PAN-AFRICAN UNIVERSITY
INSTITUTE FOR WATER AND ENERGY SCIENCES
(Including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the master's degree in
Climate Change

Presented by
Promise Delight Udochukwu

Climate Change Effect on Land Use, Cassava Production and Yield in

PAN AFRICAN UNIVERSITY FOR WATER AND ENERGY SCIENCES
(Including climate change)

Climate Change Effect on Land Use, Cassava Production and Yield in Nigeria

A master's thesis submitted to the Pan African University for Water and Energy Sciences (Including Climate Change) in partial fulfillment of the requirements for the award of a Master of Science degree in Climate Change.

By

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May, 2024

Tlemcen, Algeria.

DISSERTATION APPROVAL PAGE

Climate Change Effect on Land Use, Cassava Production and Yield in Nigeria

Submitted by

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DEDICATION

This work is dedicated to all cassava farmers in Nigeria. I have the utmost respect for the crucial role you play in feeding the nation each day through your efforts in cassava farming. It is my sincere hope that this work in some way helps raise awareness of the importance of cassava agriculture and supports initiatives aimed at enhancing the livelihoods of those engaged in this vital sector.

STATEMENT OF THE AUTHOR

I, Promise Delight Udochukwu, declare that this dissertation titled, Climate Change Effect on Land use, Cassava Production and yield in Nigeria has never been submitted to any institution of higher education. I have followed all Pan African University (PAU) Scholarship regulations and recognized scholarly matters through proper citations and references. I affirm that I have made every effort within my means to avoid plagiarism.

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BIOGRAPHICAL SKETCH

Promise Delight Udochukwu graduated with honors from the University of Nigeria with a bachelor's and master's degree in library and information science. She is quite interested in the numerous facets of the Sustainable Development Goals. Working for companies both domestically and abroad has given her professional experience. Promise is currently enrolled in the Pan African University for Water and Energy Sciences in Algeria (PAUWES) to pursue an MSc in Climate Change. The African Union Commission fully funds Promise's studies there. She worked as a research assistant in the University of Nigeria, Nsukka's Nnamdi Azikiwe Library following the completion of her bachelor's degree. She also co-facilitated the Wikipedia Edit-a-thon on art and feminism for four years. She served as the academic coordinator for the Kings Call 2 Koma Hill during the National Youth Service Corps (NYSC) throughout her required service.

She worked as a sustainability intern with the Lebanon chapter of the Association of Energy Engineers. Her desire to contribute significantly to the agriculture industry is driven by passion. She enthusiastically assumed the role of team lead, and with the help of four other people, her team won the prestigious global Switzerland Graduate Challenge (Geneva Challenge 2023) by coming up with a ground-breaking plan to minimize loneliness for seniors and members of Generation Z. Her current goal is to become a climate change communicator, and she supports sustainable approaches to combat climate change as a research associate in this capacity. She hopes to pursue a PhD in the future.

ACKNOWLEDGMENTS

My deepest gratitude goes out to my thesis supervisor, Professor Uchendu Eugene Chigbu, for all of his advice, clarifications, and great understanding that enabled me to finish my project on time.

My sincere gratitude goes out to Mr. Uchenna, my internship coordinator, whose insight and help made this task feasible. I sincerely appreciate my family's unwavering love, support, and encouragement.

I am appreciative to the University of Tlemcen, GIZ, PAUWES, and the African Union for their sponsorship and hosting of my master's program.

I also want to express my gratitude to all of my friends, colleagues, and well-wishers who helped make this research a success. Thank you very much to the entire 2022 Climate Change class! Our days of personal and professional development taught me a lot.

ABBREVIATIONS AND ACRONYMS

ACMD- African Cassava Mosaic Disease

Albedo - The fraction of solar energy reflected from Earth back into space.

ALC- Arable lands cover

BVOCs - Biogenic volatile organic compounds.

CAD- cassava anthracnose disease

Cass – Cassava

CBB- cassava bacterial blight

CBSD- Cassava brown streak virus disease

CBSD- Cassava brown streak virus disease

CGM - Climate Global Model.

CM- cassava mealybug

CMD - Climate Model Diagnostics

CMD- cassava mosaic virus disease

CO_2 - Carbon dioxide

CO_2 - Carbon dioxide

El Niño - A natural phenomenon involving fluctuations in ocean temperatures and weather patterns across the tropical Pacific.

ENSO - El Niño-Southern Oscillation. It is a recurring climate pattern involving changes in the temperature of waters in the central and eastern tropical Pacific Ocean.

FAO - Food and Agriculture Organization of the United Nations

FAO - Food and Agriculture Organization of the United Nations.

FAOSTAT - Food and Agriculture Organization Corporate Statistical Database

FLC- Forest Lands Cover

GDP - Gross domestic product

$GtCO_2$-eq - Gigatonnes of carbon dioxide equivalent.

IPBES - Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

IPCC - Intergovernmental Panel on Climate Change

Kg – kilogram

Kj – Kilojoule

La Niña - The cool phase of the El Niño-Southern Oscillation climate pattern, characterized by cooler-than-average sea surface temperatures across the equatorial Pacific.

LIA- Little Ice Age

LUCC - Land use and land cover change.

M3 - Cubic meter

MJ - Megajoule

NAP - National Agricultural Policy

NGN - Nigerian Naira

NIMET - Nigerian Meteorological Agency.

NOAA - National Oceanic and Atmospheric Administration

RLC- Range Lands Cover

SLCFs - Short-lived climate forcers.

SLM- Sustainable Land Management

SRCCL - Special Report on Climate Change and Land.

SSA - Sub-Saharan Africa.

UN - United Nations.

UNCCD - United Nations Convention to Combat Desertification.

UNEP - United Nations Environment Programme.

UNFCCC - United Nations Framework Convention on Climate Change

UNSD - The United Nations Statistics Division

USD - United States Dollar

Table of Contents

List of figures

List of Tables

Abstract

Climate change is a global challenge affecting human beings, their socioeconomic activities, health, livelihood, and food security. Cassava is Africa's most important staple food after maize, in terms of calories consumed and also a major source of calories for roughly two out of every five Africans. Despite being the highest producer of cassava globally with over 9 million ha devoted to cassava production annually, Nigeria's yield (tonnes/ha) has progressively declined. There is a need for an investigation of the effects of climate change on the declining yield status of Nigeria. The objectives of this study were to determine the effects of temperature and rainfall variability on cassava land use, production and yield between 1980 and 2021. The study employed the mixed-method (quantitative and qualitative) to analyze the impacts of climate change on land use, cassava production and yield in Nigeria. Data collection for quantitative method utilized time series data covering the period from 1980 to 2021, encompassing two climatic variables, temperature and precipitation. These yearly national climatic data were sourced from the Nigerian Metrological Institute (NIMET). The dataset ranged from 1980 to 2021 for all the stations. The historical datasets on land use, cassava yield and production was sourced from the Food and Agricultural Organization of the United Nations (FAOSTAT). Multiple linear regression was used to model relationships and project future climate impacts. Surveys (n=400 farmers) provided quantitative yield and production data and qualitative perceptions of impacts. Focus groups (n=20) generated qualitative data on adaptation strategies. Results showed increasing temperatures and slightly higher rainfall overall. Quantitative analysis of meteorological data (1980-2021) showed rising temperatures and rainfall trends. Multiple regression modeled relationships between climate variables and yield quantitatively. Results showed that cassava yield increased slowly pre-2000 (9.58 – 9.70 t/ha), increased steeply from 2001 to 2010 (9.60 – 12.22 t/ha), and fell drastically post-2010 (12.22 – 5.84 t/ha). The decline in cassava yield post-2010 was associated with soil degradation, poor access to improved farming materials, pest and diseases, poor management, quality of rainfall rather than amount (regularity and duration) and increase in temperature. Farmers reported delayed rains, excess rain, higher temperatures and longer sun hours as factors that negatively impacted yield. In conclusion, continued adaptation is needed based on quantitative trends and farmers' qualitative experiences in coping with climate risks.

Keywords: Cassava production, Climate adaptation strategies, Rising temperature effect, Climate change contraints, Land management practices, Rainfall variability.

CHAPTERS OF THE THESIS AND DISSERTATION

Chapter 1. Introduction

Chapter 2. Literature Review

Chapter 3. Methodology and Data Description

Chapter 4. Results and Discussion

Chapter 5. Summary, Conclusions, and Recommendations

Chapter 6. References

Chapter 7. Appendix

CHAPTER ONE

1.0 Introduction

1.1 Background

The United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (UNFCC, 2019). A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer is called climate change. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use *(IPCC, 2007).*

When fossil fuels burn, they release greenhouse gases - mostly carbon dioxide (CO_2). This traps extra energy in the atmosphere near the Earth's surface, causing the planet to heat up. Since the start of the Industrial Revolution - when humans started burning large amounts of fossil fuels - the amount of CO_2 in the atmosphere has risen by about 50%. The CO_2 released from burning fossil fuels has a distinctive chemical fingerprint, which matches the type increasingly found in the atmosphere. It has now been confirmed that 2023 was the warmest year on record, driven by human-caused climate change and boosted by the natural El Niño weather event. The last nine years were all among the nine warmest years on record (NOAA, 2022; BBC, 2024).

El Niño is a climate phenomenon characterized by the periodic warming of sea surface temperatures in the central and eastern Pacific Ocean. This warming of ocean waters can have far-reaching effects on weather patterns around the world. El Niño events typically occur every 2-7 years and can lead to significant disruptions in global weather, including changes in precipitation, temperature, and atmospheric circulation. These effects can impact various regions, causing droughts, floods, and other extreme weather events. El Niño is part of the broader El Niño-Southern Oscillation (ENSO) climate pattern, which also includes La Niña, the opposite phase characterized by cooler sea surface temperatures in the central and eastern Pacific.

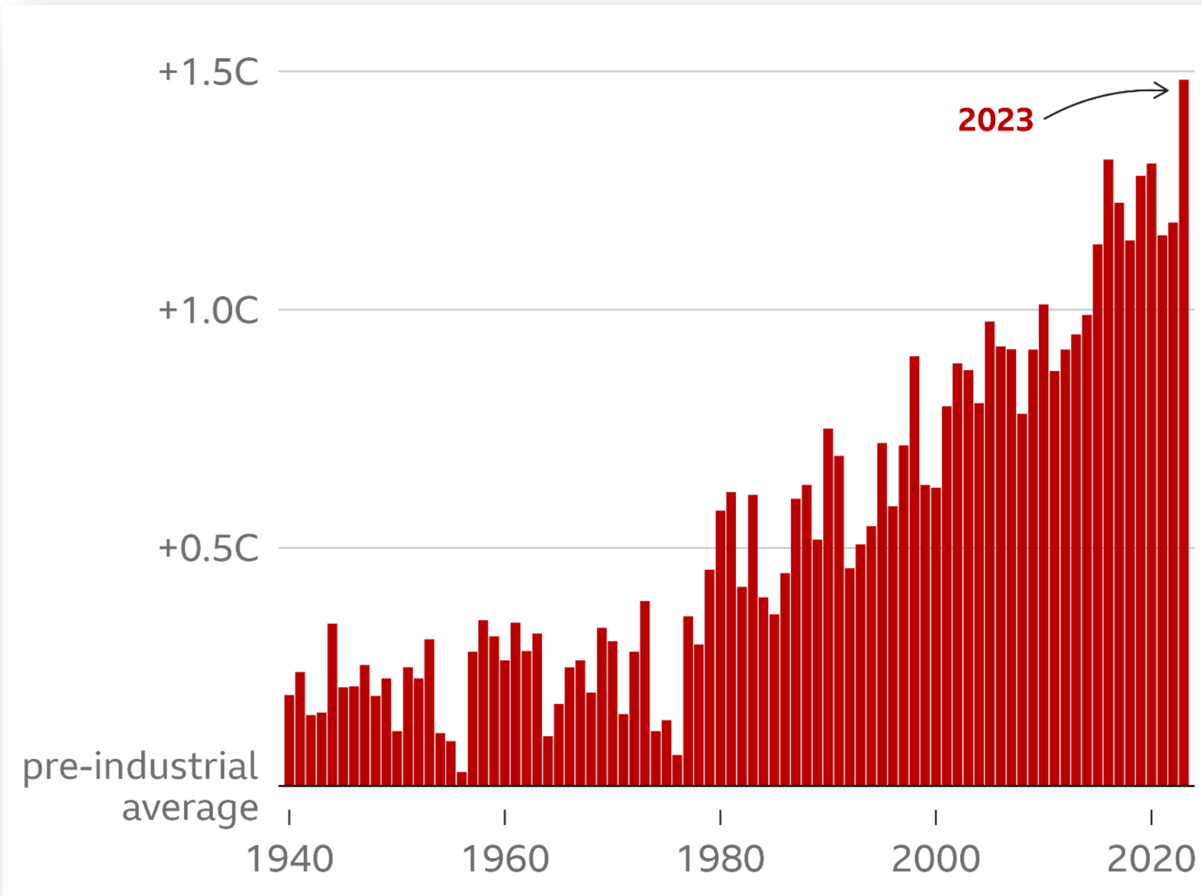

Figure 1: Trend of Heat showing the hottest year on record

This figure shows *Global average temperature by year, compared with pre-industrial average (1850-1900).*

Scientific evidence indicates that the earth's climate is rapidly changing, owing to increases in greenhouse gas emissions. The global climate is continuously changing and has severe impacts on human life (UNFCC, 2007). Climate change is a global challenge affecting human beings and their socioeconomic activities, health, livelihood, and food security (*FAO, 2016, Ghebrezgabher, Yang, & Yang, 2016)*. It consists of changes in the variation of temperature, rainfall, and wind patterns (IPCC, 2007). Developing countries and regions are more vulnerable to the impacts of climate change than developed ones (*Adger, et al., 2009)*. Impacts of climate change will be greater in the areas where the human livelihoods depend on the subsistence farming system (*Hailegiorgis, et. al., 2018).* Thus, rural farmers in sub-Saharan African (SSA) countries are likely to be more vulnerable to climate change than other regions, particularly because of compounding challenges of poverty, low infrastructural and technological developments, and the high dependence on rain-fed agriculture (*Thornton, Jones, Ericksen, & Challinor, 2011*). Climate change and variability significantly affect crop production, especially in drought-prone areas, where farmers depend only on rainfall. According to Menikea and Keeragala (2016), Climate change is one of the crucial factors that has threatened the agricultural sector for decades, and the sector is more sensitive to climatic conditions.

