vulnerability stems partly from the country's agriculture-based economy, limited capital for adaptation measures, and existing exposure to high baseline temperatures and extreme weather events. As of 2022, about 18% of the population (about 40 million people) suffer from undernourishment, highlighting the sensitivity of food availability and affordability to climate variability.

The economic assessment of climate loss and damage is crucial for understanding both the potential costs and benefits of climate policy. Such evaluation gives policymakers a robust basis for setting adaptation and mitigation priorities. In this context, climate damage typically comprises:

I. Economic losses in market sectors (agriculture, labour productivity, energy, etc.), often quantifiable through direct monetary evaluations.

II. Impacts on non-market sectors (public health, ecosystems, coastal resources), which are harder to measure but significantly affect societal well-being.

Between 2000 and 2023, Nigeria experienced direct economic losses of around US$21 billion from natural disasters, primarily meteorological events such as floods, droughts, and rainstorms (CRED, 2023; NEMA, 2013). When including non-market factors, total climate loss and damage estimates could rise by an additional 25%. Major flood events in 2012 and 2022 exemplify this trend, causing substantial damage to production systems and infrastructure while increasing health risks (NEMA, 2013).

Given Nigeria's diverse climate and frequent extreme weather events, it is critical to collate scientific evidence on the potential climate damage in agriculture. Doing so enables robust cost-benefit analyses of adaptation and mitigation efforts, ensuring that climate-related policies are tailored to local conditions. Climate change affects many processes of food systems directly and indirectly, but the primary effects often appear in crop production. Projections of crop production under future climate change in Nigeria have been studied since the recent decade. From the 2011 onward, researchers (notably, the BNRCC Project[2] and Cervigni *et al.*, 2013) have used future climate data and crop simulation models to project the impacts of climate change on crop yields under various scenarios. Since the pioneering efforts of the BNRCC effort, there is still a dearth of crop simulation modelling studies that simulate yields for different crops under a range of climate scenarios and growing conditions.

[1] Vulnerability rankings | ND-GAIN Index

[2] BNRCC – Building Nigeria's Response to Climate Change

In the next section, we briefly show the literature search approach. In section 3, we present an overview of climate change loss and damage in Nigeria stemming from the devastating flood event of 2012 and focus on the assessed impacts on the agricultural sector. In section 4, we present results from the literature on climate change impacts on the agricultural sector as well as climate damage functions. In section 5, we summarise the study.

2. METHODS

2.1. Data collection

This report synthesizes available peer-reviewed and gray literature on agricultural modelling studies relevant to Nigeria (Figure 1). Priority is given to research examining crop responses under multiple climate change scenarios – particularly those guided by Intergovernmental Panel on Climate Change (IPCC) frameworks or other established modelling protocols. Most of the identified studies focus on changes in cereal yields (e.g., maize, rice, wheat), reflecting the prominence of these staple crops in the nation's food security landscape.

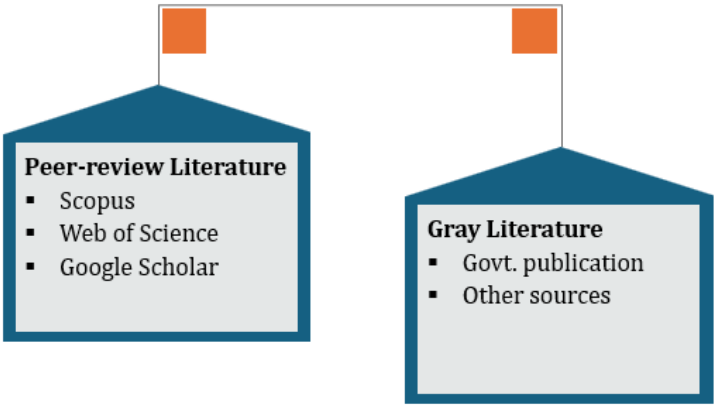


Figure 1. Literature Search

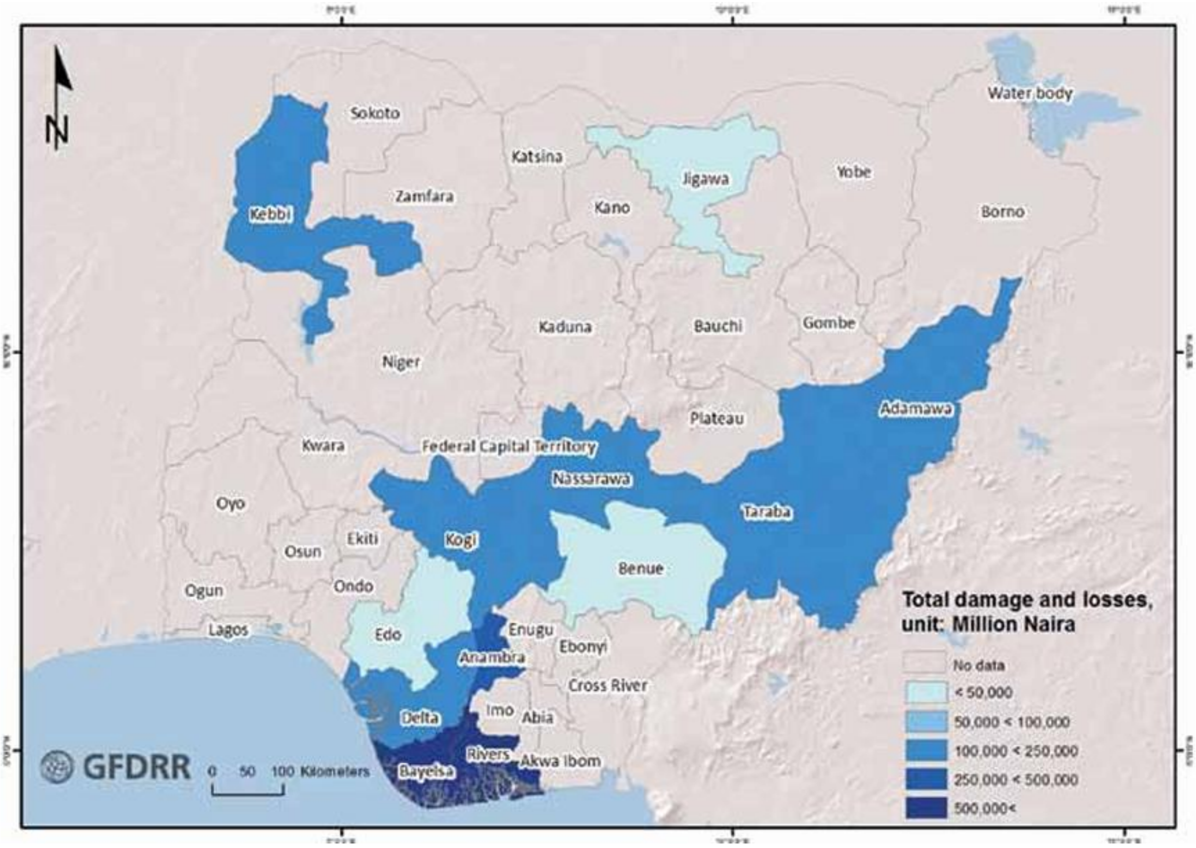
Source: Author's diagram

3. LOSS AND DAMAGE FROM THE 2012 FLOODS IN NIGERIA

Floods are among the most frequent and disruptive disasters in Nigeria, and the 2012 floods were especially severe. Heavy rains from July to October 2012, coupled with rising water levels, led to flooding downstream of major dams on the Niger, Benue, Gongola, and other rivers. In certain cases, dams suffered structural damage; in others, full-force water releases were necessary to prevent overflows. According to the National Emergency Management Agency (NEMA, 2013), the floods claimed 363 lives, injured 5,851 people, affected nearly 3.9 million others, and displaced around 3.87 million individuals.

Estimates indicate that these floods led to ₦1.48 trillion (US$9.5 billion) in destruction of physical and durable assets in the most severely impacted states. An additional ₦1.1 trillion (US$7.3 billion) was lost in terms of economic activity across various sectors, bringing the total damage and loss value to ₦2.6 trillion (US$16.9 billion). This was equivalent to a 1.4% reduction in 2012 real GDP growth, mainly attributed to disrupted production.

Figure 2. Map Showing the Most-Affected States



Source: NEMA (2013)

3.1. Effects on the Agricultural Sector

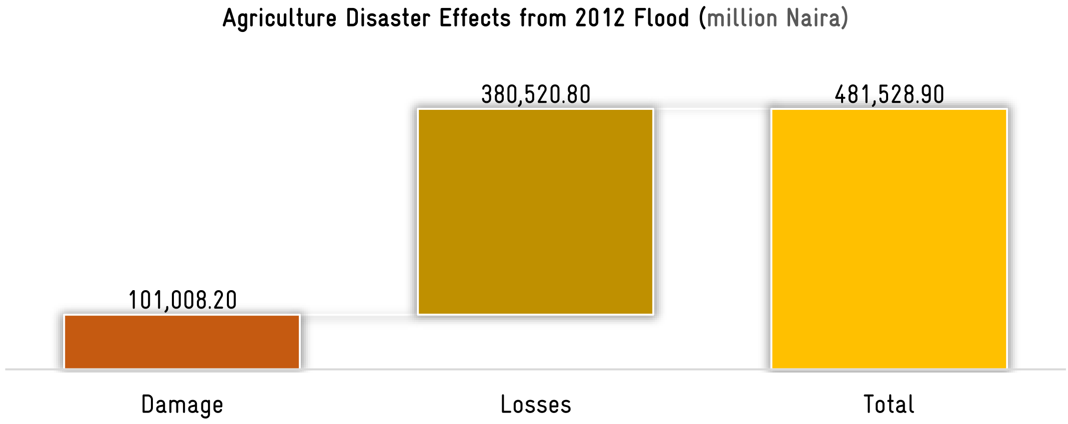
Agricultural and livestock activities in Nigeria often take advantage of the proximity to water in fertile, low-lying flood plains, leaving them particularly exposed when floods occur. It is precisely for that reason, combined with the widespread absence of flood control works and of effective flood warning schemes, that production in these very important sectors of the economy is highly vulnerable to floods. Worse yet, the extraordinary 2012 floods occurred in the last quarter of the calendar year, near the time of harvest for many food crops, which went sub merged for several days and caused the massive loss of production. An early assessment of the flood impact covering the affected states[3] of the federation by the Food and Agriculture Organization (FAO), the Federal Ministry of Agriculture and Rural Development (FMARD), and the World Food Program (WFP) found that approximately 30% of rice production was lost to floodwaters, with somewhat lower but still significant losses for sorghum, cassava, yams, and maize. While stocks were generally sufficient to meet national demand, mobilizing them to deficit areas presented logistical challenges.

[3] Adamawa, Anambra, Bayelsa, Benue, Delta, Edo, Jigawa, Kebbi, Kogi, Nasarawa, Rivers, Taraba.

3.2. Estimates of Damage and Losses in the Agricultural Sector

The agricultural sector, which comprises crop production, livestock raising and fishery, was the most affected production sector, wherein the most important features of disaster effects are production losses (amounting to ₦381 billion) and the destruction of physical assets, at a cost of a further ₦101 billion (Figure 3).

Figure 3. Agricultural sector disaster effects from 2012 nationwide flood in Nigeria



Source: Author's diagram based on information from NEMA (2013)

Beyond these direct impacts, the indirect losses in employment and income are shown in Table 1. They highlight how disrupted agricultural activities translate to lost workdays and lower incomes for both crop and fisheries workers.

Table 1. Impact of the flood disaster on employment and income in the agricultural sector

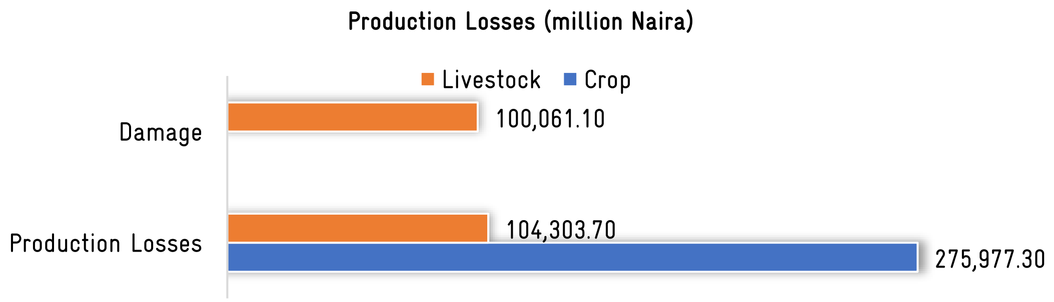
STATE	WORKING DAYS LOST IN CROP PRODUCTION	INCOME LOSS BY WORKERS IN CROP PRODUCTION (MILLION NAIRA)	WORKING DAYS LOST IN FISHERIES	INCOME LOSS OF WORKERS IN FISHERIES (MILLION NAIRA)	TOTAL WORKING DAYS LOST IN AGRICULTURE	TOTAL INCOME LOSS OF WORKERS IN AGRICULTURE
ADAMAWA	1,070,935	107.3	24,416	61.1	1,315,351	168
ANAMBRA	1,096,470	493.2	283,056	70.8	1,379,526	564
BAYELSA	2,820,685	1,268.70	2,444,112	611	5,264,797	1,880
BENUE	1,512,610	680.6	294,816	73.7	1,807,426	754
DELTA	1,367,390	615.3	2,898,720	724.7	4,266,110	1,340
EDO	218,950	98.1	1,005,312	251.3	1,224,262	350
JIGAWA	285,560	128.4	1,629,408	407.3	1,914,968	536
KEBBI	2,996,520	1,348.30	617,760	154.4	3,614,280	1,503
KOGI	2,681,265	1,206.50	204,816	51.2	2,886,081	1,258

NASARAWA	-	-	-	-	-	0
RIVERS	-	-	-	-	-	0
TARABA	2,911,355	1,310.20	1,018,368	254.6	3,929,723	1,565
TOTAL	16,961,740	7,257	10,640,784	2,660	27,602,524	9,917

3.2.1 Crop

Across the assessed states, crop production losses reached nearly ₦276 billion (see Figure 4). Additionally, the report notes that the irrigation and drainage systems also suffered, with estimated damage of ₦1.6 billion. The report notes that without rebuilding these systems promptly, further losses could ensue in subsequent seasons.

Figure 4. Estimated production losses of crops

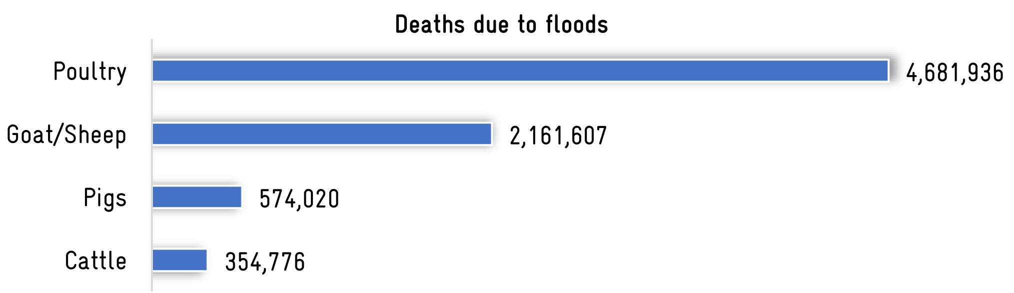


Source: Author's diagram based on information from NEMA (2013)

3.2.2 Livestock

Many domestic animals drowned in the floods. Figure 5 summarises the numbers of animals lost, and the monetary values of dead animals, and of subsequent production losses are shown in the orange bars of Figure 4 above. Over 354,776 cattle, 574,020 pigs, 2.16 million goats/sheep, and 4.68 million poultry were lost in the floods. Such extensive losses affect both immediate food supply and longer-term breeding programs.

Figure 5. Number of drowned animals due to the 2012 floods

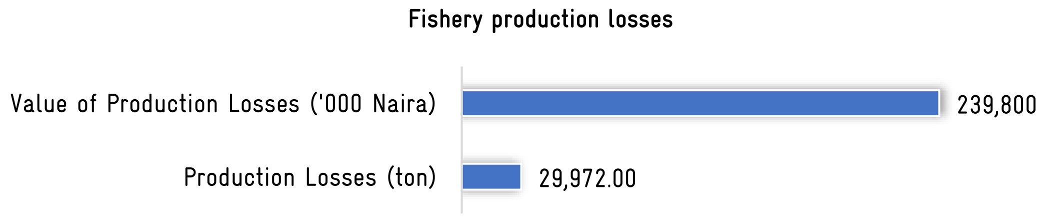


Source: Author's diagram based on information from NEMA (2013)

3.2.3 Fishery

Fishing and aquaculture facilities located in the flood plains were also affected, losing stock and equipment, including loss of fish stock in ponds, destruction of fishing gear, and future production and income losses. Two months of lost fish production in flooded ponds cost about ₦239.8 million, with total fish stock losses nearing 30,000 tonnes (Figure 6).

Figure 6. Fishery production losses due to the 2012 floods



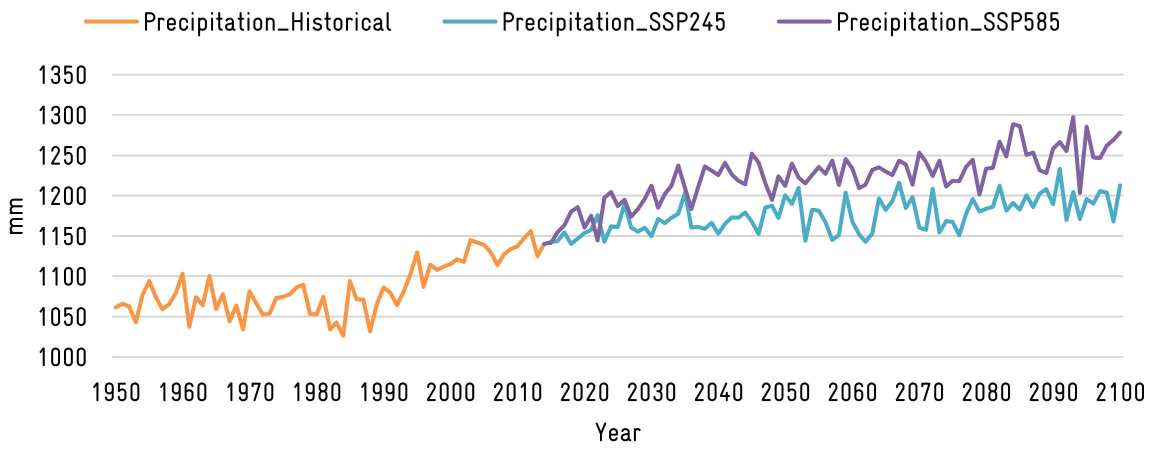
Source: Author's diagram based on information from NEMA (2013)