Cassava as a crop originated from South America and it is extensively propagated as an annual crop in the tropical and sub-tropical regions for its edible starchy tuber as root. It is an annual crop that may often be left longer than 12 months and usually planted as a sole crop or in combination with other crops. Production is all year round activity and it does well in a warm, moist climate. Cassava is very tolerant and has the ability to grow on marginal land where other food crops cannot grow well, but for its high yield and productivity moderate climatic condition and best soil properties like a light, sandy loamy soil of medium fertility and good aerations or drainage are all crucial (Akanbi, Olabode, 2004). Hence, extreme weather conditions such as prolonged drought and excessive amount of rainfall that leads into flood may be detrimental to cassava outputs and critically affect its productivity.

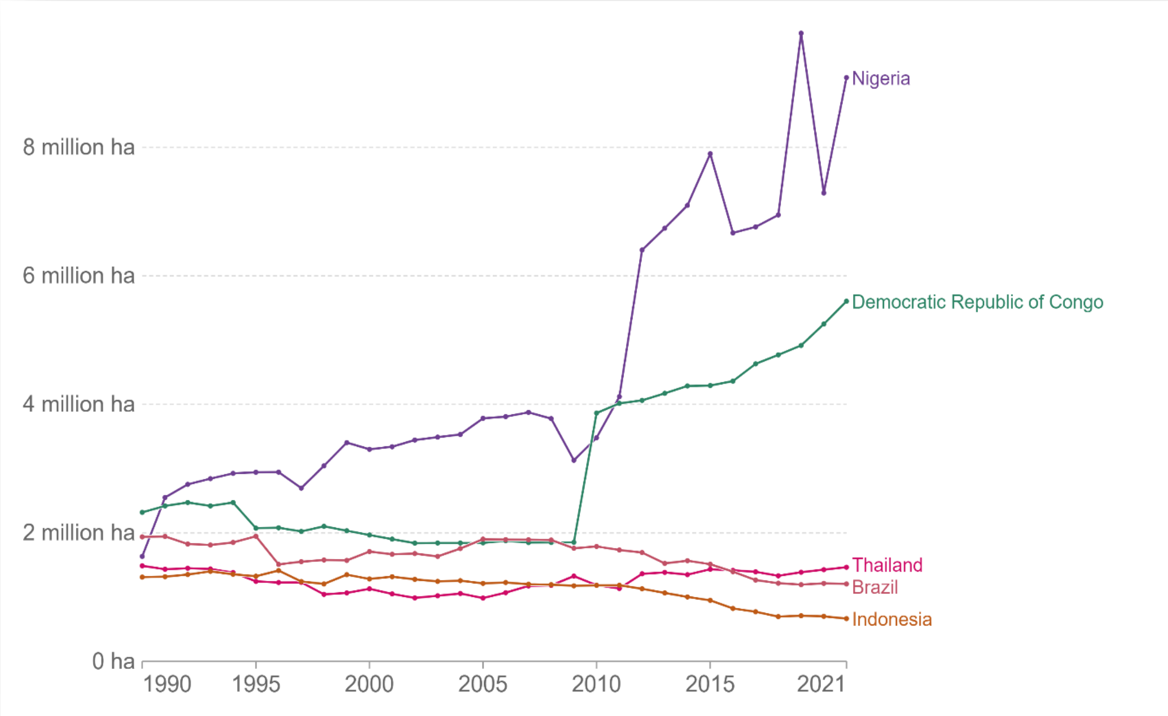

Figure 2: Land use for cassava production among the five-world largest cassava producers from1990 to 2021

Source: Our World in Data

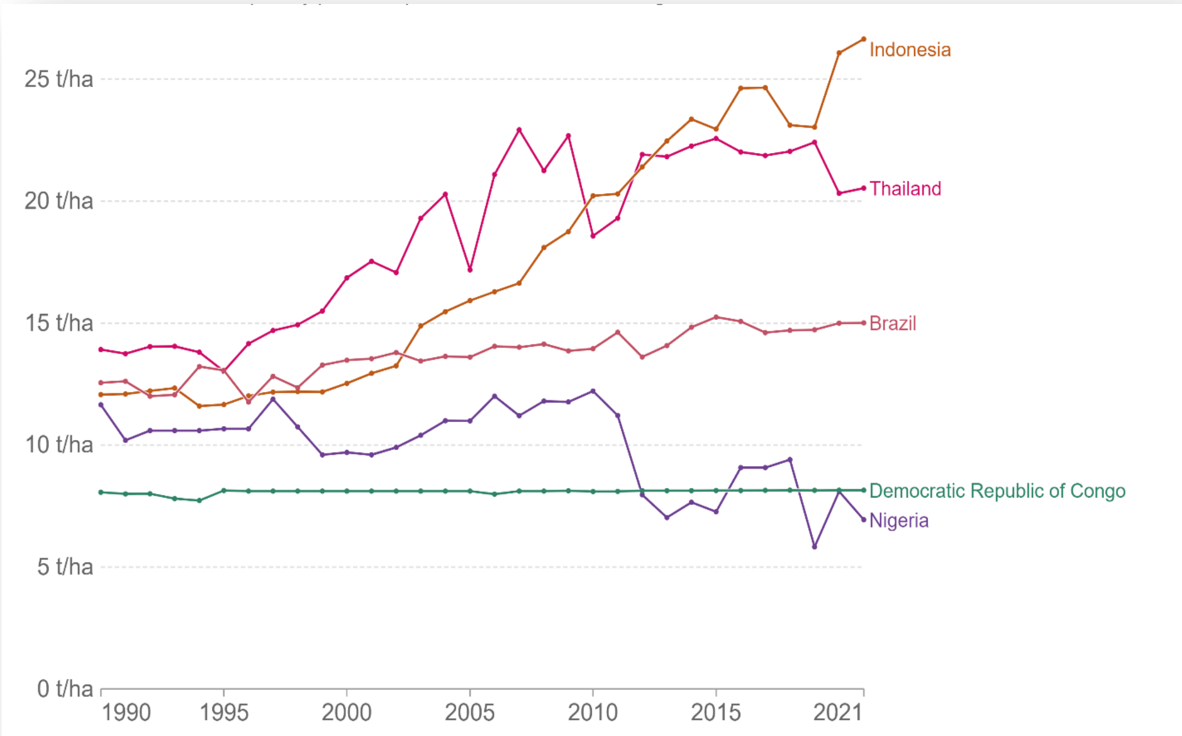

Figure 3: Cassava Yield, among the five highest producing countries from 1990 to 2021

Source: Our World in Data

Cassava production is essential for food security in sub-Saharan Africa and serves as a major calorie-intake source in Nigeria. Cassava production, being an important food crop among Nigerians, remains a possible and reliable alternative to: confront this impending hunger; and subtle means for sustaining the rural economy while the macro-economy heals back gradually. A cue can be taken from the way Thailand and Indonesia are promoting cassava production as a catalyst for their development (Ikuemonisan, 2020). Yet, the available indicators show that Nigeria has the potentials (available arable land and labour) to do it better if appropriate measures are put in place. Evidence across States in Nigeria shows that government investments and intervention to enhance cassava production have resulted to increased output and also stimulated the rural economy.

Local processing of cassava has created jobs for many rural women and the local fabricators and thus, has significantly stimulated the rural economy in sub-Saharan Africa. Similarly, it has also influenced the agricultural input supply market. Therefore, it contributes to capital formation and securing markets for the agro-industry in Nigeria. However, whether or not, the present cassava production (supply) can meet the increasing demand for cassava as food and industrial use remains a serious concern. An understanding of the relationship between climate change, land use, and cassava production trends is essential for the study presented in this thesis. Since land use and cassava production have been impacted by Nigeria's climate change patterns, it is important to fully understand how these factors interact. This study aims to analyze the relationship between climate change, land use, and cassava production in Nigeria to offer useful insights for addressing the challenges that arise from these trends.

1.2 Towards understanding the research problem: An overview of climate change, land use and cassava production

Projected increases in temperatures, changes in precipitation patterns, changes in extreme weather events, and reductions in water availability may all result in reduced agricultural productivity. Climate change can disrupt food availability, reduce access to food, and affect food quality. The changing climate may change the agricultural suitability of the land, and the main crop growing areas may be rearranged in the future. The impacts of climate change vary across Europe depending on climatic, geographic and socio-economic conditions. (Pipitpukdee et al., 2020) Aside from the issues of climate change, the quest for individually-owned land has given rise to the phenomenon of land speculation in which some group of individuals, who have no intention to put a piece of land into any productive use, acquire it by outright purchase and hold on to it for a long period of time sufficient to increase the commercial value of the land which is later disposed of at 10–100 times the initial purchase cost 5–20 years after.

The pace at which these speculators are encroaching agricultural lands in the peri-urban and rural communities is increasing thus denying farmers from cultivating the lands. Speculation has been made possible through lack of or inadequate land policy/reform that prevents speculators from engaging in this nefarious activity that has compounded land access problems/issues in SSA's urban and peri-urban areas. Land speculation is often made possible by the high rate of urbanization in African cities and their adjoining peri-urban areas. It is also fueled by the current defective/very defective public land policy in most of African countries (Adedoyin et al., n.d.)

Therefore, estimating the yield gap in Nigeria is essential to indicate the most important limiting factors for production and identify the yield gap hotspot areas. Secondly, these assessments may help set agendas in policy development and research prioritization where current information is scarce (Srivastava AK, 2023). In addition, understanding the yield gap can also aid in the formulation of targeted interventions and the allocation of resources to improve agricultural productivity. By pinpointing the specific areas and factors contributing to the yield gap, policymakers and researchers can develop strategies to address these challenges effectively. This can lead to more sustainable and efficient agricultural practices, ultimately benefiting both farmers and the overall economy. Climate change impacts food security, land use, and terrestrial ecosystems, and exacerbates land degradation situations and leads to shifts in weather patterns, resulting in more frequent and intense extreme weather events such as droughts, floods, and storms.

These events can have devastating effects on agriculture, leading to crop failures, livestock losses, and food shortages. Additionally, rising temperatures and changing precipitation patterns can alter the suitability of land for farming, further threatening food production and food security. The resulting land degradation can also lead to loss of biodiversity and ecosystem services, further compounding the impacts of climate change on terrestrial ecosystems (Smith et al., 2020; Sunderland & Rowland, 2019. The impact of climate change on land use, cassava production, and yield is a critical issue that requires attention. As climate patterns shift, the agricultural sector, including cassava production, faces significant challenges.

Changes in temperature, precipitation, and extreme weather events can directly affect crop growth and yield, leading to potential shifts in land use patterns and productivity. Understanding the specific ways in which climate change affects cassava production and yield is crucial for developing adaptive strategies and mitigating potential losses. Addressing this issue is essential for ensuring food security, sustainable agricultural practices, and economic stability in the face of a changing climate.

1.3 Climate change effect on land use, cassava production and yield: A problem statement

Climate change is a big problem for the world's environment, affecting climatic factors like weather, temperatures, and rainfall (Dawson & Spannagle, 2008). It is one of the most serious threats to Nigeria agricultural sector and food security because of its sensitivity and vulnerability to high ambient temperature and rainfall fluctuations. For instance, higher temperatures lower the yield of desirable crops while encouraging weeds and pests' proliferation and changes in precipitation patterns increase the likelihood of short-run crop failure and long run production declines, thus its variability creates a huge challenge for food production (Deutsche Bank Research, 2009). The reduction in agricultural productivity is often attributed to anticipated changes in extreme weather events, such as rising temperatures, alterations in precipitation patterns, shifts in relative humidity, windstorms, and more (Kemi and Olusegun, 2020). In Nigeria, it is causing issues for how the land is used, especially in farming. This is a big deal because it is changing how farmers grow important crops like cassava, which is crucial for food and money in the country.

To really understand what is happening, there is need to look closely at how the climate changes are affecting how land is used in Nigeria. The way land is used in Nigeria is closely tied to farming, especially with important crops like cassava. Projections indicate that the impacts of climate change on land will escalate in all regions, with some areas encountering risks that were previously unforeseen (Huong & Pathirana, 2013; Patz et al., 2005). In numerous cases, the climate's response to land use and land-cover change may surpass the contribution from increasing deforestation and land degradation. Cassava plays a vital role as a staple food for over 213.4 million people worldwide (World Bank, 2021), serving as a primary dietary component in numerous countries, particularly in Sub-Saharan Africa, where it stands as the leading source of carbohydrates among staple crops (Montagnac et al., 2009). Additionally, cassava is a key crop for bioethanol production in various countries (Marx, 2019), and it thrives primarily in hot lowland tropical regions, including depleted soils (Falade & Akingbala, 2011).

In recent years, cassava production in Nigeria has seen remarkable growth, making the country a global leader in cassava production. However, there is limited research on how climate change affects both land use and cassava yield in Nigeria. In 2018, the global cassava production reached an estimated 277 million tonnes and was expected to reach 291 million tonnes by the end of 2020, with Africa contributing approximately 62% of the total production. Nigeria, being the world's leading cassava producer, contributed around 21% of the global output in 2018. Despite a decline in global production levels since 2016, the total world production of 277.6 million tonnes in 2018 significantly exceeded the 10-year average from 2009 to 2018, which stood at 270.9 million tonnes (PWC, 2018). Climate change is making the weather and rainfall different, which directly impacts where it's good to grow cassava. Studying these changes in how land is used is important to figuring out what it means for cassava production.

Cassava is one the widely cultivated staple crops in Nigeria, and the changing temperatures and irregular rainfall can hurt how cassava grows and how much is produced. This can be a big problem for farmers and the country's food supply. The reduction in cassava productivity is often attributed to anticipated changes in extreme weather events, such as rising temperatures, alterations in precipitation patterns, shifts in relative humidity, windstorms, and more (Kemi and Olusegun, 2020), yet the demand for cassava and its derivatives remains high in the domestic economy. However, the actual yields, which should ideally bolster the supply, have struggled to meet the substantial demand. For instance, the supply-demand gap for High-Quality Cassava Flour amounts to approximately 485,000 metric tonnes (MT) annually, while the gap for cassava starch is about 290,000 MT (PWC, 2018).

Despite cassava's resilience to climate change due to its ability to withstand intra-seasonal droughts and high temperatures, prolonged periods of drought can reduce root yields by up to 60% (Jarvis et al., 2012). Therefore, there is need to look at the direct connection between climate change and cassava production, finding ways to make sure cassava can survive and thrive. To look at how climate change, land use, and cassava production are all connected can get pretty complicated. To address these problems, there is need for smart objectives that can guide the study.

1. 4 Research Objectives

This study aims to investigate the impact of climate change on land use, cassava production, and yield in Nigeria. The main objective is to determine the climate change adaptation and coping strategies adopted by farmers in Nigeria. To achieve this, the main objective is divided into two sub-objectives for ease of structure and research practicality.

- To assess the effects of climate change on cassava land use, production, and yield from 1980 to 2021.
- To assess the current adaptation and coping strategies adopted by farmers in Nigeria in response to climate change impacts.

1. 5 Research Questions

The research objectives were formulated to address specific questions necessary to achieve them. Consequently, the main research question was: *What climate change* adaptation and coping strategies adopted by farmers in Nigeria*?*

This main research question has been divided into sub-research questions. These are:

- What climate change challenges does Nigeria face and how do these challenges relate to land use, cassava production and yield trends in the country?
- What are the current adaptation and coping strategies adopted by farmers in Nigeria in response to climate change impacts?

1.6 Working Hypothesis

This study used a working hypothesis. The use of a hypothesis in research is influenced by its quantitative nature, which depends on estimating the relationships between a dependent variable (outcomes) and independent (predictor) variables. In this case, the variables under investigation are cassava yield and climate change. As a result, a working hypothesis was developed for the study and is given below:

Null Hypothesis (H_0): *There is no statistically significant relationship between climate change and cassava yield in Nigeria over a period of 1980-2021, and land use changes have no significant influence on cassava production practices or yields over this periods.*

1.7 Scope and Delimitations

This study focuses specifically on the effects of climate change on land use and cassava production in Nigeria. This study aims to investigate the impact of climate change on land use, cassava production and yields in Nigeria. It will analyze historical climate data and cassava yield trends to identify key climate variables influencing cassava agriculture. Crop modeling will then be used to project future cassava yields under different climate change scenarios. The study will focus on the top five cassava producing states in Nigeria, which account for over 50% of national cassava production. Insights on climate risks and adaptation options for cassava farmers will also be provided. The scope takes note of an in-depth analysis of climate-related changes in temperature, precipitation, and other relevant factors affecting land use patterns and cassava yields. However, it is important to note that the study did not cover all possible factors influencing cassava production, and there could be limitations in accessing certain data or conducting on-the-ground assessments due to logistical constraints.

1.8 Justification and significance of the Study

This study is very important because it clarifies the relationship between crop productivity and climate change in sub-Saharan Africa, especially in Nigeria. Since Nigeria is heavily dependent on cassava as a staple food, understanding the impact of climate change becomes critical.

Along with providing practical insights that can be used to adapt agricultural practices to effectively address the challenges posed by climate change, the study also addresses the theoretical side by adding to the growing body of knowledge on the relationship between managing land use and climate change. Stakeholders can use these insights to formulate strategies that enhance overall resilience while mitigating negative impacts on land use and cassava production. Also, this study becomes part of a larger conversation on sustainable agriculture, food security, and climate change adaptation. Its implications are not limited to Nigeria; they also affect other regions facing comparable challenges. Nigeria was selected for a country case study as part of the International Fund for Agricultural Development's global strategy for cassava development because of its vast experience and leadership in the crop's development, multiplication, and processing into a variety of forms for food, feed, and raw materials. Maintaining these gains will be important, highlighting the necessity of diversifying cassava usage for industrial purposes. There are several reasons why it is important to comprehend how climate change is affecting land use and cassava production in Nigeria.

Although it is a global problem, the local impacts of climate change can have a big impact on farming, particularly in places like Nigeria, where cassava is a staple crop. Researching these effects can help farmers, policymakers, and communities understand the problems they face and provide ideas for solutions. Because cassava is a staple crop in Nigeria, it is crucial to understand how to produce it under changing climate conditions to ensure food security and promote sustainable crop practices.

1.9 Thesis Structure

The first chapter will give a quick overview of how climate change affects land use, specifically focusing on cassava production in Nigeria. It talks about the relationship between climate, farming, and the potential impact on food supply. The next chapter will review literature to show what has been done, how climate change affects land, and cassava production. It will also discuss why the land is used the way it is, especially how it affects cassava farming. Because everything is connected, some early findings in this chapter will be shown, setting up a more detailed discussion ahead of the next chapter. After that, the third chapter will talk more about where this study takes place, like the location explain how the study was done, like the methods used to collect and analyse information. The fourth chapter presents the results. It should be noted that in some cases a sharp separation between method and result is not possible due to a high degree of interconnectedness. Thus, some intermediate results serve as the basis for following methodological steps and are therefore presented in chapter three. The fifth chapter discusses the results, applied methods, and thesis limitations. Moreover, it aims to relate the results to the current scientific discourse and provide an outlook by giving impulses for points of improvement.

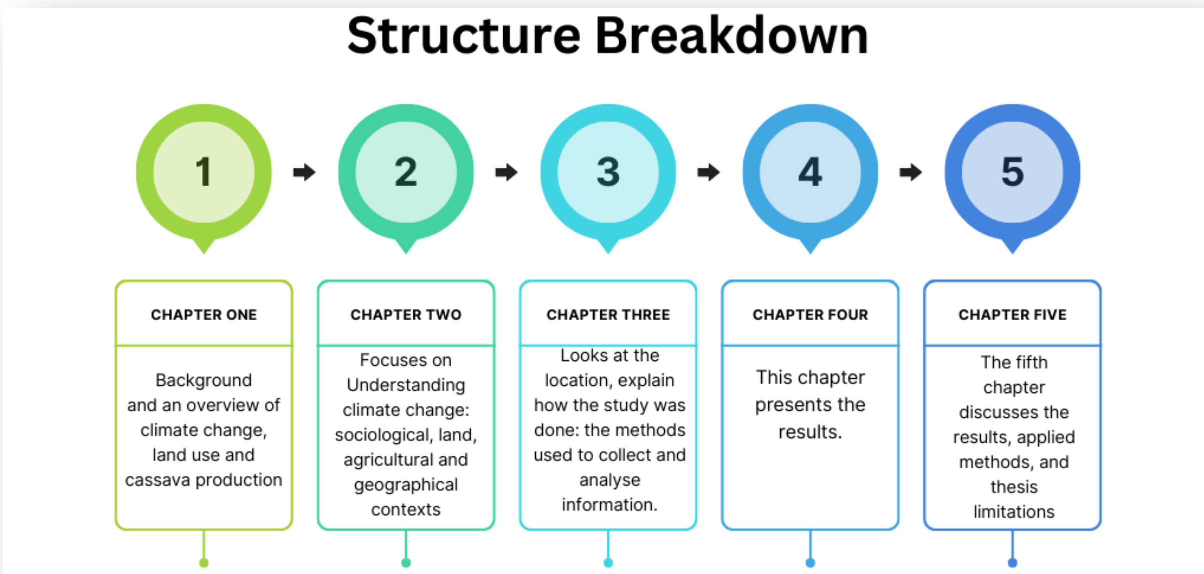

Figure 4. Structure breakdown of the thesis

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Understanding climate change: sociological, land, agricultural and geographical contexts

According to the United Nations report on what climate change is, Climate change refers to long-term shifts in temperatures and weather patterns. Such shifts can be natural, due to changes in the sun's activity or large volcanic eruptions. Nevertheless, since the 1800s, human activities have been the main driver of climate change, primarily due to the burning of fossil fuels like coal, oil and gas. Burning fossil fuels generates greenhouse gas emissions that act as if a blanket wrapped around the Earth, trapping the sun's heat and raising temperatures (United Nations Educational Scientific and Cultural Organization., 2023).

The main greenhouse gases that are causing climate change include carbon dioxide and methane. These come from using gasoline for driving a car or coal for heating a building, for example. Clearing land and cutting down forests can also release carbon dioxide. Agriculture, oil and gas operations are major sources of methane emissions. Energy, industry, transport, buildings, agriculture and land use are among the main sectors causing greenhouse gases. (UN, 2018). The Earth's climate is changing and the global climate is projected to continue to change over this century and beyond.

The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse (heat-trapping) gases emitted globally and on the remaining uncertainty in the sensitivity of the Earth's climate to those emissions. With significant reductions in the emissions of greenhouse gases (GHGs), global annual averaged temperature rise could be limited to 2°C or less. However, without major reductions in these emissions, the increase in annual average global temperatures, relative to preindustrial times, could reach 5°C or more by the end of this century. The global climate continues to change rapidly compared to the pace of the natural variations in climate that have occurred throughout Earth's history. Trends in globally averaged temperature, sea level rise, upper-ocean heat content, land-based ice melt, arctic sea ice, depth of seasonal permafrost thaw, and other climate variables provide consistent evidence of a warming planet. These observed trends are robust and confirmed by multiple, independent research groups around the world (Mohammadi et al., 2023a).

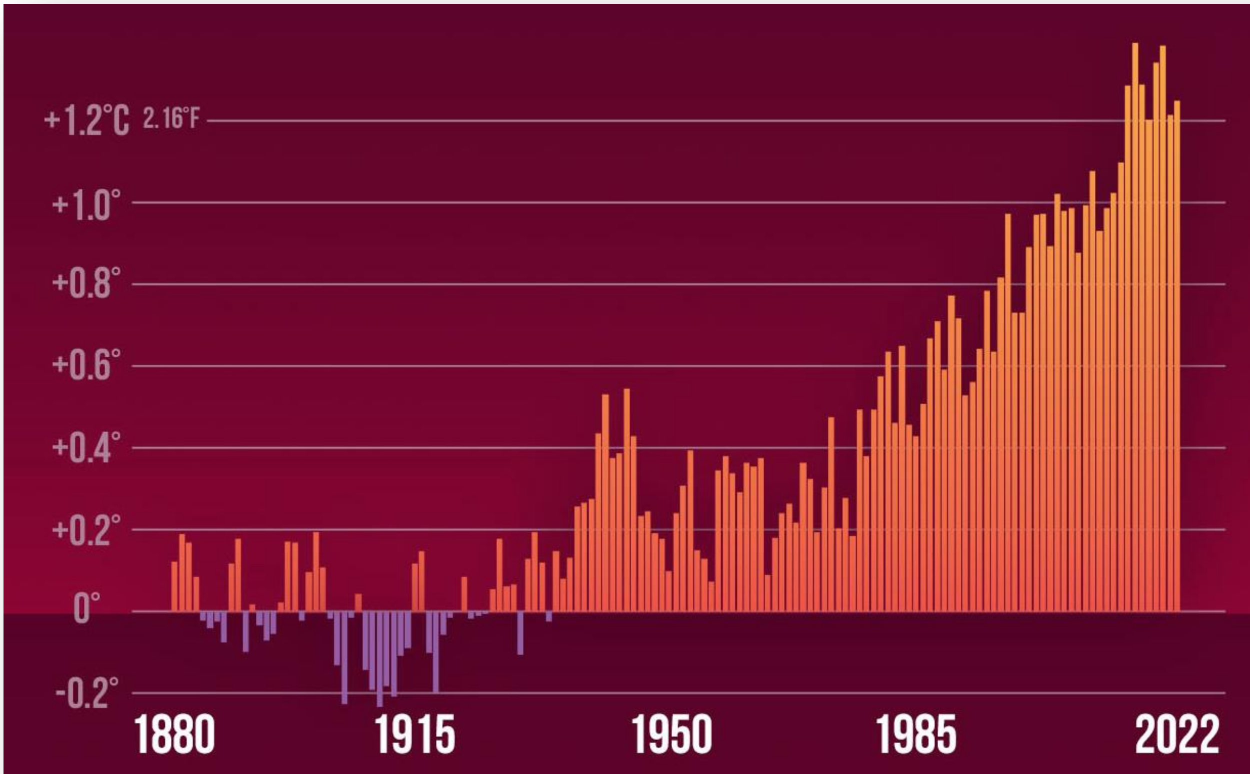

Figure 5. *Global Average Temperature Anomalies, departure from 1881-1910.*

The plot shows how much global annual average temperatures for the years 1880-2022 have been above or below the 1881-1910 average. Temperatures for years warmer than the early industrial baseline are shown in red; temperatures for years cooler than the baseline are shown in purple. *Graphic: Climate Central; Data: NASA GISS and NOAA NCEI. Global temperature anomalies averaged and adjusted to early industrial baseline (1881-1910). Data as of 1/12/202.*

From the figure five above, one can see the alarming trend of rising global temperatures highlights the urgent need for addressing climate change from a sociological perspective, as it has profound implications for the development and well-being of societies around the world.

2.2 The Sociological lens of climate change: why climate change matters for the development of societies

In 2018, the US National Climate Assessment concluded that the “earth’s climate is now changing faster than at any point in the history of modern civilization, primarily as a result of human activities” (Jay et al. 2018, p. 34). Koch et al. (2019) suggest that the so-called Little Ice Age (LIA) of the sixteenth to nineteenth centuries may have been driven in part by the Great Killing of the sixteenth century, when Europeans, through direct violence and disease, caused the deaths of much of the indigenous human population in the Americas. The resulting reduction in human activity led to vegetation changes that removed substantial carbon dioxide (CO2) from the atmosphere and thus contributed to a cooling and highly variable climate. In turn, the LIA had a strong influence on social change around the globe (Parker, 2013). By the end of the nineteenth century, it was clear that shifts in atmospheric concentrations of greenhouse gases (GHGs) could change planetary climates (Weart 2008). Since the industrial revolution, especially starting in the mid-twentieth century, human actions have increased the atmospheric concentration of GHGs: CO2, methane, nitrous oxides, and chlorofluorocarbons, while also decreasing the albedo, or reflectivity, of Earth’s surface (US Glob. Change Res. Program, 2017).

A central finding of sociology is that unequal power dynamics shape patterns of social mobility and access to social, political, and economic resources. An understanding of inequality is one of the most powerful tools that sociologists can bring to the study of global climate change. It is widely documented that the effects of global climate change will not be equally distributed around the world, and many of the countries least responsible for the rise in greenhouse gases will be most likely to feel its impacts in changes in weather, sea levels, human health costs, and economic hardships. These inequalities will be further exacerbated by the unequal burdens inflicted by climate-related disasters and limited disaster response capacities. One important predicted outcome of climate change is human migration out of poorer regions and countries into more developed, less impacted areas; this environmental migration has the potential to strain the resources and social fabrics of receiving societies and deplete the human capital in sending communities. (Ingram & Hong, 2011; Poudel & Shaw, 2016).