4. CLIMATE PROJECTIONS FOR NIGERIA

4.1. Historical Context (1950–2014)

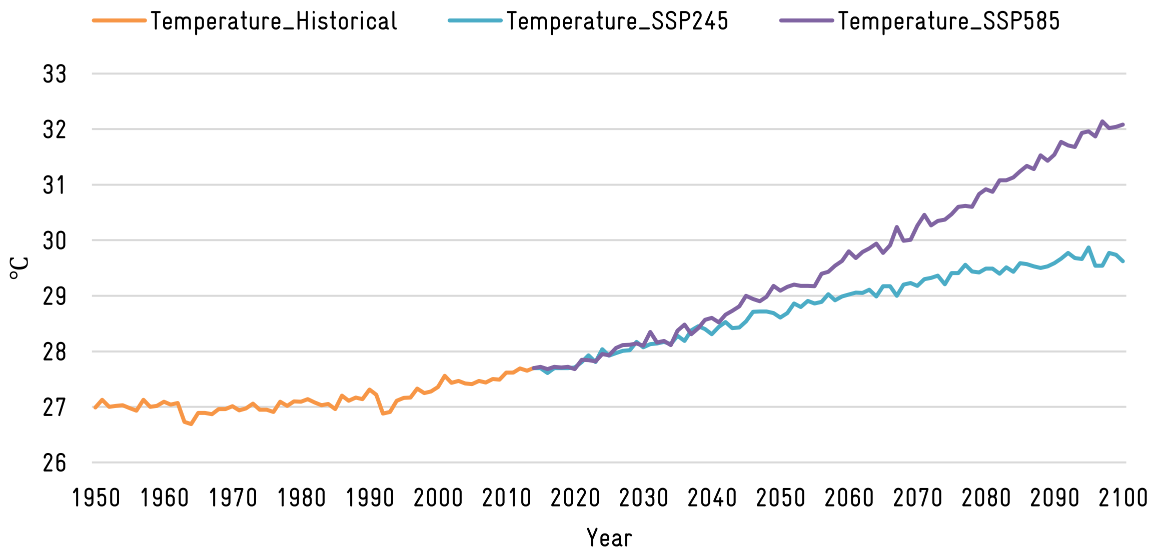
From 1950 to 2014, precipitation averaged around 1,000–1,150 mm per year, though it trended a bit higher in the final decades (often exceeding 1,100 mm) (Figure 7). Meanwhile, mean surface air temperature remained close to 26.9–27.7 °C, with a baseline mean of 27.45 °C over 1995–2014 (Figure 8). The historical SPEI values mostly fell below zero, indicating generally drier conditions, though these gradually moderated near the end of the historical series (Figure 9). Key Insight: By 1995–2014, Nigeria's climate was already warmer and slightly wetter than many earlier decades. Even so, mild dryness prevailed in some regions, as reflected in the negative average SPEI.

Figure 7. Nigeria Annual Precipitation; historical, SSP245 and SSP585 (1950-2100)



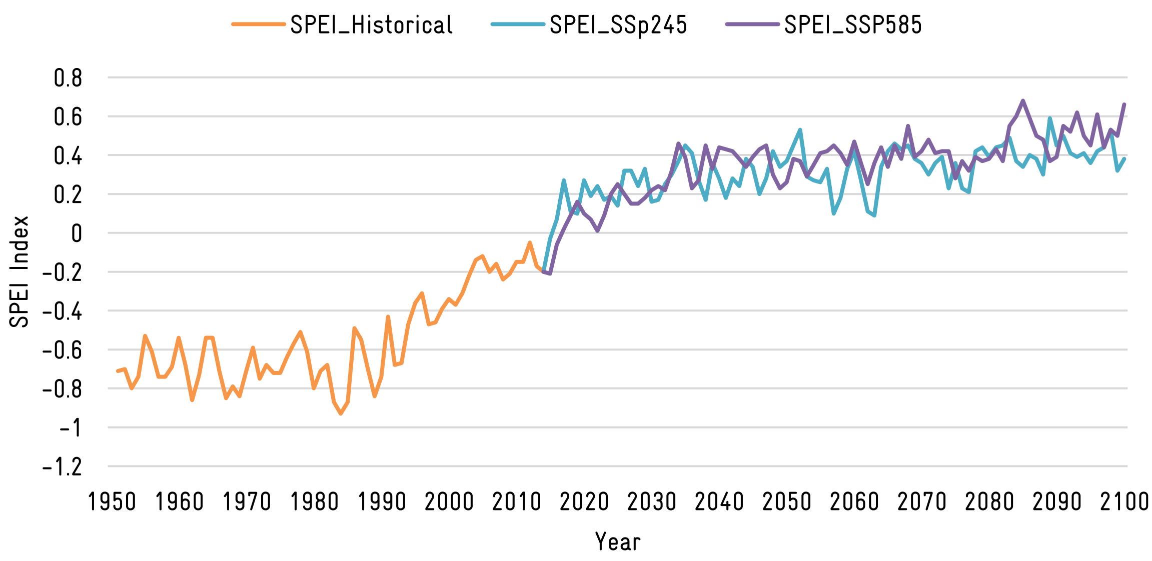
Note: Median estimates form CMIP6 Multi-model Ensemble Scenarios (Reference Period: 1995-2014).
Source: Author's diagram using World Bank Climate Change Knowledge Portal (CCKP) data.

Figure 8. Nigeria Average Mean Surface Air Temperature; historical, SSP245 and SSP585 (1950-2100)



Note: Median estimates form CMIP6 Multi-model Ensemble Scenarios (Reference Period: 1995-2014).
Source: Author's diagram using World Bank Climate Change Knowledge Portal (CCKP) data.

Figure 9. Nigeria Annual SPEI Drought Index; historical, SSP245 and SSP585 (1950-2100)



Note: Median estimates form CMIP6 Multi-model Ensemble Scenarios (Reference Period: 1995-2014).
Source: Author's diagram using World Bank Climate Change Knowledge Portal (CCKP) data.

4.2. Projected Changes (2019–2060) and Anomalies

Two Shared Socioeconomic Pathways (SSP245 and SSP585) show increasing temperatures, rising precipitation totals in most years, and a shift toward positive SPEI anomalies (indicating reduced dryness or moderate wetness). Under SSP245, the temperature anomaly stabilizes around +0.9 to +1.4 °C by mid-century. Under SSP585, the warming is more pronounced, nearing +2.1 °C by 2060. This progressive warming, especially under SSP585, may increase heat stress and evapotranspiration demands.

Projected changes in annual precipitation vary, but overall anomalies tend to be positive. SSP245 exhibits larger swings, with some years surpassing +50 mm relative to the base period. Such increases could benefit water resources but may also bring heavier rainfall events and associated risks like flash flooding.

Positive SPEI (drought index) anomalies become more frequent in both pathways. This suggests fewer prolonged dry spells if rainfall effectively offsets increased evaporation. Nevertheless, higher temperatures under SSP585 might still challenge water balance in some regions, given greater evaporative losses.

Below are selected anomalies for years 2030, 2035, 2040, 2045, 2050, 2055, and 2060 (relative to 1995–2014). These snapshots illustrate evolving trends (Table 2).

Table 2. Anomalies of key climate variables in Nigeria across scenarios

YEAR	ΔPRECIP_245 (MM)	ΔPRECIP_585 (MM)	ΔTEMP_245 (°C)	ΔTEMP_585 (°C)	ΔSPEI_245 (SPEI INDEX)	ΔSPEI_585 ((SPEI INDEX)
BASE (2019)	1,146.80	1,185.92	27.70	27.72	0.10	0.16
2030	3.04	26.53	0.37	0.38	0.06	0.12
2035	57.13	23.47	0.58	0.65	0.35	0.29
2040	6.05	39.85	0.61	0.88	0.18	0.34
2045	20.59	66.30	0.84	1.28	0.24	0.29
2050	53.71	26.16	0.91	1.37	0.27	0.16
2055	34.60	49.46	1.16	1.45	0.16	0.31
2060	20.74	47.42	1.32	2.08	0.32	0.37

Source: Author's compilation using CCKP data.

5. CLIMATE DAMAGE ASSESSMENTS

Climate change is expected to impose significant economic damages on Nigeria's agriculture if no adaptation actions are taken. This section provides evidence of assessments of potential damages in Nigeria's agricultural sector. We provide projections for future years 2030, 2040, 2050, and 2060, considering plausible climate trajectories (Representative Concentration Pathways RCP 4.5 and RCP 8.5) and socio-economic pathways (SSP2 "medium" development and SSP5 "high fossil-fuelled development").

5.1. Statistical Analyses of Historical Performance

Nigeria's agriculture has suffered recurrent losses from extreme weather events such as droughts, floods, and storms. Though there is no comprehensive national inventory of these losses in monetary terms for all events, various sources provide snapshots:

- **Crop Production Losses:** Farmer surveys and studies indicate that adverse weather shocks routinely reduce crop harvests. A World Bank analysis using micro-data (Living Standards Measurement Survey - LSMS) found that in Nigeria, climatic disasters (droughts, floods, etc.) reduced total national crop production by about 3% in 2018-2019 (Wollburg *et al.*, 2024). This is an aggregate figure for those years – meaning actual farmers in affected areas lost a much larger share of their crop, but nationally some areas had normal output. The same study noted that up to 48% of Nigerian farmers reported experiencing a crop loss due to an extreme event in a given season. Over the last few decades, severe droughts (e.g. the mid-1970s, 1983, 2011) and flood years (notably 2012 and 2022) have caused sharp declines in the production of staples. In 2012, record flooding destroyed 12% of all cropland nationally and caused multi-billion naira losses (NEMA, 2013; Reed *et al.*, 2022). In northern Nigeria, drought years have seen harvests of rain-fed cereals plunge by 20-30% regionally.
- **Livestock Losses:** Droughts and heat waves particularly hit pastoral and agro-pastoral communities. During the great Sahel droughts, Northern Nigeria saw large-scale livestock mortality. The 1973 drought, for example, led to herd size reductions as pastures and waterholes dried up (documented in Niger and Chad with livestock losses over 20-30%; Nigeria saw similar patterns in its far north states). More recently, the 2012 flood killed over 5 million livestock (mostly small ruminants and poultry) in Nigeria (NEMA, 2013; Reed *et al.*, 2022). Gradual climate trends like desertification are reducing grazing lands: with 350,000 ha of land turning to desert each year in the far north (NAGGW, 2024), pastoralists are forced to crowd into smaller areas or migrate south, leading to overgrazing and more losses. Heat stress also affects livestock productivity – high temperatures beyond comfort thresholds reduce milk production and can cause livestock deaths (Cervigni *et al.*, 2013). For instance, an extreme heatwave in 2019 in parts of northern Nigeria was reported to have caused some poultry farms to lose significant birds (exact figures not systematically recorded, but anecdotal evidence suggests heat strokes in animals). In economic terms, livestock losses not only mean immediate loss of animals (capital) but also lower reproduction rates and milk/meat output in subsequent periods.
- **Fisheries and Aquaculture Losses:** Climate change has manifested for fisheries largely through water stress. The most dramatic is the shrinkage of Lake Chad on Nigeria's northeastern border – the lake has lost over 90% of its area since the 1960s (UNEP, 2018) due to prolonged droughts and water abstraction. This has led to the collapse of fisheries that supported thousands of livelihoods in Borno/Yobe states. Fish catch in the Nigerian portion of Lake Chad is a fraction of what it was decades ago (some estimates say current catches are down >75% from the 1970s). In coastal areas, rising sea temperatures and ocean acidification could affect fish migration and breeding, though that impact is less documented for Nigeria so far. However, coastal fisheries are also hit by extreme weather – for example, ocean storm surges and flooding (like the 2020 flooding in coastal Lagos and Niger Delta) damage fishponds and wash away stock. Aquaculture (fish farming) is growing in Nigeria, but heavy rains and floods pose risks by overflowing ponds: E.g., in 2022 floods, many fish farms in Anambra

and Delta states lost their fish stock, with reports of entire ponds being swept away (FAO reported floods washing away fish stock and resulting income losses).[4]