Extreme heat events have led to particularly high rates of mortality and morbidity in cities, as urban populations are pushed beyond their adaptive capacities, leading to an increase in mortality rates of 30–130% in major cities in developed countries (Norton et al. 2015). Increased mortality and morbidity from extreme heat events are exacerbated in urban populations by the urban heat island effect (Gabriel and Endlicher, 2011; Schatz and Kucharik, 2015), which can be limited by developing green infrastructure in cities. Urban green infrastructure includes public and private green spaces – such as remnant native vegetation, parks, private gardens, golf courses, street trees, urban farming – and more engineered options, such as green roofs, green walls, biofilters and raingardens (Norton et al., 2015). Increasing the amount of vegetation, or green infrastructure, in a cityis one way to help reduce urban air temperature maxima and variation. Increasing vegetation by 10% in Melbourne, Australia was estimated to reduce daytime urban surface temperatures by approximately 1°C during extreme heat events (Coutts and Harris, 2013). Urban farming (a type of urban green infrastructure) is largely driven by the desire to reconnect food production and consumption (Whittinghill and Rowe, 2012). Even though urban farming can only meet a very small share of the overall urban food demand, it provides fresh and local food, especially perishable fruits and crops that are usually shipped from far and sold at high prices (Thomaier et al., 2015).

Food-producing urban gardens and farms are often started by grassroots initiatives (Ercilla-Montserrat et al., 2019) that occupy vacant urban spaces. In recent years, a growing number of urban farming projects (termed Zero-Acreage farming, or Z-farming, were established in and on existing buildings, using rooftop spaces or abandoned buildings through contracts between food businesses and building owners. Almost all Z-farms are in cities with more than 150,000 inhabitants, with a majority in North American cities such as New York City, Chicago and Toronto (Thomaier et al., 2015). They depend on the availability of vacant buildings and roof tops, thereby competing with other uses, such as roof-based solar systems. Urban farming, however, has potentially high levels of soil pollution and air pollutants, which may lead to crop contamination and health risks. These adverse effects could be reduced on rooftops (Harada et al., 2019) or in controlled environments.

Variations in individual, community, and national vulnerability to the impacts of climate change are only part of the structure of inequality in global climate change. As the 2007 IPCC report notes, there is an unequal distribution of impacts and vulnerabilities to climate change associated with social class and age in both developed and developing countries. Furthermore, there is inequality between women and men, adults and children, and present and future generations. The quest for prosperity drives the rapid economic growth of large countries like China and India without whose cooperation, global mitigation efforts will fail (Matewos, 2019).

The unequal impacts of climate change are coupled with inequalities of representation in global and national policy-making arenas leaving global climate change policy efforts open to charges of bias. Sociology's attention to people, communities, and the socio-economic ordering of resource distribution, especially in contrast to research in the natural sciences or economics, makes sociological research on climate change critical to protecting vulnerable populations, e.g., the poor, elderly, children, women, and communities of color. Environmental justice researchers have shown that efforts to rebuild communities and distribute resources in the wake of environmental disasters require that researchers pay attention to the power differentials shaping people's access to fair and just protection from these disasters.

Environmental justice scholarship builds on existing research by documenting how social inequalities are structured and exacerbated by environmental disasters and economic development in both industrial and industrializing countries. Sociological research on the intersections of race, gender, and class offers a lens for analyzing environmental justice dimensions of global climate change. Weather-related disasters like Hurricane Katrina can serve as a laboratory for future sociological research on equitable and inequitable rebuilding and aid practices, and can ensure that research on vulnerable populations is included in decision-making processes and policy-setting agendas (United Nations Development Programme., n.d.).

To fully analyze the complex relationship between climate changes and land use, it is imperative to have a thorough understanding of the sociological aspects of climate change and how it affects vulnerable populations.

2.3 The land perspective: the climate change and land use relationship

Over the last decades, land use cover change (LUCC) has affected more than half of the Earth's land surface, mainly reflecting the growth of the agriculture sector (Ward et al., 2014). The acceleration of LUCC and land degradation in the latter three to four decades of the twentieth century is due to the rising population and a significant need for agricultural growth to feed the growing population (Wondie et al., 2016). Some investigations indicate that changes from natural to agricultural land use contributed to changes in the quality of soil and land productivity (Wu et al., 2007; Fernández-Romero et al., 2014). Organic carbon in the soil can be significantly degraded due to long-term and intensive agricultural practices (Benbi and Brar, 2009).

Growing atmospheric concentrations of CO_2 and other greenhouse gasses (GHGs), along with consequent impacts on farming systems, will increase air temperature, and also will change the global precipitation patterns in different regions, including the Northern Hemisphere (Hatfield et al., 2011). Arable Lands Cover (ALC), like Range Lands Cover (RLC) and Forest Lands Cover (FLC), appears to be related to climate change and vice versa. The fundamental cause of changes in large-scale rangelands' vegetation patterns, water demands for growing forage and meeting animal needs, forage production efficiency, and heat stress on cattle is climate change (Wang et al., 2017b; Chaplin-Kramer and George, 2013). LUCC consists of many regional, interregional, and national scales. Therefore, to better mitigate future environmental risks and global changes, it is necessary to anticipate the impacts of LUCC on climate change and vice versa. Ghebrezgabher et al. (2016) assessed and quantified climate change and drought in the Horn of Africa over a long-term period.

Linear regression and interpolation were simply adopted to analyze the pattern and spatial distribution of average annual precipitation and temperature. Their results showed that statistically, the precipitation trend decreased insignificantly. The temperature trend was observed to fall between 1930 and 1969, while this trend significantly increased from 1970 to 2014. Up to this time, many studies have been carried out on the trend and anticipation of climate change (Wang et al., 2017c) and LUCC (Li et al., 2017) and the impacts of some types of land covers and land uses such as forestlands (Pütz et al., 2011), rangelands (Polley et al., 2013; Zandi et al., 2017), and arable lands (Yawson et al., 2017) on climate change and vice versa (Rodríguez-Echeverry et al., 2018).

The fifth evaluation report (AR5) calculates anthropogenic emissions of GHGs and extractions from agriculture, forestry, and other land uses (Tubiello et al., 2015). Although there are many studies (Pütz et al., 2011; Yawson et al., 2017; Zandi et al., 2017) that tried to investigate the relationship between climate change and LUCC, it seems that there is not a comprehensive and time-oriented study in this field yet that includes all countries. This study tries to apply a different perspective in terms of time and place to this issue that has not been done before by other researchers. According to Roser and Ritchie (2018), 90 % of the earth's surface is covered by rangelands cover (RLC), forestlands cover (FLC), and crops or arable lands cover (ALC), but only 71 % of the earth's surface is habitable.

Humans have to change the land cover for centuries, but recent change rates are higher than ever (Verburg, 2006; Chen et al., 2018; Mahmood et al., 2010; Munsi et al., 2010). Land-use change reflected in land cover change, the main component of Climate change, affects land-use decisions (Lambin & Meyfroidt, 2011; Thapa, 2020). It is pre-dominated by deforestation for cultivated land and then other land-use types like built-up industrial areas. Land use and land-cover change (LULCC) impact weather and climate at the synoptic scales and the mesoscale (Wang et al., 2019). LULCC study provides essential data support for the research of human activities on environmental change (Cao et al., 2020; Smith et al., 2020; Sunderland & Rowland, 2019; Dawson & Spannagle, 2008).

Last three centuries, many developing countries are moving through transition economics, increasing demand for food and energy due to a growing population that has caused deforestation, cropland increased, and urbanization (ielke Sr et al., 2011). Several studies in China found that cropland area increased and forest decreased, a similar trend of cropland sharp raised and forest area declined in India, Nepal, and other South Asia (IPCC, 2014; Huong & Pathirana, 2013). Every country from Asia, Africa, and Europe has faced landuse change due to economic and population growth. Since the past few decades, land-use change influences climate. The significant contribution is the precipitation cycle at a local and regional level (Lambin & Meyfroidt, 2011). Climate change brings unpredictability of rainfall and extreme weather events, which will increase risk in the long term. Given the historical trend of increasing demand for food and energy, coupled with population growth and economic transitions in many developing countries, it is essential to examine the effects of climate change on land use.

2.4 Climate change effects on land use

Climate change adversely influenced food security, terrestrial ecosystems, land degradation, and land use (Pielke Sr et al., 2011; IPCC, 2014). Similarly, it is a significant driver for land degradation processes, which results in a land-use change. In many lower-latitude regions, yields of some crops (e.g., maize and cassava) have declined. In contrast, in many higher-latitude areas, yields of some plants (e.g., maize, corn, and sugar beets) have increased over recent decades

(Patz et al., 2005). Deforestation means land surface air temperature has increased from the growth of industries than the global land and ocean temperature (Huong & Pathirana, 2013).

Land surface characteristics such as albedo and emissivity determine the amount of solar and long-wave radiation absorbed by land and reflected or emitted to the atmosphere. Surface roughness influences turbulent exchanges of momentum, energy, water and biogeochemical tracers. Land ecosystems modulate the atmospheric composition through emissions and removals of many GHGs and precursors of SLCFs- SLCFs stands for Short-Lived Climate Forcers. These are pollutants and particles that have a relatively short atmospheric lifetime compared to other greenhouse gases. They include substances such as black carbon, methane, tropospheric ozone, and hydro-fluorocarbons. SLCFs have a significant impact on climate change and are important targets for mitigation efforts due to their potent warming influence in the atmosphere, including biogenic volatile organic compounds (BVOCs) and mineral dust. Atmospheric aerosols formed from these precursors affect regional climate by altering the amounts of precipitation and radiation reaching land surfaces through their role in clouds physics.

Biophysical interactions are exchanges of water and energy between the land and the atmosphere. Land warms up from absorbing solar and long-wave radiation; it cools down through transfers of sensible heat (via conduction and convection) and latent heat (energy associated with water evapotranspiration) to the atmosphere and through long-wave radiation emission from the land surface. These interactions between the land and the atmosphere depend on land surface characteristics, including reflectivity of shortwave radiation (albedo), emissivity of long wave radiation by vegetation and soils, surface roughness and soil water access by vegetation, which depends on both soil characteristics and amounts of roots. Over seasonal, inter-annual and decadal timescales, these characteristics vary among different land cover and land-use types and are affected by both natural processes and land management (Anderson et al. 2011). A dense vegetation with high leaf area index, like forests, may absorb more energy than nearby herbaceous vegetation partly due to differences in surface albedo (especially when snow is on the ground).

However, denser vegetation also sends more energy back to the atmosphere in the form of evapotranspiration (Bonan, 2008; Burakowski et al., 2018; Ellison et al., 2017). Climate change will exacerbate poverty among some categories of dryland populations. Depending on the context, this impact comes through declines in agricultural productivity, changes in agricultural prices and extreme weather events (Hertel and Lobell 2014; Hallegatte and Rozenberg 2017). There is high prediction that poverty limits both capacities to adapt to climate change and availability of financial resources to invest into SLM (Gerber et al., 2014; Way, 2016; Vu et al., 2014), SLM stands for Sustainable Land Management. It refers to the responsible use of land resources to ensure long-term productivity while conserving the environment. This can involve practices such as soil conservation, water management, and the promotion of sustainable agricultural techniques. In this context, it suggests that poverty can hinder the ability of individuals or communities to invest in sustainable land management practices, which are crucial for adapting to climate change and ensuring long-term environmental and agricultural sustainability.

The IPCC Special Report on Global Warming of 1.5°C noted that limiting global warming to 1.5°C instead of 2°C is strongly beneficial for land ecosystems and their services, such as soil conservation, contributing to avoidance of desertification (Hoegh-Guldberg et al., 2018). Desertification is defined as land degradation in arid, semi-arid, and dry sub-humid areas resulting from many factors, including climatic variations and human activities (United Nations Convention to Combat Desertification (UNCCD), 1994). Land degradation is a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans. Arid, semi-arid, and dry sub-humid areas, together with hyper-arid areas, constitute drylands (UNEP, 1992), home to about 3 billion people (van der Esch et al., 2017). The difference between desertification and land degradation is not process-based but geographic. Although land degradation can occur anywhere across the world, when it occurs in drylands, it is considered desertification.

Desertification is not limited to irreversible forms of land degradation, nor is it equated to desert expansion, but represents a complex and gradual process of soil erosion, loss of vegetation, and decline in biodiversity. The literature on the human drivers of desertification is substantial (D'Odorico et al., 2013; Sietz et al., 2011; Yan and Cai, 2015; Sterk et al. 2016; Varghese and Singh, 2016) and there have been several comprehensive reviews and assessments of these drivers very recently (Cherlet et al. 2018; IPBES 2018a; UNCCD 2017). IPBES (2018a) identified cropland expansion, unsustainable land management practices including overgrazing by livestock, urban expansion, infrastructure development, and extractive industries as the main drivers of land degradation. IPBES (2018a) also found that the ultimate driver of land degradation is high and growing consumption of land-based resources, e.g., through deforestation and cropland expansion, escalated by population growth. What is particularly relevant is to evaluate if, how and which human drivers of desertification will be modified by climate change effects.

Incorporating land restoration into climate change adaptation and mitigation strategies is therefore essential for ensuring the long-term health and productivity of the land. This can be achieved through a combination of reforestation, regenerative agriculture practices, and sustainable land management techniques. It is important to ensure that people who rely on land for their livelihoods benefit from the potential and opportunities provided by a range of land management and restoration activities. According to Chigbu (2023), land tenure is a key component of a comprehensive approach to land restoration.

When well-established and made inclusive, it becomes a vital part of progressing towards sustainable futures for all, ensuring that no one is left behind. Land tenure security is essential for empowering local communities and smallholder farmers to invest in sustainable land management and restoration practices. By providing secure rights to land, these individuals are more likely to adopt long-term strategies that promote soil health, water conservation, and biodiversity conservation. This not only benefits the environment but also enhances the resilience of these communities to climate change and other external pressures. Therefore, it is crucial to prioritize land tenure as a foundational element of any successful land restoration initiative which can help to improve food security.

2.5 Food security and insecurity, the food system and climate change

The goal to end hunger and food insecurity by the year 2030 is currently threatened by the changing precipitation pattern and the more intense weather. Climate change is affecting the dynamics of crop production globally. Water is the most critical climatic factor influencing crop productivity as virtually all life processes is dependent on water (Ukwu et al., 2024). The food system encompasses all the activities and actors in the production, transport, manufacturing, retailing, consumption, and waste of food, and their impacts on nutrition, health and well-being, and the environment (United Nations Educational Scientific and Cultural Organization., 2023)

The activities and the actors in the food system lead to outcomes such as food security and generate impacts on the environment. As part of the environmental impacts, food systems are a considerable contributor to GHG emissions, and thus climate change. In turn, climate change has complex interactions with food systems, leading to food insecurity through impacts on food availability, access, utilization and stability. Food systems lens in the Special Report on Climate Change and Land (SRCCL) is taken to recognize that demand for and supply of food are interlinked and need to be jointly assessed in order to identify the challenges of mitigation and adaptation to climate change. Outcomes cannot be disaggregated solely to, for example, agricultural production, because the demand for food shapes what is grown, where it is grown, and how much is grown. Thus, GHG emissions from agriculture result, in large part, from 'pull' from the demand side. Mitigation and adaptation involve modifying production, supply chain, and demand practices (through, for example, dietary choices, market incentives, and trade relationships), so as to evolve to a more sustainable and healthy food system.(Mohammadi et al., 2023b). According to FAO (2001a), food security is a situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. 'All people at all times' imply the need for equitable and stable food distribution, but it is increasingly recognized that it also covers the need for inter-generational equity, and therefore sustainability in food production. 'Safe and nutritious food … for a healthy life' implies that food insecurity can occur if the diet is not nutritious, including when there is consumption of an excess of calories, or if food is not safe, meaning free from harmful substances (FAO et al., 2018),

2.6 The Food security dimension of climate change: The cassava crop in focus

Climate change is projected to negatively influence the four pillars of food security – availability, access, utilizations and stability – and the Interactions (FAO et al. 2018). This chapter assesses recent work since AR5 that has strengthened understanding of how climate change affects each of these pillars across the full range of food system activities. While most studies continue to focus on availability via impacts on food production, more studies are addressing related issues of access (e.g., impacts on food prices), utilizations (e.g., impacts on nutritional quality), and stability (e.g., effects of increasing extreme events) as they are affected by a changing climate (Bailey et al. 2015).

Low-income producers and consumers are likely to be most affected because of a lack of resources to invest in adaptation and diversification measures (UNCCD 2017; Bailey et al. 2015). Food is predominantly produced on land, with, on average, 83% of the 697 kg of food consumed per person per year, 93% of the 2884 kcal per day, and 80% of the 81 g of protein eaten per day coming from terrestrial production in 2013 (FAOSTAT, 2018).1 With increases in crop yields and production, the absolute supply of food has been increasing over the last five decades. Growth in production of animal-sourced food is driving crop utilization for livestock feed (FAOSTAT 2018; Pradhan et al. 2013a). Global trade of crop and animal-sourced food has increased by around 5 times between 1961 and 2013 (FAOSTAT, 2018). During this period, global food availability has increased from 2200 kcal/cap/day to 2884 kcal/cap/day, making a transition from a food deficit to a food surplus situation (FAOSTAT, 2018; Hic et al. 2016).

The availability of cereals, animal products, oil crops, and fruits and vegetables has mainly grown (FAOSTAT 2018), reflecting shifts towards more affluent diets. This, in general, has resulted in a decrease in prevalence of underweight and an increase in prevalence of overweight and obesity among adults (Abarca-Gomez et al., 2017). During the period 1961–2016, anthropogenic GHG emissions associated with agricultural production has grown from 3.1 GtCO2-eq yr–1 to 5.8 GtCO2-eq yr–1. The increase in emissions is mainly from the livestock sector (from enteric fermentation and manure left on pasture), use of synthetic fertilizer, and rice cultivation (FAOSTAT 2018).

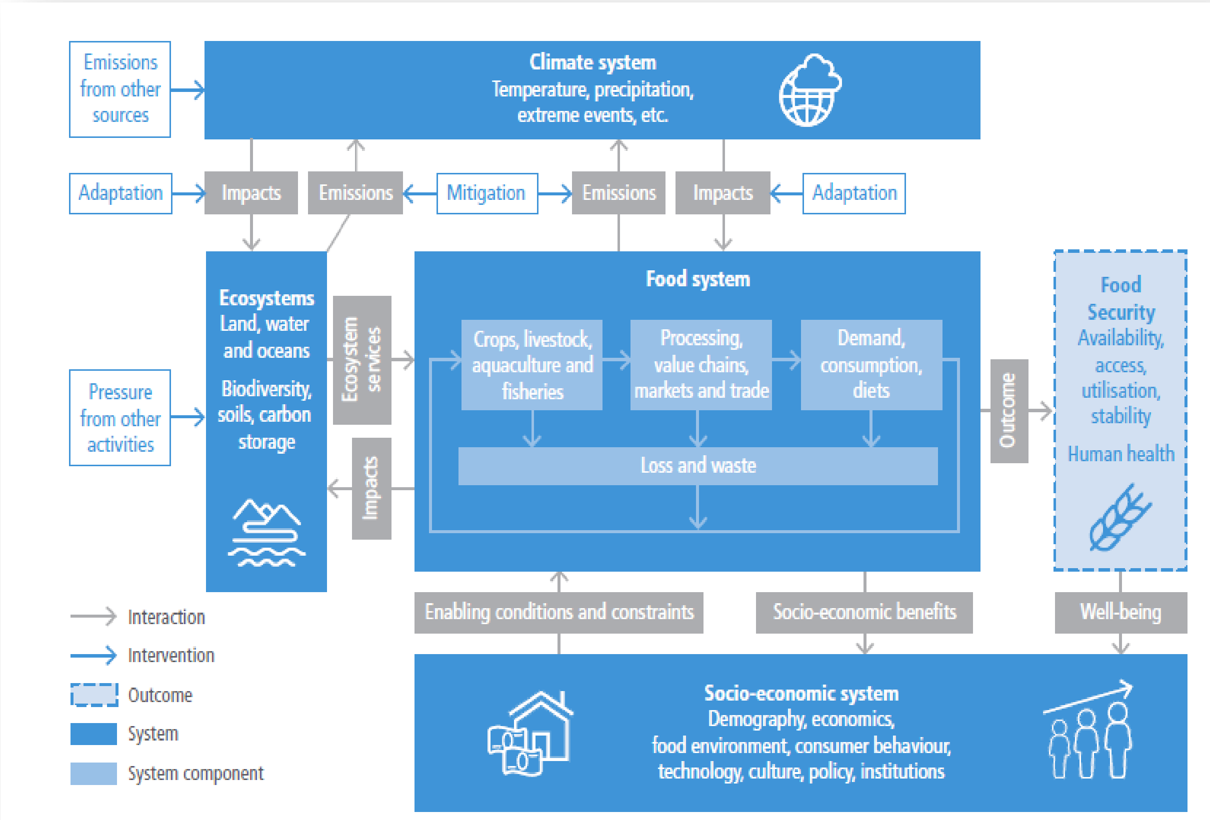

Figure 6. Interlinkages between the climate system, food system, ecosystems (land, water and oceans) and socio-economic system.

These systems operate at multiple scales, both global and regional. Food security is an outcome of the food system leading to human well-being, which is also indirectly linked with climate and ecosystems through the socio-economic system. Adaptation measures can help to reduce negative impacts of climate change on the food system and ecosystems. Mitigation measures can reduce GHG emissions coming from the food system and ecosystems.

Traditionally, cassava is produced on small-scale family farms. The roots are processed and prepared as a subsistence crop for home consumption and for sale in village markets and shipment to urban centres. Over the past 30 to 50 years, smallholders in Ghana and Nigeria have increased the production of cassava as a cash crop, primarily for urban markets. This shift from production for home consumption to commercial production for urban consumers, livestock feed and industrial uses can be described as the cassava transformation.(*Cassava-Production-Nigeria-Report-2020*, n.d.) During the cassava transformation, high-yielding cassava varieties increase yields while labour-saving harvesting methods and improved processing technology reduce the cost of producing and processing cassava food products to the point where they are competitive with food grains such as wheat, sorghum and rice for urban consumers (Jarvis, Ramirez-Villegas, Campo, et al., 2012)

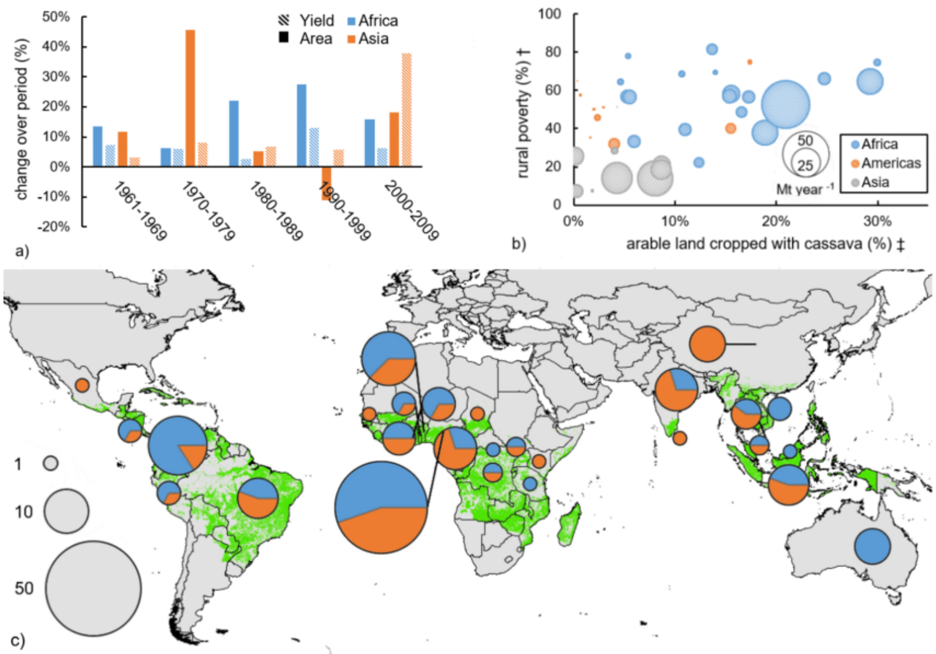

Figure 7 shows the trends in cassava production and research: cassava production has intensified over the past five decades, both in terms of area and yield (a). Countries across the developing-world tropics have a high degree of dependence on cassava in their agricultural systems and high levels of rural poverty as seen in (b) where each bubble represents a single country (FAOSTAT, 2016). Looking ahead, as the costs of cassava production, harvesting, processing and marketing are reduced, one can expect cassava to play an expanded role as a source of industrial raw material in Africa and as a source of foreign exchange earnings through the export of cassava pellets for livestock feed. Nigerian cassava production is by far the largest in the world; a third more than production in Brazil and almost double the production of Indonesia and Thailand. Cassava production in other African countries, the Democratic Republic of the Congo, Ghana, Madagascar, Mozambique, Tanzania and Uganda appears small in comparison to Nigeria's substantial output.