- **Forestry Losses:** The forestry sector's climate-related damages are more indirect, as deforestation in Nigeria is mainly driven by human activities (logging, farming) but climate stress exacerbates it. Prolonged dry seasons and occasional wildfires in savannah and montane forests can reduce forest cover. Also, pests and diseases in forests can worsen with climate change (for instance, warmer climates can increase the range of wood-boring insects). While forestry is a small part of GDP, rural communities rely on forest products (fuelwood, wild foods). There is evidence that desertification in the north has caused the loss of economic trees (like date palms, and gum arabic trees) – e.g., desert encroachment has rendered formerly productive semi-arid woodlands barren in parts of states like Yobe and Sokoto. Financially, the Environment Ministry in 2009 estimated Nigeria loses $750 million annually from the depletion of 350,000 ha of forest partly due to climate factors and unsustainable use.[5] This figure combines the lost value of forest services and resources.

Aggregating these sub-sectors, historical data suggest that climate variability already imposes a significant toll on Nigeria's agriculture – easily in the order of 1–2% of GDP in bad years (for instance, 2012's agricultural losses were roughly ₦481 billion (Reed *et al.*, 2022), which was about $3 billion or about 0.8% of that year's GDP, and that's just one event). The World Bank study cited earlier found that across 11 years (2008–2019), Nigeria's likelihood of crop disaster losses grew, implying a rising trend in impact (Wollburg *et al.*, 2024). These observed impacts form the empirical basis for calibrating damage functions.

5.2. Future Modelling Studies

Despite extensive research and substantial empirical evidence, reaching a definitive consensus regarding the expected impacts of climate change on agricultural productivity remains challenging (Roson & Sartori, 2016). The difficulty arises primarily because the issue is inherently complex, involving several interdependent factors that are hard to predict beforehand. Key factors contributing to this complexity, according to Roson and Sartori (2016), include:

I. the role of adaptation behaviour by farmers, firms and organisations, including variety selection, crop rotation, sowing times, etc.;
II. the amount of fertilization due to higher CO2 concentration; and
III. the actual level of water available for irrigation, and irrigation techniques.

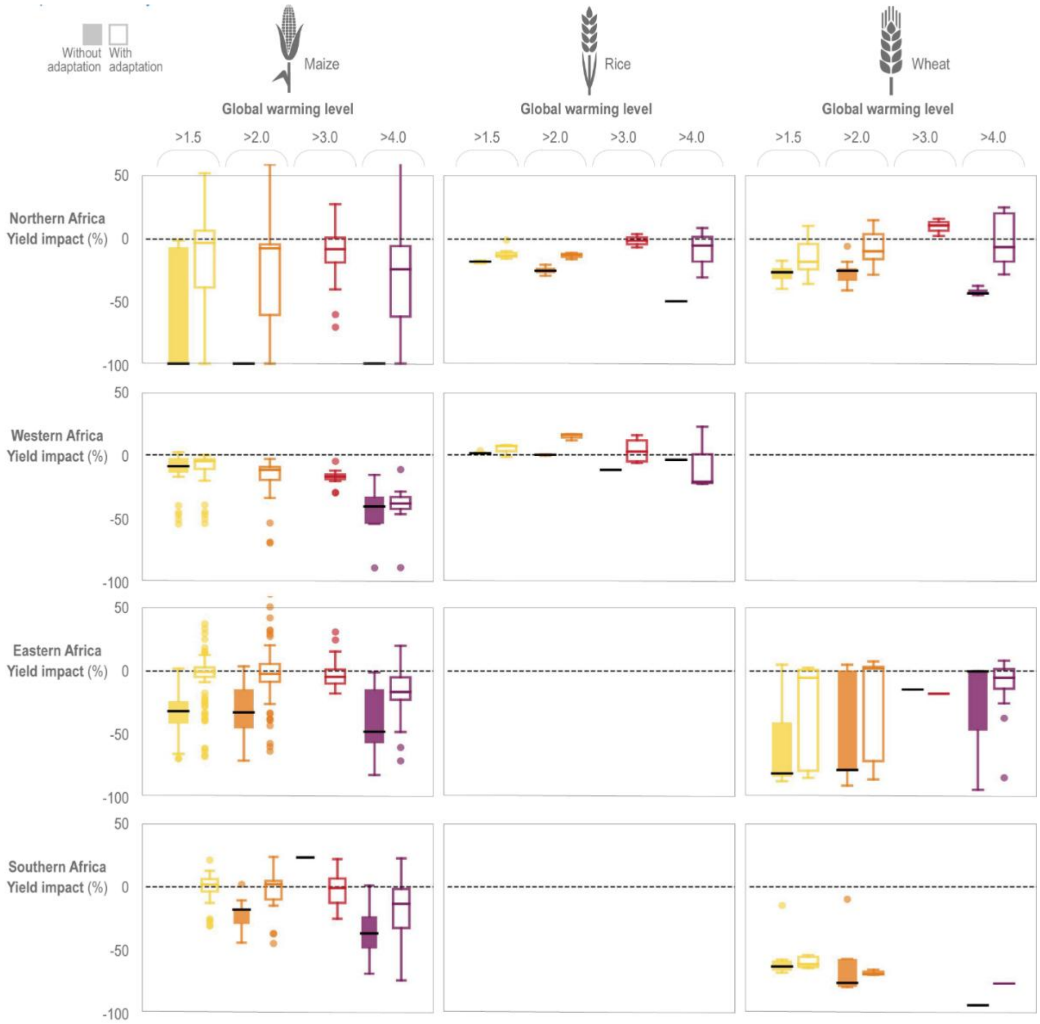
Studies on this topic typically use either controlled experimental settings or crop simulation models, which vary by crop type, geographic area, and climate scenarios. Currently, there are efforts aimed at standardizing these agronomic experiments and modelling approaches. Due to the diversity of existing data and methodologies, most studies generally employ two distinct strategies. The first is a meta-analysis approach, offering central estimates of yield changes for major crops across different regions under various warming scenarios (e.g., +1°C to +5°C). The second approach, exemplified by Cline (2007), provides estimates of productivity changes aggregated for the entire agricultural sector in various regions. Selecting which estimates to use in general equilibrium (GE) models depends on the detail with which agriculture is represented. Roson and Sartori (2016) recommend using the first set of parameters if major crops like

[4] FAO (2012). Mitigating the impacts of flood on fish farmers.
[5] Global Times (2009). Nigeria loses $750 mln annually to climate change

maize, wheat and rice are considered as separate industries, and the second set for the rest, or for the whole agricultural sector if this is regarded as a single aggregate industry.

Following the first approach, the IPCC Sixth Assessment Report (AR6) (IPCC, 2022) graphically presents a synthesis by Hasegawa *et al.* (2022), summarizing projected yield changes for four major crops—maize, rice, soybean, and wheat—in Africa under various temperature increase scenarios, based on studies conducted between 1984 and 2020 (Figure 9.22; IPCC, 2022). The synthesis, accounting for increased CO_2 levels and adaptation measures, uses the 2001–2010 period (mid-point year 2005) as the baseline. For example, median maize yields in West Africa are projected to decrease by approximately 9% at 1.5°C global warming and by 41% at 4°C without adaptation (Figure 10). However, significant uncertainties persist due to varying responses of crops to increased CO_2 levels and the effectiveness of adaptation strategies.

Figure 10. Projected yield changes for major staple crops in Africa due to climate change (compared to 2005 yield levels)



Note: Projected impacts are grouped by projected global warming levels. Boxplots show a synthesis of projected staple crop impacts, with and without adaptation measures (e.g., planting date, cultivar, tillage or irrigation). On average crop yields are projected to decrease with increasing global warming across staple crops in Africa. The overall adaptation potential to offset yield losses across Africa for rice, maize and wheat reduces with increasing global warming. On average, in projections including adaptation options, yield losses in the median case are reduced from −33% to −10% of 2005 levels at 2°C of global warming and from −46% to −23% at 4°C. Global warming levels were calculated using a baseline for pre-industrial global mean temperature of 1850–1900. Data are a synthesis across 35 studies for nearly 1040 locations and cases of projected impacts for regions of Africa for maize, rice and wheat.

Source: (Hasegawa et al., 2022; Trisos et al., 2022).

The synthesis uses "relative yield impacts" (i.e., simulated grain mass per unit land area is used to derive the impact of climate change on yield (YI), which is defined as:

$$YI(\%) = \frac{Y_f}{Y_b} - 1 \times 100 \tag{1}$$

where Y_f is the future yield, and Y_b is the baseline yield. When adaptation measures are considered, YI incorporates both climate change and counterfactual scenarios without climate change:

$$YI(\%) = \left[\frac{(Y_{f\_cc} - Y_{b\_cc}) - (Y_{f\_ncc} - Y_{b\_ncc})}{Y_{b\_cc}} - 1\right] \times 100 \tag{2}$$

Here, Y_{f_cc} and Y_{b_cc} are the future and baseline average yields with climate change, Y_{f_ncc} and Y_{b_ncc} are the future and baseline average yields under counterfactual no climate change scenario.