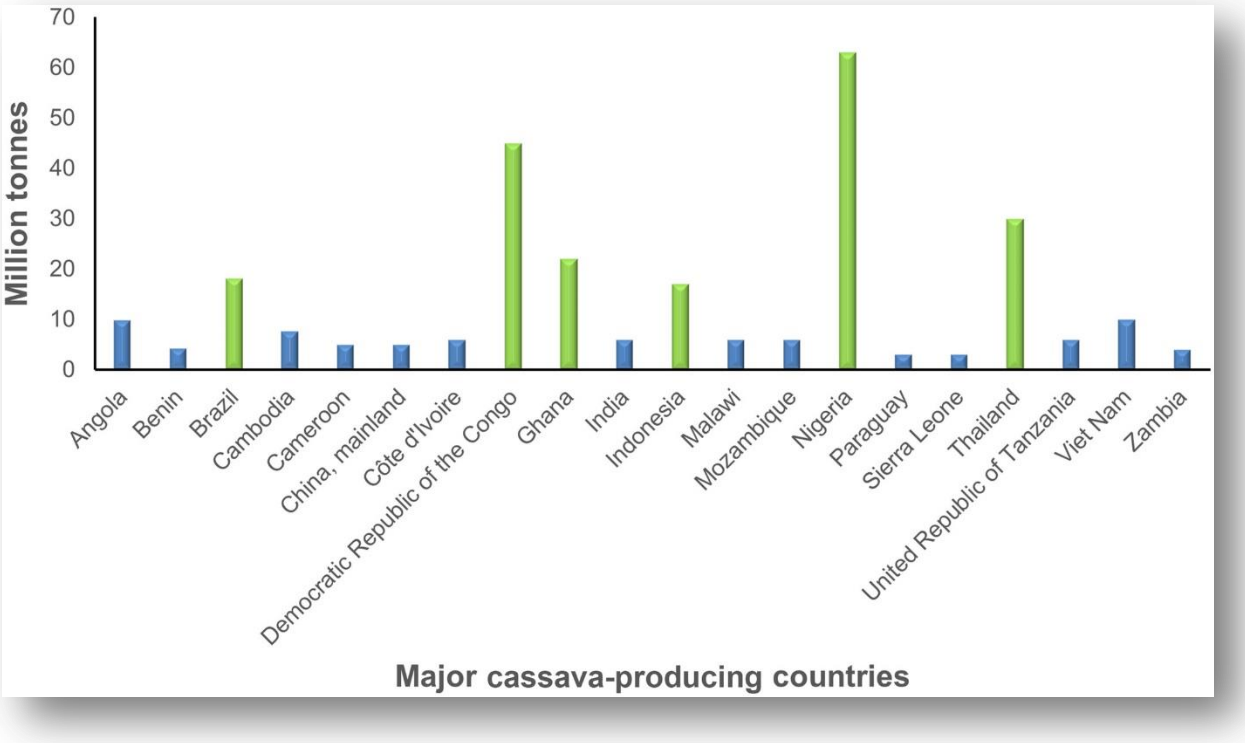

***Figure 8**:* Leading World Producers of Cassava

Source: FAOSTAT, 2022

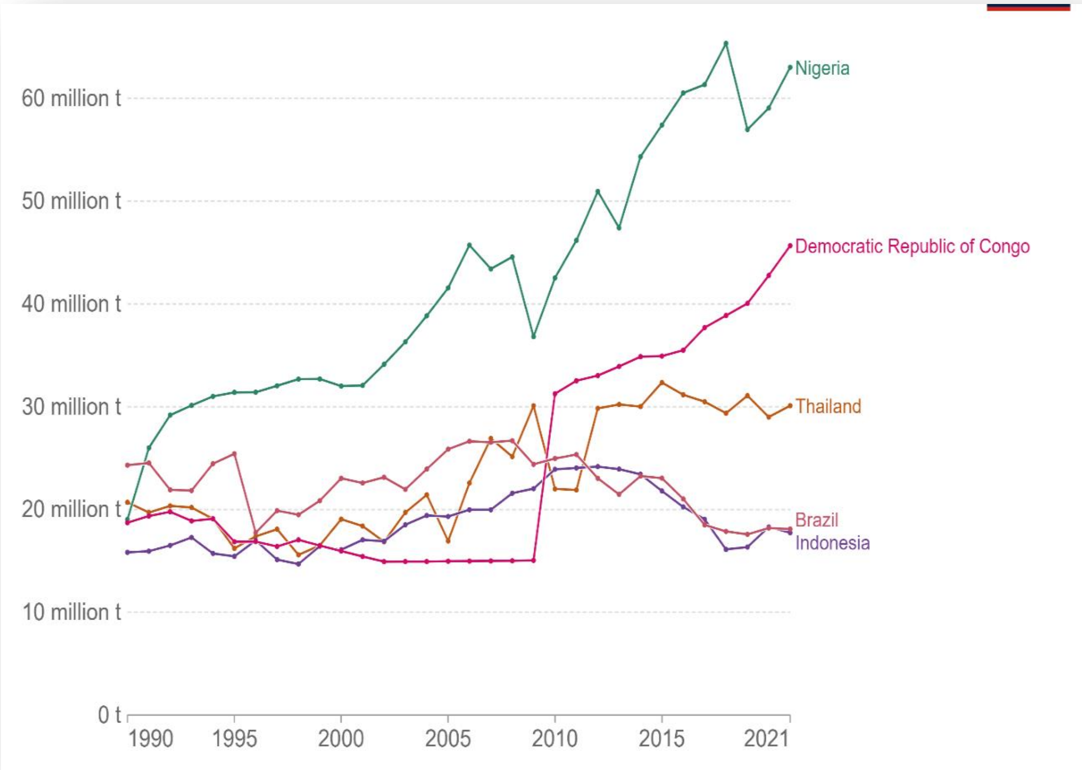

Figure 9: Cassava production among the highest producing countries from 1990 to 2021. This figure shows that Nigeria was the highest cassava producing country among the known producers of cassava in the world and the African Continent.

Source: Our World in Data

In the early 1960s, Africa accounted for 40 percent of world cassava production and Brazil was the world's leading cassava producer. However, thirty years later in the early 1990s, Africa produced half of the total world cassava output and Nigeria replaced Brazil as the leading producing country globally (FAOSTAT, 2022). Two forces explain this dramatic growth. First, demand for cassava has expanded because of rapid population growth and increased poverty thus, encouraging consumers to search for cheaper sources of calories. Second, the supply of cassava has expanded because genetic research and better agronomic practices have boosted cassava yields, especially in Ghana and Nigeria. Major cassava producing states in Nigeria are Benue, Kogi, Cross River, Ondo, Imo, Akwa Ibom, and Rivers states (Daniels et al., 2011).

Experts have argued that the cassava production is one of the well-developed agricultural crops in Nigeria because of its relatively well established and processing techniques. Cassava can be processed into varieties of products–e.g. food and starch for industrial use. According to International Institute of Tropical Agriculture (IITA), cultivating cassava comes with a lot of convenience. Some of which include: its ability to do well in poor soils, its labour requirements are low, it can be inter-cropped with other crops, it matures within a period of 6 months–3 years after planting. According to Hauser et al. (2014), the most preferred precipitation for cassava plant is an annual rainfall of 1000 mm or more. It thus implies that an average of 50mm rainfall per month spreading over a period of 6 months can sufficiently meet the water need of cassava plant. The plant does not tolerate extremely stony or sandy, clayey, salt affected, waterlogged and shallow soils but performs excellently well on well-drained soils rich in aluminum and manganese. Notwithstanding, cassava is highly tolerant to erratic weather conditions including a range of rainfall (El-Sharkawy, 2003). This was the observation found in 2003.

2.7 Climate Change Impact on Cassava in Nigeria

As opposed to the findings of the study done by El-Sharkawy, (2003), Adhikari and colleagues (Adhikari et al., 2015) reviewed previous studies investigating the impact of climate change on cassava production in Africa and concluded that cassava yield in the future is projected to drop approximately 8% or increase 10% of its yield based on different projection scenarios. Using panel data from 37 countries in Sub-Saharan Africa during 1961–2002, Blanc (2012) projected that cassava yield will almost be unchanged in 2100 under SRES scenarios. A recent study considered the effect of climate change on cassava in Nigeria, and found that increase in rainfall has a mixed effect on cassava yield, depending on the location (upland or coastal) (Isaiah et al., 2020). The study revealed that increase in rainfall positively affected cassava yield in the upland area, but it negatively influenced cassava yield in the coastal area.

While most previous studies investigated the impact of climate change on cassava in Africa, they only focused on cassava yield and did not incorporate the role of land use in the analysis. Several studies revealed that increasing populations have increased the pressure on agricultural land for non-agricultural use (Miao et al., 2016, & Attavanich et al., 2016). During the past two decades, studies have investigated climate change impact on cassava yield and founded heterogeneous effects across regions in the world. One of the most important crops grown in Nigeria that is severely impacted by climate change and climate variability is cassava cultivation (IPCC, 2013:

Owoeye, 2020). With an annual production of over 60 million tonnes of cassava tubers, Nigeria is recognized as the world's largest cassava producer (FAOSTAT, 2019).

Cassava tuber is crucial to the development of Nigeria's food economy because 84% of it is consumed locally and 16% is used as a raw material in the industries (Ikuemonisan et al., 2020, Agwu & Anyaeche, 2007). Kormawa and Akoroda (Kormawa) and Nwokoro et al. (Nwokoro et al., 2002) noted that where other food crops fail, the drought-tolerant cassava crop thrives on marginal soils with a moderate climate. However, Nigeria's recent extreme weather events, including flooding, a protracted drought, higher temperatures, and variable rainfall, have exposed cassava production to the negative effects of climate change. There is evidence that climate change has caused an increase in pest and disease activity, slowed growth, discoloration of cassava roots and leaves, and reduced tuber production (Akanbi et al., 2004). This unpleasant incidence has also increased the rate of tuber decays and pre-harvest losses in cassava farming (Matemilola, 2017) and inadvertently raised the unit cost of cassava derivatives [Ceballos et al., 2011; Owoeye, 2020). Consequently, farmers pay dearly through low productivity and profitability when these disasters hit (Ezekiel et al., 2012; Owoeye, 2020).

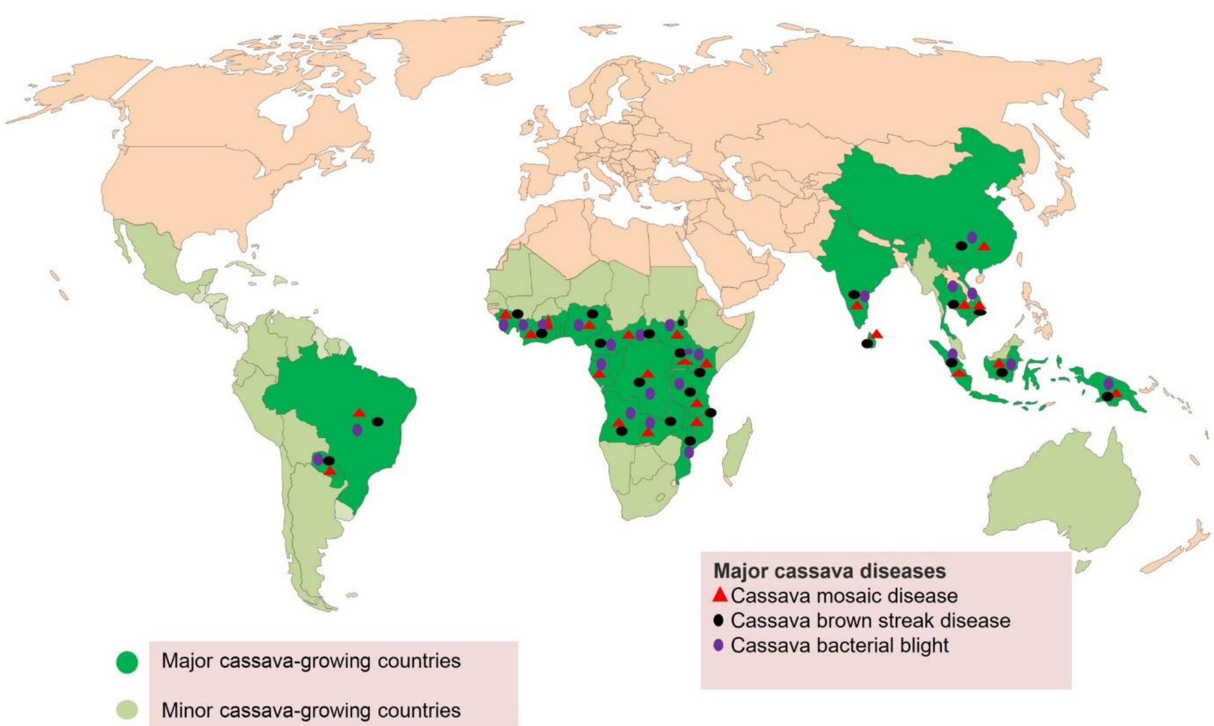

Figure 10: Cassava-producing countries and the distribution of major cassava diseases: cassava mosaic disease, cassava brown streak disease and cassava bacterial blight.

Source: FAOSTAT, 2022

Recently a team from the Food and Agriculture Organization of the United Nations (FAO), carried out a comprehensive literature review on major staple crops feeding the world and the major pests and diseases affecting them, and the impact of climate change on those crops, particularly. Cassava is a crop, which will likely be highly resilient to future climate change stressors. A study from (Jarvis, Ramirez-Villegas, Herrera Campo, et al., 2012) has shown that cassava production will vary from -3.5 percent to +17.5 percent within Africa under 2030 climate projections. Unfortunately, cassava will be vulnerable to pests and diseases. Over a third of attainable cassava yield is lost every year to pests and disease alone.

For example, an outbreak of the African cassava mosaic virus disease (CMD) in Africa in the 1920s led to a major famine. The virus is spread by the whitefly insect and by transplanting diseased plants into new fields. Cassava brown streak virus disease (CBSD) has been identified as a major threat to cultivation worldwide. An overall loss of US$750 million a year caused by CBSD has been estimated across Kenya, Tanzania, Uganda and Malawi.

The whitefly is a pest of cassava and transmitter of pathogens, and its abundance is growing in Africa. High temperatures, before arriving at an upper extreme, can increase populations of this pest. In Côte d'Ivoire, (Fargette et al., 1996) noted that high temperatures are associated with high fecundity, rapid development, and greater longevity of this insect. Broadly speaking, excessive heat stress and cold conditions restrict mealybug propagation. In Africa, projections of the area at risk of mealybug infestation include Sub Saharan Africa except for most southern parts of this region (Jarvis, Ramirez-Villegas, Herrera Campo, et al., 2012). Unfortunately, information is still sparse on the impact of climate change on pests and diseases of major crops. And experts are unsure how it will affect crop production and yields, through its impact on land, soil, water, ecosystem services, precipitation, atmospheric temperatures, and pollinators.

2.8 Production Constraints in Nigeria

Shortening fallow periods and declining soil fertility. The predominance of different fallow systems varies among villages, depending on soil fertility status and on pest/disease, market and demographic pressures. It is often reasoned that as fallow periods decline, cassava will increasingly replace crops which demand higher soil fertility and production labour. However, although cassava is well adapted to growing under continuous cultivation, it is not as frequently grown under that system as other major staples.

The farmers' ability to respond to declining fallow periods due to demographic, market, pests/disease and other pressures by replacing more susceptible crops with cassava is constrained by its long cropping cycle. Cassava can be harvested from six months after planting, but most available local varieties do not attain maximum yield before 22 months. Currently improved varieties attain their maximum yield at 12–15 months. Under intensive cultivation where the fallow period is often less than one year, such varieties are not ideally suited because they may be harvested before they attain maximum yield. However, early-bulking varieties are not likely to reduce this pressure unless they are combined with agronomic practices for greater water and nutrient-use efficiency. Shortening fallow periods require varieties selected for efficient nutrient assimilation and for better ability to be intercropped with legumes or other soil fertility conservation strategies (Okeleye et al., 2023).

Insufficient and poor quality planting material: Cassava production is dependent on a supply of vegetative planting materials (i.e. stem cuttings). The multiplication rate of these materials is very low in comparison with grain crops which are propagated by true seed. In addition, cassava planting materials are bulky and highly perishable as they dry up within a few days after harvest and hence their multiplication and distribution are expensive relative to conventional (grain-based) seed services. The yield stability and environmental development of cassava is highly dependent on the quality of planting materials and there is evidence that the initial use of healthy cuttings is a very important factor in the subsequent attainment of good yields. Conversely, cuttings with low vigour and which are infested/infected by pests and diseases, often limit cassava production. However, there is insufficient knowledge concerning criteria appropriate for selection of vigorous and clean cuttings and on the optimal conditions for their propagation and maintenance. Pests and diseases, together with poor cultural practices, combine to contribute to yield losses that may be as high as 50 percent.

In dry agro-ecosystems, where biomass production is usually low in comparison with more humid areas and in areas where new materials such as improved varieties are being introduced for the first time, the production of planting materials in sufficient quantities is a major restriction to the widespread and rapid adoption of the crop or a variety (Adedoyin et al., n.d.; Fao, n.d.; Okeleye et al., 2023)

Lack of well adapted varieties. Research findings show that farmers are abandoning old cultivars and introducing new ones. This indicates the farmers' need for better varieties, but also highlights the danger of loss of genetic diversity. While it is increasingly evident that cassava is expanding into the semi-arid and mid-altitude zones, the available improved germplasm is mostly adapted to the lowland humid tropics. Therefore, germplasm adapted to more agro-ecological zones is needed. Expansion of the utilization of cassava to new industrial uses requires germplasm with high yield as well as quality that is tailored to specific end-uses.

Plant pests and diseases. Historically, cassava had few serious pests and diseases in Africa. However, the situation changed as cassava cultivation intensified and exotic pests were introduced. Although it is now widely accepted that cassava in Africa is attacked by a number of serious pests, only a few in-depth studies of the ecological and economic importance of any of these species have been carried out. The major cassava pests in Africa include relatively few phytophagous arthropods, plant pathogens and weeds compared to the pest complex found in the neotropics. Together, these species could reduce cassava production by as much as 50 percent. The most severe pests are the exotic species accidentally introduced into areas where the local germplasm is susceptible to attack, where effective natural enemies/antagonists are absent and where a tradition of practices to cope with the introduced pests has not had time to evolve.

In addition, pest problems are being created where intensification of cassava production erodes the environmental stability inherent in balanced agro-ecosystems. The major pest concerns are cassava green mites, variegated grasshopper during outbreak episodes, root mealybug in the rain forest ecozones, African Cassava Mosaic Disease (ACMD, cassava bacterial blight (CBB), cassava anthracnose disease (CAD) and root rot in the humid lowlands. The role of termites, nematodes and certain weed species particular to specific ecozones have been reported as constraints but have not received adequate attention. Other root rot are also found in other ecozones including the highlands. (Adedoyin et al., n.d.; Fao, n.d.; Okeleye et al., 2023)

The appearance of cassava mealybug (CM) and CGM as introduced pests in the 1970s in Africa had devastating effects in farmers' fields. In particular, the CM attack was so severe that it threatened the future of cassava in Africa. Massive efforts spanning several continents and involving numerous international and national research institutions under the leadership of IITA led to the development of a successful continent-wide biological control programme. Natural enemies of CM were identified in South America and the parasite *Epidinocaris lopezi* has been released in many countries in Africa. Biological control, along with improved varieties and cultural practices, provide a cost-effective, sustainable and environmentally friendly technology for the control of CM without using insecticides. The wide-spread establishment and documented impact of exotic predatory mite species offers good hope for biological control of the CGM as well. (Adedoyin et al., n.d.; Fao, n.d.; Okeleye et al., 2023)

2.9 Theoretical Concerns / Situating the Study in the Field

This study will examine the effects of climate change on land use and cassava yield, conducted within the unique context of Nigeria. Situated in the tropical zone of West Africa, Nigeria spans from latitudes 4°N to 14°N and longitudes 2°2'E to 14°30'E, encompassing a total land area of 923,770 square kilometers. The country extends approximately 1,050 kilometers from north to south and up to 1,150 kilometers from east to west, boasting an estimated population of around 213.4 million inhabitants (World Bank, 2021). Nigeria shares its borders with Benin to the west, Niger to the northwest and north, Chad to the northeast, and Cameroon to the east, while the southern coastline meets the Atlantic Ocean.

While previous researchers have explored the broader impact of climate change on agricultural production in Nigeria, such as in "Climate Change and Agricultural Production in Nigeria: A Review of Status, Causes, and Consequences," "Cassava Production in Nigeria: Trends, Instability, and Decomposition Analysis (1970–2018)," "Factors Influencing Cassava Farmers' Choice of Climate Change Adaptation Practices and Their Effect on Cassava Productivity in Nigeria," and "Cassava Production in Nigeria: Trends, Instability, and Decomposition Analysis (1970–2018)," this study takes a distinct approach. It focuses on the specific influences of climate change on land allocated to cassava production, with a particular emphasis on cassava yield. The 2014 Synthesis Report of. the Intergovernmental Panel on Climate Change (IPCC) emphasizes how crucial it is to understand the complex interactions between land use and climate change. An extensive summary of the effects and current status of climate change is given in this article.

Adger et al. (2009) offer a paradigm that incorporates social variables into the comprehension of climate change impacts on coastal areas, which makes a substantial conceptual contribution to the conceptualization of the social components of adaptation to climate change. The findings of

Foley et al. (2005) provide information about the worldwide effects of land use change by emphasizing the connections, both direct and indirect, between land use patterns and climate variables. The necessity of a complex knowledge of these connections is emphasized by their work. Lambin and Meyfroidt (2011) examine the dynamics of land use change on a worldwide scale, highlighting the influence of economic globalization on these changes. Their study clarifies the intricate interactions between economic variables that influence patterns of land usage. Turner et al. (1990) offer a historical viewpoint on how human activity has changed the Earth. Their study clarifies the complex relationships between economic variables that influence patterns of land usage. Turner et al. (1990) offer a historical viewpoint on how human activity has changed the Earth. Their research provides insightful analysis of long-term patterns by following the development of land use change drivers over the previous three centuries.

The book Creswell and Plano Clark (2017) offers a thorough manual for planning and carrying out mixed-methods research. Understanding how to incorporate theoretical frameworks into empirical investigations is made possible in large part by their work, especially when using mixed-methods approaches. By providing insights into the advantages and difficulties of combining quantitative and qualitative methodologies, Teddlie and Tashakkori (2009) establish the groundwork for mixed-methods research. Their study offers a convincing defense of using a mixed-methods approach in research. This research contributes to the evolving discourse on climate change's impact on land utilization and agricultural crop yield, filling a significant gap. Notably, there exists little similar no studies detailing the effect of climate change on cassava yield and the associated land use for cassava production, particularly over the 40-year period examined in this study.

2.10 Research Gap

This study aims to fill this gap by exploring how climate variations impact land use and cassava production, with a focus on cassava yield. Understanding this is crucial because Nigeria faces challenges from rapid infrastructure expansion and increased industrial activities, which can affect agricultural growth. It's important to consider how we can optimize the use of high-yield cassava stems rather than solely relying on expanding cultivation areas. Additionally, peri-urban agricultural land is under pressure due to increasing land speculation and infrastructure development for a growing population. Many cassava producers are small-scale farmers, which adds complexity to the situation. This exploration is essential to develop effective adaptation and mitigation measures that enhance resilience (IPCC 2014; Serdeczny et al. 2017). This work's significance lies in its potential to support food security, catering to the increasing demand beyond local consumption for primary cassava output and the following objectives will guide this research.

CHAPTER THREE

3. METHODOLOGY AND DATA DESCRIPTION

This chapter outlines the research methods and data description used to study the impact of climate change on land use, cassava production, and yield in Nigeria. The study utilized a combination of methods to model and analyze this impact. Both quantitative and qualitative approaches were triangulated to comprehensively address the research aims. The chapter is divided into three steps for clarity: systematic literature mapping, materials and methods, and the description of model. Trend analysis, correlations and crop modeling provided objective quantitative insights while surveys and interviews captured local stakeholder experiences. To better understand the cassava topic under study and to answer some of the research question, a comprehensive analysis of literature was done. This formed a basis for subsequently exploring opportunities and constraints in literature.

3.1 Systematic literature mapping

In contrast to systematic literature reviews, systematic mapping does not aim to address a specific research question but rather collects, describes, and categorizes available evidence (e.g., primary, secondary, theoretical, economic) related to a topic or question of interest (James et al., 2016, p.3). Therefore, it differs from the quantitative or qualitative objectives and concentrates on describing the state of knowledge (James et al., 2016). The systematic mapping undertaken here adhered to the Guidelines and Standards for Evidence Synthesis Methodology in Environmental Management (Collaboration for Environmental Evidence, 2018) to ensure rigorous, unbiased, and transparent conclusions from an expanding body of scientific information. Furthermore, it utilized a comprehensive methodology in environmental sciences. Due to the absence of a systematic overview regarding the impact of climate change on land use and cassava production and utilization, a literature mapping was conducted. Since this method has been employed in other studies (Savilaakso et al., 2014; Sola et al., 2017), it was deemed suitable for the task of exploring and synthesizing knowledge about the overview.

3.1.1 Literature screening and study inclusion criteria

To conduct an inclusive search, both peer-reviewed papers and grey literature were included in the systematic mapping. The inclusion of grey literature is frequently recommended to reduce the issue of *publication bias* as well as to retrieve practitioner-generated documentation (e.g. policies, reports from consultancies or NGOs) (Haddaway et al., 2015).

Three relevance criteria were used to select the literature for the systematic mapping. It had to provide:

- A thematic focus on the driving forces, impact of climate change or variability on land use, cassava production or yield.
- A limited geographic extent of the study area. This included studies that comprised parts of, intersected with, or included Nigeria entirely. Global scale studies were taken into consideration if providing a detailed description for Nigeria.
- Research and data from 2000 to 2021 to draw from findings that capture more recent developments.

Literature was excluded from further processing if:

- Conceptual or theoretical papers that do not present empirical evidence, data, or case studies. The goal is to synthesize and analyze existing research, so conceptual works alone would not provide useful insights.

- Literature that investigates only the downstream results or impacts of deforestation, such as reduced food security or effects on community resilience. The research is looking at impacts of climate change specifically, so literature only addressing impacts of deforestation would not align

- Literature that does not have a nexus to climate change, land use, and cassava production in Nigeria. The geographic and topic scope needs to be limited to be relevant to the research question.

To draw efficiently from a wide pool of relevant scientific literature, online databases were utilized – more specifically, the Web of Science, Scopus, and Science Direct. Based on the stated criteria, keywords were derived and combined with Boolean operators (“AND”, “OR”, etc.) to a search string (keywords and strings will be attached at the Appendix). The output was limited to research papers in the English language and to some of the most relevant subject areas. A total of 163 studies were identified after eliminating duplicates (Figure 11**).**

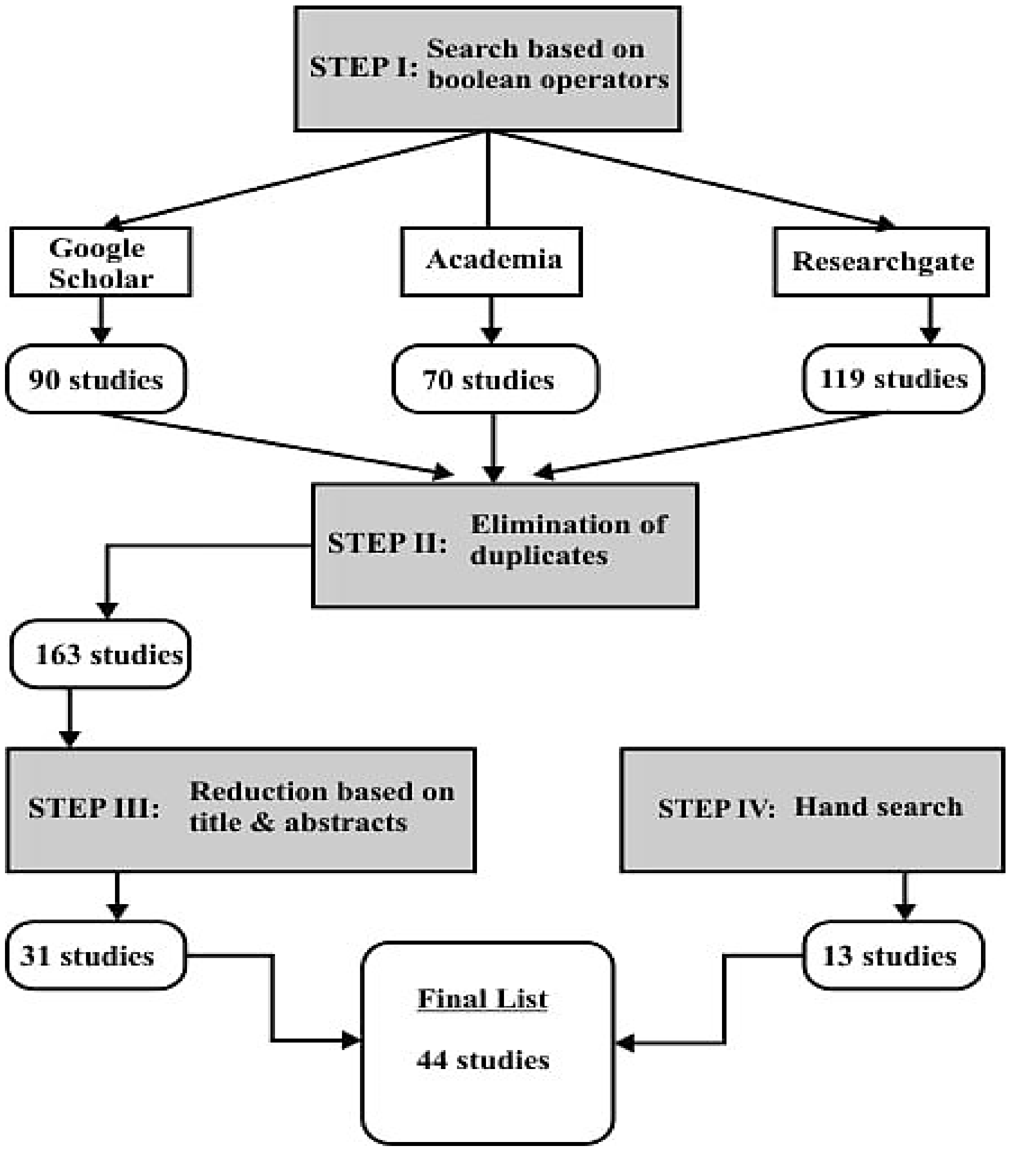

Figure 11. *Flow chart showing the four sub-steps applied for reducing the number of studies included in the literature mapping. Source: Author's representation.*

The resulting list was then further narrowed down, based on titles and abstracts. Finally, the content of the full text was assessed and the citation list scanned where deemed appropriate. The identification of grey literature was done manually through a *hand search* and the use of conventional search engines (Google, Google Scholar) and databases of major organizations (e.g UNEP, FAO). The systematic analysis resulted in a final number of 44 documents.

3.1.2 Study coding strategy

The qualitative and quantitative information from the selected literature was compiled into excel spreadsheets and structured in categories. To allow for a flexible emergence of information, a combined *inductive* and *deductive* approach was applied to derive frequent, dominant, and significant themes (Thomas, 2006). The category system was based on the proximate causes and underlying framework proposed by Geist and Lambin (2002) and Vinya et al. (2011). The distinction can, however, be difficult to maintain since the classification in proximate and underlying factors may be subjective and perceived differently depending on the analyst (Kamelarczyk & Smith-Hall, 2014).

The background information on the study locations will be presented to help interpret the primary data collection results, by providing context on the varied farming environments and conditions across the different cassava production zones examined.

3.2 Background of the study Area

Nigeria is located in West Africa, between latitudes 4° and 14°N, and longitudes 2° and 15°E. The country borders Niger to the north, Chad to the northeast, Cameroon to the east, and Benin to the west. Nigeria has a total land area of about 923,768 square kilometers and an estimated population of over 216 million people as of 2022, making it the most populous country in Africa. Agriculture is a major sector of the economy, with over 40% of Nigerians employed in farming and accounting for about 25% of GDP. Cassava, yams, maize, millet, rice, sorghum, cowpeas, soybeans, groundnuts, cocoa, rubber and oil palm are some of the principal crops grown (Chukwuone, 2015).