For Nigeria specifically, Hasegawa *et al.* (2022) provide projections only for maize and rice; wheat projections were available at the African average level, and soybean and other crops' data were unavailable. The climate impact results, summarised in Table 3, clearly demonstrate differential impacts across crops and adaptation strategies under various Representative Concentration Pathways (RCPs).

› **Maize:** Without adaptation, yields sharply decrease, particularly under severe climate scenarios (e.g., reductions of up to 40.8% under RCP8.5 by mid century). Adaptation measures significantly mitigate yield losses, particularly irrigation, which reduces impacts to approximately 4-9% in moderate scenarios (e.g., RCP2.6).

› **Rice:** Interestingly, rice yields without adaptation show marginal positive to neutral impacts in less severe scenarios but become negative under extreme conditions (RCP8.5, end-century). Combined adaptation measures consistently improve rice productivity significantly across scenarios (up to 22.6% increase), highlighting the efficacy of integrated management strategies.

› **Wheat:** Yield declines for wheat remain substantial even with adaptation, though slightly mitigated. Adaptation reduces yield losses by approximately 5-10 percentage points across various climate scenarios, emphasizing wheat's vulnerability and the need for robust adaptation strategies.

Table 3. Hasegawa et al. (2022) average of climate impacts on Nigerian staple crops

CLIMATE SCENARIO • Time slice

			RCP2.6			RCP4.5			RCP6.0			RCP8.5		
Crop	Adaptation	Adaptation type	NF <2040	MC 2040=<2070	EC 2070=<2100	NF <2040	MC 2040=<2070	EC 2070=<2100	NF <2040	MC 2040=<2070	EC 2070=<2100	NF <2040	MC 2040=<2070	EC 2070=<2100
Maize	No	No	-46.0	-51.6	-55.4	-40.5	-55.3	-71.1	–	–	–	-48.2	-40.8	-90.6
	Yes	Combined	-11.3	-17.0	-19.0	-13.2	-23.6	-32.1	-5.3	-12.9	-22.9	-9.9	-22.4	-41.4
		Irrigation	-4.1	-8.6	-9.5				–	–	–	-5.0	-17.1	-35.2
Rice	No	No	3.4	1.2	1.9	1.2	0.3	0.1	–	–	–	0.4	-0.5	-18.7
	Yes	Combined	7.9	7.4	7.0	6.4	11.7	16.7	–	–	–	7.3	16.3	22.6
		Cultivar	–	–	–	–	–	–	–	–	–	–	–	7.4
		Fertiliser	–	–	–	–	–	–	–	–	–	-0.9	-5.7	-22.4
Wheat*	No	No	-38.9	-37.6	-32.3	-40.0	-19.4	-19.7	–	–	–	-35.6	-20.4	-21.8
	Yes	Combined	-35.7	-33.2	-28.5	-36.3	-30.8	-28.0	–	–	–	-27.4	-24.8	-19.7

Note: *African average for wheat due to lack of data for Nigerian. Time slice [NF = Near future (<2040); MC = Mid-century (2040=<2070); EC = End century (2070=<2100)]. "–" means no information. For adaptation options: if the amount and timing of fertiliser application are changed from the current conventional method, it is treated as adaptation. In the irrigation option, if the simulation program determines the irrigation scheduling based on the crop growth, climatic and soil moisture conditions, it is treated as adaptation because the management is adjusted to future climatic conditions. If rain- fed and irrigated conditions are simulated separately, they do not consider irrigation as an adaptation. Cultivar options are the use of cultivars of different maturity groups and/or higher heat tolerance than conventional cultivars. The planting time option corresponds to a shift of planting time from conventional timing. If multiple planting times are tested, the one that gives the best yield is selected. The soil organic matter management option corresponds to application of compost and/or crop residue. The tillage option corresponds to reduced- or no-till cultivation compared to no conventional tillage.

Source: Author's compilation based on Hasegawa et al. (2022).

Adaptation strategies include irrigation, cultivar selection, fertilizer management, soil organic matter management, altered planting times, tillage practices, and combinations thereof. Effective implementation of these adaptations could substantially reduce the negative impacts of climate change on Nigeria's staple crops. Policymakers should prioritize irrigation infrastructure and integrated management approaches, particularly for maize and wheat, given their pronounced vulnerability under future climate scenarios.

In their own study, Roson and Sartori (2016) provide crop level climate impacts for a wide range of temperature increases in Nigeria (Table 4).

- **Maize:** Productivity steadily declines with increasing temperature, reaching significant losses beyond 10% at higher temperature increases (+4°C and +5°C).
- **Wheat:** While initially showing a marginal increase at +1°C, wheat productivity suffers severe losses from +3°C onwards, underscoring its vulnerability.
- **Rice:** Rice shows relatively moderate impacts at lower temperatures but faces substantial declines at higher temperatures (+4°C and +5°C), reflecting increasing vulnerability with warming.

Table 4. Roson and Sartori (2016) estimates of climate impacts on major crops in Nigeria's agricultural sector

PERCENTAGE VARIATION IN MULTI-FACTOR PRODUCTIVITY					
Maize	+1°C	+2°C	+3°C	+4°C	+5°C
	-3.33%	-6.88%	-8.65%	-10.88%	-13.33%
Wheat	+1°C	+2°C	+3°C	+4°C	+5°C
	1.98%	-4.45%	-17.08%	-28.15%	-36.13%
Rice	+1°C	+2°C	+3°C	+4°C	+5°C
	-0.90%	-2.23%	-3.55%	-6.23%	-9.80%

Note: Red highlights indicate productivity losses exceeding 10%. Temperature variations refer to changes in average annual temperature specific to Nigeria, differing from global average temperature changes.
Source: Roson and Sartori (2016).

As previously noted, Roson and Sartori (2016) recommend a second approach using the reduced form Agricultural Response Functions as proposed by Cline (2007). This approach focuses on three critical climate variables affecting crop yields: temperature (T), precipitation (P), and CO_2 fertilization/concentration (K). The relationship is summarized, also known as a **damage function**, as:

$$\Delta Y = f(\Delta T, \Delta P, \Delta K) \tag{3}$$

For a specified scenario (e.g., 2050 under RCP8.5), with temperature increase (ΔT), precipitation change (ΔP), and CO_2 concentration increase (ΔK/K), the simplified yield equation is:

$$\Delta Y = 115.992\Delta T - 9.936\Delta T^2 + 0.4752\Delta P + 7.884\Delta K/K \tag{4}$$

This formulation uses historical climate data (1980-2004) and projections (2050-2074 under RCP8.5), assuming a steady CO_2 increase from 365 ppm at 2.11 ppm annually over 70 years (1992 to 2062). This then translates yield changes into percentage variations ($\Delta Y/Y$), calibrated to baseline productivity levels. Table 5 presents productivity changes for Nigeria's broader agricultural sector:

Table 5. Roson and Sartori (2016) estimates of percentage variation in multi-factor productivity for Nigeria's broad agricultural sector

Panel A: Percentage Variation: Broad Agricultural Sector				
+1°C	+2°C	+3°C	+4°C	+5°C
-3.30%	-6.85%	-10.64%	-14.68%	-18.98%

Note: Values reflect Nigeria-specific average annual temperature changes, differing from global averages. These sector-wide estimates complement crop-specific data where detailed crop-level analyses are unavailable.
Source: Roson and Sartori (2016).

The simulation results from Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3b), using the CROVER crop model and GFDL-ESM4 climate forcing (Jägermeyr *et al.*, 2024), provide a similar picture of the potential impacts of climate change on Nigeria's agricultural productivity under different share climate/socioeconomic pathways (SSP126, SSP370, SSP585) and adaptation through irrigation. Table 6 presents the absolute yield levels (Panel A) and yield changes (Panel B).

For maize, the results indicate high climate sensitivity, with yields declining or stagnating without irrigation. Panel A shows that under SSP370 and SSP585, maize yields remain persistently below the 2019 baseline of 0.90 t/ha, falling to 0.83 t/ha and 0.81 t/ha, respectively, by 2060. Irrigation improves outcomes across all scenarios, raising yields above baseline in most periods—for example, to 1.07 t/ha under SSP126 by 2040. However, Panel B indicates that even with irrigation included in the model framework, percentage yield changes remain negative under mid- and high-emission scenarios, falling to -11.18% under SSP585 by 2060. This suggests that while irrigation is partially effective, it cannot fully offset the adverse impacts of high-end warming on maize. Thus, maize production remains highly vulnerable, with irrigation serving as a necessary but insufficient adaptation.

Table 6. Jägermeyr et al. (2024) projected crop yield and yield changes in Nigeria

		CLIMATE/ SOCIOECONOMIC SCENARIO														
Panel A: Yield (t ha^{-1})		SSP126					SSP370					SSP585				
Crop	Adaptation	2019	2030	2040	2050	2060	2019	2030	2040	2050	2060	2019	2030	2040	2050	2060
Maize	No	0.96	0.89	0.88	0.96	0.88	0.90	0.83	0.86	0.83	0.83	0.85	0.90	0.84	0.86	0.81
	Yes	1.04	1.07	1.07	1.06	1.04	1.02	0.97	0.99	0.93	0.90	1.03	1.00	0.95	0.95	0.92
Rice	No	1.10	0.98	1.01	1.09	1.04	1.00	1.03	0.99	1.05	1.03	0.99	1.08	1.05	1.06	0.98
	Yes	1.17	1.06	1.12	1.15	1.09	1.13	1.12	1.08	1.12	1.11	1.07	1.17	1.13	1.15	1.03
Soya Bean	No	1.19	1.06	1.12	1.23	1.06	1.11	1.06	1.11	1.21	1.21	1.03	1.22	1.21	1.23	1.10
	Yes	1.05	0.97	1.05	1.05	0.96	0.99	1.01	1.00	1.04	1.06	0.96	1.07	1.07	1.12	0.98
Wheat	No	1.27	1.15	1.21	1.29	1.19	1.18	1.18	1.20	1.27	1.25	1.16	1.30	1.28	1.30	1.17
	Yes	1.36	1.23	1.29	1.33	1.18	1.28	1.29	1.25	1.30	1.30	1.21	1.40	1.33	1.36	1.25
Panel B: Pre-processed and bias-adjusted yield changes (%)																
Maize		5.78	-2.72	-3.95	5.12	-6.55	-1.52	-10.93	-7.32	-10.28	-9.55	-8.63	-1.62	-8.65	-5.64	-11.18
Rice		16.63	1.87	5.52	15.32	10.31	5.43	8.77	4.56	10.91	8.57	3.84	13.83	10.85	11.82	2.59
Soya Bean		23.70	11.69	18.22	28.79	13.00	16.60	12.71	17.52	26.72	27.74	10.21	28.20	27.84	30.59	16.03
Wheat		33.37	1.22	-3.84	22.94	10.73	-0.33	3.86	8.17	12.64	10.28	1.81	21.00	21.54	15.01	0.85

Note: The adaptation measure is full irrigation. Simulation round (ISIMIP3b); Impact model (CROVER); Climate forcing (GFDL-ESM4); Bias adjustment (w5e5); Direct human forcing experiment (2015soc). For yield changes, simulations combine rain-fed and irrigated yields, while fractional changes are calculated from total production of each crop per grid cell and year.

Source: Inter-Sectoral Impact Model Intercomparison Project (ISIMIP)[6] and Jägermeyr et al. (2024): Pre-processed and bias-adjusted yield data from ISIMIP3b simulations of the Agriculture Sector.

[6] ISIMIP (2025). https://data.isimip.org/10.48364/ISIMIP.910253

In contrast, rice exhibits greater resilience and responsiveness to irrigation. Without irrigation, rice yields fluctuate but remain near or slightly above baseline. With irrigation, Panel A shows consistently higher yields across all SSPs—reaching up to 1.15 t/ha by 2050 under SSP126 and SSP585. These gains are reinforced by Panel B, where yield changes are consistently positive across all scenarios and years, peaking at 15.32% under SSP126 by 2050. The alignment between rising absolute yields and increasing percentage gains under irrigation suggests that rice is not only climate-resilient but highly responsive to water availability. These attributes make it a strong candidate for scale-up in adaptation policy.

Soya bean results are more complex. Panel A shows that irrigation does not consistently improve yields; in several cases (e.g., SSP126 in 2060), irrigated yields (0.96 t/ha) are lower than those without irrigation (1.06 t/ha). This counterintuitive result may reflect diminishing returns to irrigation or interactions with other climate variables. However, Panel B presents a compelling case: yield changes are strongly positive under all SSPs, with values exceeding 25% in several scenarios and peaking at 30.59% under SSP585 by 2050. These results suggest that soya bean benefits more from favourable climate conditions than from irrigation per se. Its high baseline yield and strong projected gains position it as a low-risk, high-return crop under future climate conditions, with or without irrigation expansion.

Wheat consistently performs well across both panels. Absolute yields increase steadily under all scenarios, and irrigation further enhances productivity—reaching 1.40 t/ha under SSP585 by 2030. Corresponding percentage yield changes in Panel B remain positive and substantial, particularly under SSP126 (33.37% in 2030) and maintain double-digit levels across most projections. The convergence of rising absolute and relative yield values indicates that wheat stands to benefit from moderate climate change, and these gains are magnified by irrigation. Wheat therefore appears to be a reliable anchor crop for future climate-smart agricultural strategies in Nigeria.

Additionally, Cervigni *et al.* (2013), under the World Bank's "Toward Climate-Resilient Development in Nigeria" program, broaden the lens to multiple crops (maize, rice, sorghum, millet, yams, cassava) and livestock risks. By 2050 (2036-2065 period), temperature change is likely to be the major driver of yield shocks, rather than precipitation. Further, most staple crops register median yield losses between −6% and −17%, with maize declining about −10% and rice −17% (Table 7). Though smaller than the losses projected in the high-end scenarios of Hasegawa *et al.* (2022), these figures still mark a serious disruption of production potential. Temperature emerges as the main driver of these negative trends, diminishing biomass accumulation and shortening critical growth phases. Rainfall variability matters too, but the consistent signal of warming across climate models suggests that moderate emission pathways alone are not enough to avert yield drops.

In terms of impacts at the agro-ecological zone (AESZ) level, obtained by aggregating impacts on individual crops using nationwide crop shares in value added as weights, AESZs in the North appear more subject to risks of large declines. Despite the significant amount of variability across space, by 2050 aggregate yield decline seems more likely in all zones, as indicated by the negative median values observed across all major AESZs.

Table 7. Cervigni et al. (2013) aggregate percent change in crop yields by major crops - 2050

	Time frame	Key message	
Crop	Median Yield	1st Percentile	99th Percentile
Maize	-10	-4	-14
Rice	-17	-12	-24

Sorghum	-12	-6	-17
Yam	-6	2	-10
Millet	-8	3	-22
Cassava	-9	4	-18
Aggregate percent change in crop Yields by AEZ – 2050			
Tall Grass Savanna	-9.5		
Short Grass Savanna	-11.5		
Rainforest	-9.2		
Mangrove	-13.5		

Climate change is projected to impose significant stress on Nigeria's livestock sector, primarily through rising temperatures and declining forage productivity. The Temperature-Humidity Index (THI) indicates that southern Nigeria, which is already in the moderate heat stress category (THI 75–79), will enter the danger zone (THI 79–84) by 2050. Meanwhile, northern Nigeria, currently experiencing mild discomfort (THI 72–75), will see increasing heat stress, negatively affecting animal health, reproduction, and productivity. This heightened thermal stress is expected to reduce livestock feed intake, lower milk yields, and increase mortality rates, particularly in poultry and cattle, which are highly sensitive to extreme temperatures.

In addition to heat stress, Gross Primary Productivity (GPP), a measure of forage availability, is projected to decline significantly, particularly in the central and northern regions. With reduced pasture productivity, grazing lands will shrink, increasing reliance on costly feed supplements. Northern Nigeria faces severe GPP reductions, exacerbating feed scarcity, while the central belt will experience moderate-to-high declines in forage availability. Without intervention, this could drive up production costs and intensify conflicts between farmers and pastoralists over land and water resources. Adaptation strategies, such as heat-tolerant cattle breeds, improved water access, shaded livestock housing, drought-resistant pasture cultivation, and enhanced feed conservation methods, are urgently needed to sustain Nigeria's livestock industry in a rapidly changing climate. Failure to act could undermine livestock productivity, rural incomes, and national food security, making climate adaptation an economic imperative.

BNRCC (2011) complements these findings by focusing on specific IPCC scenarios (A2 and B1) and their effect on key crops up to late-century (2081–2100). Maize stands out again as a major concern: in A2 (high emissions), yields in the Northeast could drop by as much as −30%, while southern farmers may face a −20% reduction by mid-century. Under B1 (lower emissions), losses may moderate to around −10% nationwide—a meaningful difference that highlights how emission trajectories shape agricultural outcomes. Moreover, temperature rises up to 38°C in the short grass savanna appear probable, substantially amplifying both heat stress and the evaporative demand for irrigation. Given these projections, the BNRCC findings reinforce the idea that bridging climate adaptation gaps (e.g., developing heat-tolerant hybrids, strengthening dam networks, upgrading extension services) is essential to minimising yield penalties and safeguarding farmer livelihoods.

5.3. Heat and labour productivity

Labour productivity is significantly influenced by working conditions, with heat stress—resulting from elevated temperatures and humidity—causing frequent breaks, disruptions, reduced work pace, and a higher risk of injury (Tawatsupa *et al.*, 2013).

Heat stress refers to heat received in excess of that which the body can tolerate without suffering physiological impairment (Kjellstrom *et al.*, 2016). Maintaining a core body temperature of around 37°C is essential for continued normal body function. Achieving this body temperature equilibrium requires a constant exchange of heat between the body and the environment. Four environmental factors contribute to the stress level experienced by a worker in a workplace with hot conditions: temperature, humidity, radiant heat (e.g. from the sun or a furnace) and wind speed (ILO, 2019).

In order to estimate the incidence of heat stress, one of the most common heat stress indices in occupational health is used, namely the wet bulb globe temperature (WBGT), measured in degrees Celsius (ILO, 2019). WBGT is a comprehensive heat exposure index (measured in °C) combining natural wet bulb temperature, black globe temperature, and shaded air temperature. Roson and Sartori (2016) compute average WBGT values using temperature and relative humidity based on equations from the Australian Bureau of Meteorology:

$$WBGT = 0.567T + 3.94 + 0.393E \tag{5}$$

$$E = (RH/100) \times 6.105 \times exp(17.27T/(237.7 + T)) \tag{6}$$

where T is average air temperature (°C), E is absolute humidity (water vapour pressure in hPa), and RH is relative humidity (%). Relative humidity was approximated using temperature and precipitation data through a validated regression equation:

$$RH = 67.1082 - 0.8438T + 0.2305P - 0.0005P^2 \tag{7}$$

where P is precipitation in mm.

Drawing on literature about "work ability," Roson and Sartori (2016) set different productivity thresholds based on the intensity of work: agricultural work (500 W), manufacturing work (300 W), and office/service work (200 W). They defined minimum heat effect thresholds at 26°C for agriculture, 28°C for manufacturing, and 30°C for services, with productivity dropping to a minimum of 25% at higher temperatures (36°C for agriculture, 43°C for manufacturing, and 50°C for services).

The computed percentage productivity levels for all months, sectors, and countries were aggregated annually, aligning with economic flow representations in CGE and numerical models. Temperature scenarios ranged from +1°C to +5°C, maintaining the same monthly temperature distribution and relative humidity levels. The relative annual productivity changes against baseline conditions were computed accordingly.

Labour productivity in Nigeria's agricultural sector (Panel A of Table 8) is highly vulnerable to temperature increases, with productivity losses accelerating dramatically with each additional degree of warming. At a moderate temperature rise (+2°C), productivity loss already exceeds 15%, intensifying to severe levels (over 44%) at higher temperature increases (+5°C). These significant declines underscore the critical need for policy interventions aimed at mitigating heat stress impacts, such as improved working conditions, adaptive practices, and appropriate infrastructure investment. The study also provides labour productivity changes for the manufacturing sector (Panel B) and services sector (Panel C) of the Nigerian economy.

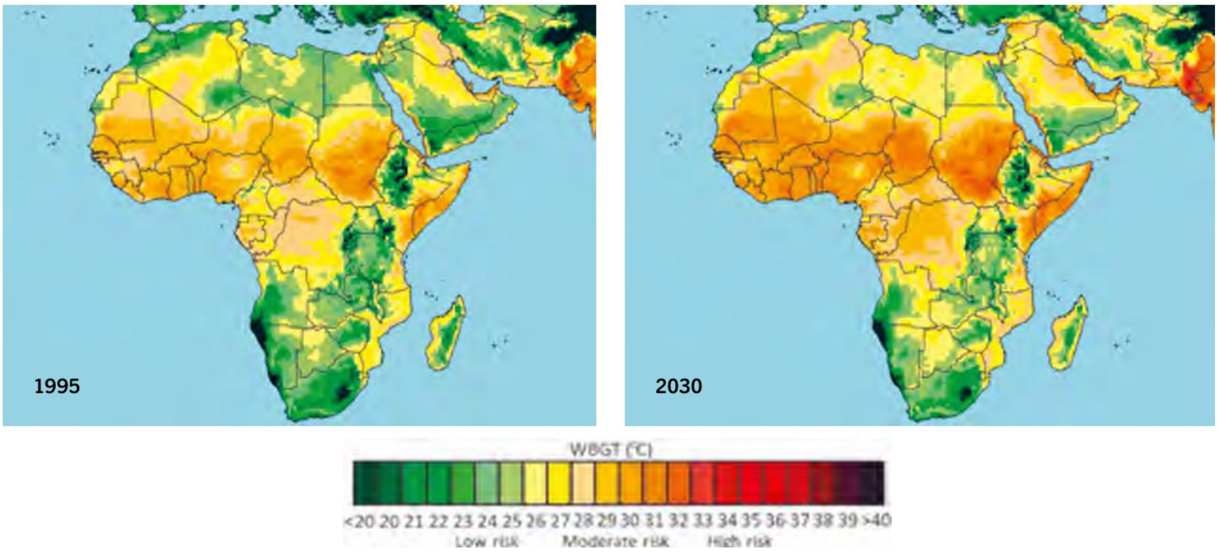
Table 8. Roson and Sartori (2016) Heat impacts on agricultural sector labour productivity in Nigeria

Panel A: Heat impacts on agricultural sector labour productivity (percentage change)				
+1°C	**+2°C**	**+3°C**	**+4°C**	**+5°C**
-7.33%	-15.37%	-24.59%	-34.45%	-44.40%
Panel B: Heat impacts on manufacturing sector labour productivity (percentage change)				
-3.45%	-7.38%	-11.94%	-16.96%	-22.68%
Panel C: Heat impacts on services sector labour productivity (percentage change)				
-0.78%	-2.23%	-5.08%	-8.12%	-11.67%

Note: Temperature variations refer specifically to Nigeria's average annual changes, differing from global averages.
Source: Roson and Sartori (2016).

A recent study by the ILO (2019) also evaluates the impacts of heat stress on labour productivity using the Wet Bulb Globe Temperature (WBGT) metric, integrating climate models, temperature projections, occupational health data, and labour force trends. Figure 11 highlights projected heat stress levels across Africa for 1995 and 2030, indicating that countries such as Nigeria experience heat levels sufficient to negatively impact labour productivity. The frequency of heatwave days in this region is projected to rise significantly throughout the twenty-first century.

Figure 11. ILO (2019) estimate of incidence of heat stress during the hottest month in Africa, 1995 and 2030 (projections)



Note: Note: The maps show averages of daily maximum WBGT during the hottest month for 1995 and 2030. The estimates for 1995 are based on a 30-year average for the period 1981–2010, and the projections for 2030 on a 30-year average for the period 2011–40 with adjustment of the value at the midpoint (2025) to give the projected level in 2030 for each country.

Source: ILO estimates based on data from the HadGEM2 and GFDL-ESM2M climate models (using as input the RCP2.6 climate change pathway, which envisages a global average temperature rise of 1.5°C by the end of the century).

Table 9 provides a detailed breakdown of the percentage of working hours lost to heat stress in Nigeria and the broader West African region. Specifically emphasising the agricultural sector, by 2030, working hours lost due to heat stress in Nigeria's agricultural sector nearly double from 5.4% to 9.79%, significantly impacting productivity. The losses are consistent across other sectors of the economy. Overall, Nigeria could see full-time job losses grow from approximately 932,000 in 1995 to around 3.6 million by 2030, highlighting the substantial economic risks posed by rising temperatures.

Table 9. ILO (2019) estimates of working hours lost to heat stress, by sector in Nigeria and Western Africa, 1995 and 2030 (projections)

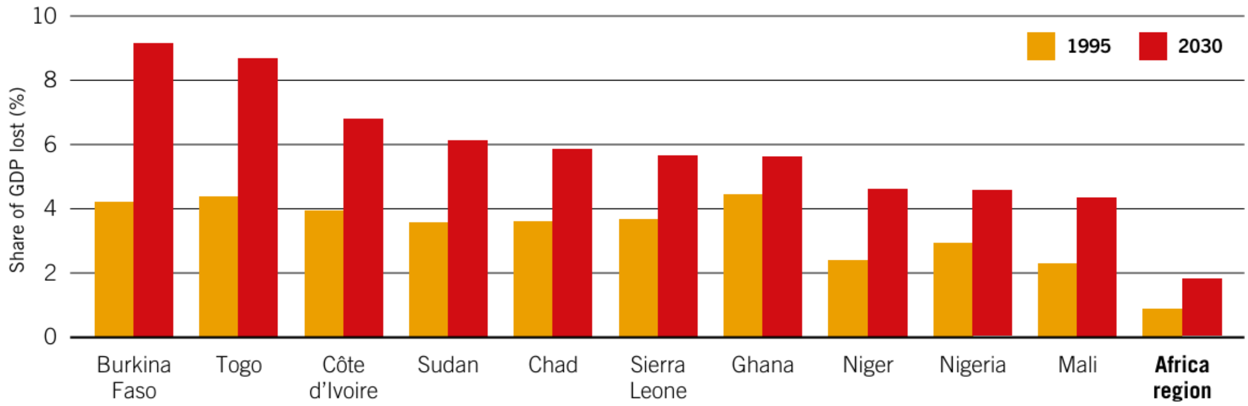
Country	Agriculture (in shade), (%)	Industry (%)	Construction (in shade), (%)	Services (%)	Total (%)	Total (thousand full-time jobs)
	1995					
Nigeria	5.40	2.27	5.40	0.33	3.18	932
Western Africa	5.23	2.20	5.23	0.29	3.37	2,088
	2030					
Nigeria	9.79	4.84	9.79	0.96	3.89	3,639
Western Africa	9.17	4.71	9.17	0.90	4.77	8,968

Note: The table shows the percentage of working hours lost to heat stress (and the associated health, well-being and productivity effects) in each sector and in the economy as a whole. It also shows the equivalent loss in terms of full-time jobs for the economy as a whole. Work in agriculture and construction is assumed to be carried out in the shade. The heat stress index for work in the afternoon sun adds around 2–3°C to the in-shade WBGT (see Appendix II for further details). The data are based on historical observations and on estimates obtained using the RCP2.6 climate change pathway, which envisages a global average temperature rise of 1.5°C by the end of the century.

Source: ILO (2019) estimates based on data from the ILOSTAT database and the HadGEM2 and GFDL-ESM2M climate models.

Moreover, working hours lost to heat stress could result in a reduction in aggregate production. Combining the equivalent losses in terms of full-time jobs with measures of GDP per worker gives a preliminary estimate of the GDP losses expected to occur as a result of heat stress. These estimates consider changes in technology and capital, and also other factors considered in the ILO projection models. Figure 12 shows the estimated GDP loss due to heat stress for the ten countries in the region that are most affected. In 1995, Nigeria lost more than 3% of its GDP as a result of heat stress. These losses are projected to increase significantly by 2030: the share of GDP lost to heat stress more approaches 5% in Nigeria.

Figure 12. Percentage of GDP lost to heat stress under a 1.5°C global warming scenario, ten most affected countries in Africa, 1995 and 2030 (projections)



Note: The figure shows the percentages of GDP lost to heat stress (and the associated health, well-being and Africa region productivity effects) in the ten most affected countries in the region, together with the averaged regional estimates, for 1995 and projections for 2030. GDP loss is calculated by multiplying the equivalent number of full-time jobs lost by GDP per worker. Technological and capital changes over time are taken into account in the measure of GDP per worker. The underlying climate data are based on observations and estimates obtained using the RCP2.6 climate change pathway, which envisages a global average temperature rise of 1.5°C by the end of the century. It is worth noting, though, that the RCP2.6 and RCP6.0 pathways envisage relatively similar temperature increases until 2030, with most of the divergence appearing thereafter.
Source: ILO (2019) estimates based on data from the ILOSTAT database and the HadGEM2 and GFDL-ESM2M climate models.

5.4. Sea Level Rise and Land Loss

According to the Fifth IPCC Assessment Report (IPCC, 2014), global temperature increases result in sea-level rise (SLR), primarily through thermal water expansion and melting glaciers. SLR affects land through coastal erosion, flooding, and saltwater intrusion, significantly influenced by country-specific factors such as shoreline composition, coastline length, and vertical land movement (VLM).

IPCC data indicate a positive relationship between SLR and global temperature rise, moderated by temporal lags due to natural inertia. Using regression analyses, a satisfactory model for adjusted sea-level rise (aSLR) was developed:

$$aSLR = [(\alpha + \beta \Delta t - V)(T - 2000)] \quad (8)$$

Here, Δt represents the global temperature increase relative to the 1985–2005 baseline, V denotes vertical land movement, and T is the reference year. Estimated parameters are α = 0.000954281 and β = 0.003421296. For example, a temperature rise of +1°C and VLM of +0.001 m/year by 2050 yields approximately 0.17 meters of adjusted sea-level rise

Using HadCM3 climate model predictions (SRES scenario A1b), a global mean SLR of 0.16 meters corresponds to a coastal wetland reduction of 0.07% in West Africa. Applying this estimate to Nigeria, assuming 70% of the coastline is erodible and accounting for agriculturally productive land, the study calculates the percentage loss of productive land at various SLR scenarios.

Table 10 illustrates the percentage losses of productive land endowments for +1, +2, +3, +4 and +5 °C increases in average temperature, at the years 2050 and 2100, for Nigeria.

Table 10. Sea level rise: percentage losses of land

2050					2100				
+1°C	+2°C	+3°C	+4°C	+5°C	+1°C	+2°C	+3°C	+4°C	+5°C
0.0000%	-0.0001%	-0.0001%	-0.0001%	-0.0002%	-0.0001%	-0.0001%	-0.0002%	-0.0003%	-0.0003%

5.5. Damage for Priority Crops in Nigeria

Nigeria's National Agricultural Technology and Innovation Policy (NATIP) identifies priority crops and livestock. Table 11 presents the crop production and their land area cultivated, production/output, and yield as of 2019—the base year for the ongoing project.

Table 11. Base year (2019) – Crop and Livestock Statistics for Nigeria

S/N	Crop	Land Area ('000) Ha	Production ('000) MT	Yield (Ton/Ha)	Source
1	Rice	4,126.67	8,435.61	2.04	NAERLS
2	Maize (corn)	6,033.41	12,598.95	2.09	NAERLS
3	Sorghum	5,821.24	6,668.24	1.15	NAERLS
4	Millet	1,747.80	1,925.08	1.10	NAERLS
5	Cowpea	4,931.32	4,064.71	0.82	NAERLS
6	Groundnut	3,578.67	4,441.01	1.24	NAERLS
7	Soybean	1,148.05	1,048.51	0.91	NAERLS
8	Beniseed	782.59	523.43	0.67	NAERLS
9	Yam	6,778.08	52,914.91	7.81	NAERLS
10	Cassava	9,776.65	56,969.16	5.83	NAERLS
11	Cocoyam	1,223.18	7,900.08	6.46	NAERLS
12	Cotton	512.38	230.65	0.45	NAERLS
13	Ginger	93.73	679.04	7.24	NAERLS
14	Tomato	1,478.42	3,102.96	2.10	NAERLS
15	Onion	568.23	1,464.28	2.58	NAERLS
16	Okra	1,430.86	1,718.17	1.20	NAERLS
17	Plantain and Banana	450.81	5,526.11	12.26	NAERLS
18	Sesame seeds	782.59	523.43	0.67	FAOSTAT
19	Sugar cane	86.40	1,503.58	17.40	FAOSTAT

20	Sweet potatoes	1,503.89	4,143.21	2.75	FAOSTAT
21	Wheat	51.65	86.90	1.68	FAOSTAT
22	Potatoes	321.79	1,210.94	3.76	FAOSTAT
23	Pineapples	192.56	1,593.87	8.28	FAOSTAT
24	Papayas	94.23	843.58	8.95	FAOSTAT
25	Oil palm fruit	3,809.95	9,790.90	2.57	FAOSTAT
26	Melon seed	875.16	567.57	0.65	FAOSTAT
27	Mangoes, guavas and mangosteens	131.45	946.99	7.2	FAOSTAT
28	Kola nuts	243.17	169.20	0.7	FAOSTAT
29	Green garlic	0.16	2.13	13.09	FAOSTAT
30	Cowpeas, dry	4,931.32	4,064.71	0.82	FAOSTAT
31	Coffee, green	1.42	1.85	1.3	FAOSTAT
32	Coconuts, in shell	36.40	274.90	7.55	FAOSTAT
33	Cocoa beans	885.57	250.00	0.28	FAOSTAT
34	Chillies and peppers, dry (Capsicum spp., Pimenta spp.), raw	36.45	63.12	1.73	FAOSTAT
35	Chillies and peppers, green (Capsicum spp. & Pimenta spp.)	102.73	765.62	7.45	FAOSTAT
36	Cashew nuts, in shell	140.00	101.50	0.73	FAOSTAT
37	Carrots and turnips	26.81	237.32	8.85	FAOSTAT

Note: NATIP's priority crops are maize, sorghum, rice, wheat, cassava, sesame, tomatoes, yam, cowpea, soybeans, cocoa, palm oil, hibiscus, cashew, potatoes, cotton, ginger, groundnuts and sugar cane (NATIP 2022-2029, [p.4]).
Livestock priority: dairy, beef, poultry, pig, sheep, goat, donkey, honeybee, leather, and micro-livestock [p. 34].
NATIP: https://agriculture.gov.ng/wp-content/uploads/2024/06/National-Agricultural-Technology-and-Innovation-Policy-NATIP-2022-2027.pdf. Data for production and yield were sourced from NAERLS (2020) Agricultural Performance Survey of 2020 Wet Season in Nigeria. https://naerls.gov.ng/reports/ and FAOSTAT (2024).

Table 12. Base year (2019) – Crop Statistics for Nigeria

Livestock	Cattle	Sheep	Goats	Pig	Chicken	Rabbits	Donkey	Horse	Guinea fowl	Turkey
Total Heads in 2019 (mln)	20.41	46.76	82.71	8.60	208.10	1.14	0.98	0.10	26.34	2.65

References

BNRCC. (2011). Climate Change Scenarios for Nigeria: Understanding Biophysical Impacts Building Nigeria' s Response to Climate Change (BNRCC) Project. Building Nigeria's Response to Climate Change (BNRCC) and Nigerian Environmental Study/Action Team (NEST).

Cervigni, R., Valentini, R., & Santini, M. (2013). Toward Climate-Resilient Development in Nigeria. The World Bank.

Cline, W. R. (2007). Global Warming and Agriculture: Impact Estimates by Country. Columbia University Press.

CRED. (2023). 'EM-DAT: The International Disaster Database.' www.%0Aemdat.be

Hasegawa, T., Wakatsuki, H., Ju, H., Vyas, S., Nelson, G. C., Farrell, A., Deryng, D., Meza, F., & Makowski, D. (2022). A global dataset for the projected impacts of climate change on four major crops. Scientific Data, 9(1), 58. https://doi.org/10.1038/s41597-022-01150-7

ILO. (2019). Working on a warmer planet: The impact of heat stress on labour productivity and decent work. Geneva, Switzerland: International Labour Organization.

IPCC. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Inter-governmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC. (2022). Climate change 2022 - mitigation of climate change - summary for policymakers (SPM). In Cambridge University Press (Issue 1).

Jägermeyr, J., Müller, C., Ruane, A. C., Elliott, J. W., Balkovic, J., Castillo, O., Faye, B., Foster, I., Folberth, C., Franke, J. A., Fuchs, K., Guarin, J. R., Heinke, J., Hoogenboom, G., Iizumi, T., Jain, A., Kelly, D., Khabarov, N., Lange, S., … Rosenzweig, C. (2024). Pre-processed and bias-adjusted yield data from ISIMIP3b simulations of the Agriculture Sector. ISIMIP Repository. https://doi.org/10.48364/ISIMIP.910253

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., & Hyatt, O. (2016). Heat, Human Performance, and Occupational Health: A Key Issue for the Assessment of Global Climate Change Impacts. Annual Review of Public Health, 37, 97–112. https://doi.org/10.1146/annurev-publhealth-032315-021740

NAGGW. (2024). National Agency for the Great Green Wall (NAGGW) - About us. https://ggwnigeria.gov.ng/about-us/

NEMA. (2013). NIGERIA Post-Disaster Needs Assessment 2012 Floods. National Emergency Management Agency (NEMA). https://www.gfdrr.org/sites/gfdrr/files/NIGERIA_PDNA_PRINT_05_29_2013_WEB.pdf

Reed, C., Anderson, W., Kruczkiewicz, A., Nakamura, J., Gallo, D., Seager, R., & McDermid, S. S. (2022). The impact of flooding on food security across Africa. Proceedings of the National Academy of Sciences, 119(43), e2119399119. https://doi.org/10.1073/pnas.2119399119

Roson, R., & Sartori, M. (2016). Estimation of Climate Change Damage Functions for 140 Regions in the GTAP9 Database. World Bank Policy Research Working Paper No. 7728. https://doi.org/10.2139/ssrn.2741588

Tawatsupa, B., Yiengprugsawan, V., Kjellstrom, T., Berecki-Gisolf, J., Seubsman, S.-A., & Sleigh, A. (2013). Association between Heat Stress and Occupational Injury among Thai Workers: Findings of the Thai Cohort Study. Industrial Health, 51(1), 34–46. https://doi.org/10.2486/indhealth.2012-0138

Trisos, C. H., Adelekan, I. O., Totin, E., Ayanlade, A., Efitre, J., Gemeda, A., Kalaba, K., Lennard, C., Masao, C., Mgaya, Y., Ngaruiya, G., Olago, D., Simpson, N. P., & Zakieldeen, S. (2022). Africa. In H.-O. Pörtner, D. C. Roberts, E. S. P. M. Tignor, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1285–1455). Cambridge University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009325844.011

UNEP. (2018). The tale of a disappearing lake. https://www.unep.org/news-and-stories/story/tale-disappearing-lake#:~:text=The tale of a disappearing,drought and the impacts

Wollburg, P., Markhof, Y., Bentze, H., & Ponzini, G. (2024). The Impacts of Disasters on African Agriculture New Evidence from Micro-Data. Policy Research Working Paper 10660. Washington D. C.: World Bank.