Nigeria is characterized by three distinct climate zones, a tropical monsoon climate in the south, a tropical savannah climate for most of the central regions, and a Sahelian hot and semi-arid climate in the north of the country. This leads to a gradient of declining precipitation amounts from south to north. The southern regions experience strong rainfall events during the rainy season from March to October with annual rainfall amounts, usually above 2,000 mm, and can reach 4,000 mm and more in the Niger Delta.

The central regions are governed by a well-defined single rainy season (April to September) and dry season (December to March). The dry season is influenced by the Harmattan wind from the Sahara. Coastal areas experience a short drier season with most rain occurring over March to October. Annual rainfall can reach up to about 1200 mm. In the north, rain only falls from June to September in the range of 500 mm to 750 mm. The rest of the year is hot and dry. Northern areas have a high degree of annual variation in its rainfall regime, which results in flooding and droughts. The most significant temperature difference in Nigeria is between the coastal areas and its interior as well as between the plateau and the lowlands. On the plateau, the mean annual temperature varies between 21°C and 27°C whereas in the interior lowlands, temperatures are generally over 27°C. The coastal fringes have lower means than the interior lowlands. Seasonal mean temperatures are consistently over 20℃ throughout the country and diurnal variations are more pronounced than seasonal ones. Highest temperatures occur during the dry season, and vary little from the coast to inland areas. Similar to rainfall, the relative humidity in Nigeria decreases from the south to the north, with an annual mean of 88% around Lagos. Mean annual temperature for Nigeria is 26.9°C, with average monthly temperatures ranging between 24°C (December, January) and 30°C (April). Mean annual precipitation is 1,165.0 mm. Rainfall is experienced throughout the year in Nigeria, with most significant rainfall occurring from April to October and with minimal rainfall occurring November to March (World Bank Group, Climate Knowledge Portal, 2024).

Nigeria Ecology Zones: The Nigeria ecological zone covers the derived savannah, the low land, fresh water swamp forest, and mangrove forest/coastal vegetation. Figure 12 shows the map of Nigeria indicating the ecological zones. The derived savannah was originally the drier part of the high forest. Due to bush burning and overgrazing, as well as cultivation and hunting activities over a long period, the high forest trees were destroyed and the forest that used to exist has now been replaced with a mixture of grasses and scattered trees. However, along the streams and in wet low-lying areas where surface water accumulates, there are still some traces of forests. The lowland forest zone is the major source of timber for all large construction and cabinet-making. This zone contains the most valuable species of vegetation.

However, due to human activities, this one-time forested area has been drastically reduced. Bush fallows, villages, and farms are found scattered throughout the zone. The drier end of its inland side is becoming reduced to derived guinea savanna because of felling and clearings. In the humid rain forest can be found economic cash crops such as oil palm, (*Elaeis guineensis*), cocoa (*Theobroma cacao*), rubber (*Hevea brasiliensis*), banana/plantain (*Musa* spp.), and cola nut (*Cola nitida*). Some principal staple food crops such as yam, cocoyams, sweet potato, maize, rice, groundnut, cowpeas, and beans can also be found in this zone, as well as a number of fruits. This zone is also good for sylviculture; a number of timber trees such as the African mahogany (*Khaya ivorensis* and *K. grandifoliola*), the scented sapele wood (*Entandrophragma cylindricum*), and iroko (*Chlorophora excelsa*) can be found here. This zone is clearly very important in terms of food production and timber production (Oyenuga, 1967).

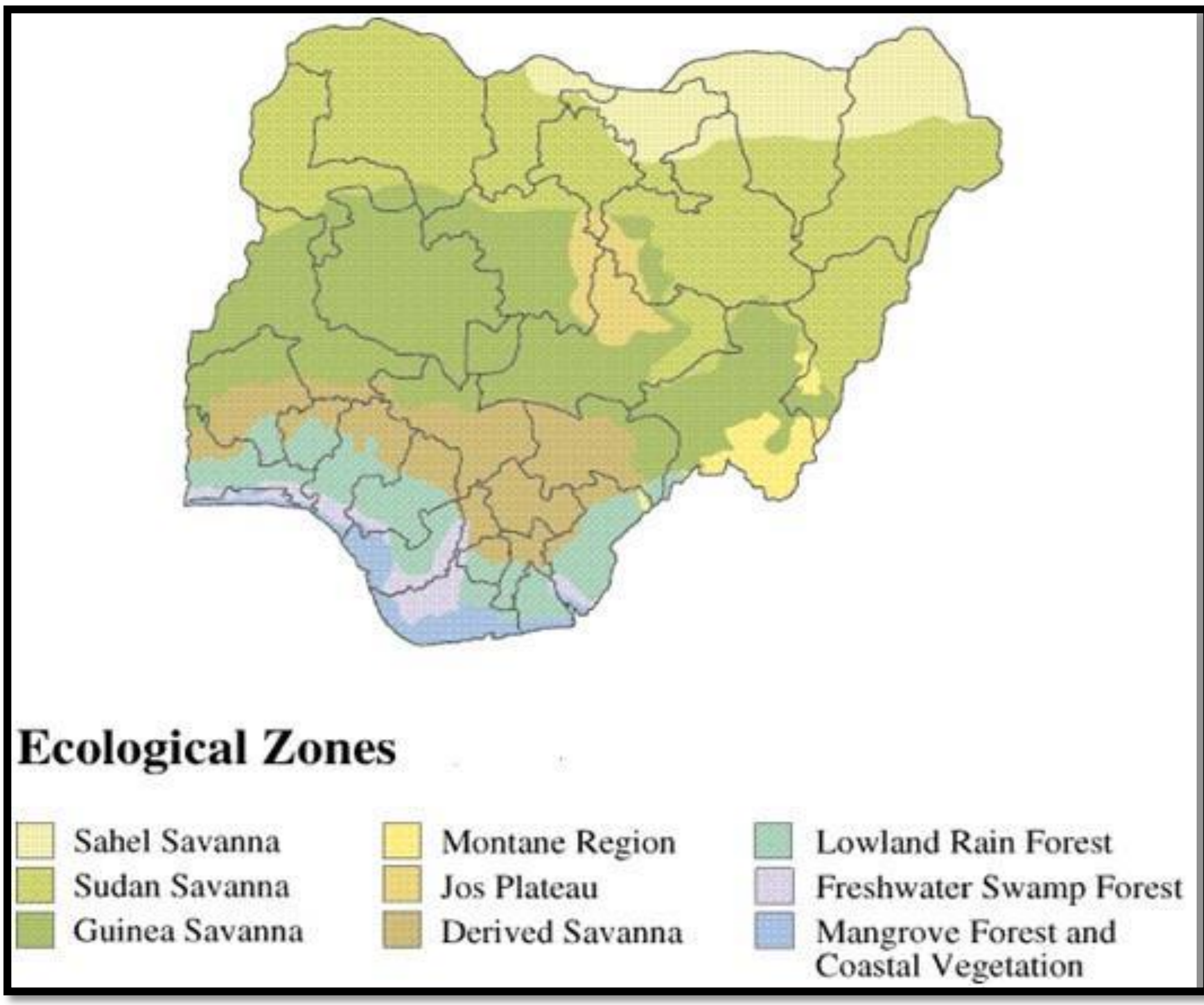

Figure 12: Map of Nigeria showing the nine ecological zones

Source: Nigeria Biodiversity Strategy and Action Plan (NBSAP), 2007

The freshwater swamp communities: This area, which originally occupied 18,130 km2, lies immediately inland of the mangrove swamp but on a slightly higher ground. The lagoons or the rivers that overflow their banks in the wet season supply it with fresh water; because the area is low-lying, it is flooded with rain water and lies under rain for sometimes eight or nine months of the year. The periodical flooding gradually deposits new layers of alluvial soils on the surface of the land, a deposit that leads to the formation of more solid ground behind the swamp, where we find the beginning of the rain forest. This zone consists of a mixture of trees and contains various important palm and fiber plants such as Raphia spp. Fishing and fiber-making are the important products of the fresh-water swamp community. The mangrove forest and coastal vegetation: This occupies the coastal areas and consists of tidal swamps, interspersed with numerous creeks and lagoons. The mangrove swamp is noted for the mangrove species of trees (Rhizophora) that dominate the swamp and to a much less extent by Conocarpus erectus and 14 Laguncularia racemosa (white mangrove). Among the Rhizophora spp. Rhizophora racemosa dominates, occupying an estimated 99% of the entire mangrove area. The coastal swamp area is not widely cultivated except for swamp rice in places where the swamp is stabilized and non-saline (Chukwuone, 2015). The mangrove forest and coastal vegetation: This occupies the coastal areas and consists of tidal swamps, interspersed with numerous creeks and lagoons. The mangrove swamp is noted for the mangrove species of trees (Rhizophora) that dominate the swamp and to a much less extent by Conocarpus erectus and 14 Laguncularia racemosa (white mangrove). Among the Rhizophora spp. Rhizophora racemosa dominates, occupying an estimated 99% of the entire mangrove area. The coastal swamp area is not widely cultivated except for swamp rice in places where the swamp is stabilized and non-saline (Chukwuone, 2015).

3.3 Data Acquisition

3.3.1 Data for Climate Change Impact Study:

Data on land use, cassava production and yield in Nigeria from 1980-2021 was obtained from FAOSTAT Database (https://www.fao.org/faostat/en/#data/QCL). Yearly national climatic data was sourced from 1980-2021 from the Nigeria Metrological Institute (NIMET). The dataset ranges from 1980 to 2021 for all the stations. This range of years was selected for data quality reasons. These stations are set in rural areas and close to agricultural rainfed lands. The vicinity of where the meteorological instruments are installed is covered with grass. The climate data used in this study were carefully processed for missing values and quality checked before using them for any analysis. There were no missing values in rainfall as well as temperature data from 1980 through 2021 for all the stations selected in this study. While scenarios was created for 2030, 2050, and 2080. The data obtained from these sources was crucial in analyzing the impact of climate conditions on cassava production in Nigeria over the past four decades. By examining temperature and precipitation trends alongside land use and yield data, we were able to identify patterns and correlations that shed light on the challenges and opportunities faced by the cassava farming sector in the country.

3.3.2 Sampling of Farmers for the Study:

A mixed-structured interview protocol was used in data collection. The nature of climate change, and of innovations to adapt to it, warrants an approach that emphasizes local-level knowledge and experience, which should be gathered through a participatory process. Mixed-structured interview was used to gather information on farmers' socio-economic attributes, their knowledge and awareness of climate change issues, adaptive measures and innovations against climate change risks, and constraints to climate change adaptation. Data on the cost and returns of farming under cassava based cropping systems was also collected.

3.4 Methods

3.4.1 Trend analysis: Mann–Kendall Test and Sen's Slope Method

To understand the linkages between climate change and agriculture in Nigeria, scientific studies on that matter need to be carried out to improve crop productivity. Regressing the historical crop yields against climate variables is a relatively accurate method for evaluating the influence of climate change on the crop yields (Gadedjisso-Tossou et al., 2018). Koudahe et al. (2019) used the Mann–Kendall test, Sen's slope estimator and multiple regressions technique to appraise the trends of the climatic variables and their influence on crops yields. The Mann-Kendall trend test is a nonparametric rank-based statistical technique used to assess the significance of the trend in time series data. The Mann-Kendall trend test is used to perceive statistically significant decreasing or increasing trend in long term temporal rainfall, temperature, evapotranspiration, humidity, pressure, stream flow etc. data. Sen's slope developed by Rasul et al. (2012) has been widely used to calculate the magnitude of trends in the long term temporal data. Sen's slope is considered better to detect the linear relationship as it is not affected by outliers in the data. The unit of the Sen's slope is the slope magnitude per year.

The Mann–Kendall (MK) test was employed through the Rstudio software to assess the trends in rainfall, T_{max} and $T_{min\ (Annual\ Average\ Temperature)}$. It is a non-parametric test, which has no prerequisite conditions on the data to be normally distributed. The MK test is grounded on a null hypothesis

(H_0), which indicates that there is no trend—the data are independent and randomly ordered—and this is verified against the alternative hypothesis (Ha), which supposes that there is a trend. The true slope (change per unit time) was predicted using Sen's slope (SS) estimator (Tabari, 2011; Mann, 1945; Koudahe et al. 2019).

3.4.2 Correlation analysis:

3.4.3 Assessing the Significance of Temperature and Rainfall Variability for Crop Yields

Multiple linear regression analysis evaluated the significance of rainfall and temperature variability on crop yield. Adapting the production function from Ochieng et al. (2016), the following equation was used:

$$\ln Y=\alpha+aR+bR2+cT+dT2+e(R*T)+\mu$$

Where lnY represents the natural logarithm of crop yield (kg ha−1), a, b, c, d and e are coefficients for rainfall, squared rainfall, average temperature, squared average temperature, and the combined effect of rainfall and temperature during the growing season (May to October), respectively. α is a constant and μ represents error terms or omitted variables that may influence crop yield. R software (R Core Team, 2019) was used to perform the statistical analysis and create figures. When the t-statistic probability was smaller than the significance level, the variable significantly influenced crop yield at that level.

3.4.4 Qualitative analysis:

Farmers were sampled from ten (10) states. To randomly select states from Nigeria for the survey, all 36 states in Nigeria were listed: Abia, Adamawa, Akwa Ibom, Anambra, Bauchi, Bayelsa, Benue, Borno, Cross River, Delta, Ebonyi, Edo, Ekiti, Enugu, Gombe, Imo, Jigawa, Kaduna, Kano, Katsina, Kebbi, Kogi, Kwara, Lagos, Nasarawa, Niger, Ogun, Ondo, Osun, Oyo, Plateau, Rivers, Sokoto, Taraba, Yobe, Zamfara.

The following steps were used tp make the survey sampling:

Step 1: A random number was assigned to each state using the RANDBETWEEN function in Excel: =RANDBETWEEN (1,1000). This generated a random number between 1-1000 for each state.

Step 2: The list of states was sorted in ascending order based on the random number. The first 10 states in the sorted list was the random sample:

S/N	**States**	**Number**
1	Taraba	8
2	Borno	23
3	Kogi	45
4	Bauchi	78
5	Benue	101
6	Enugu	123
7	Kaduna	145
8	Kwara	167
9	Ogun	189
10	Ekiti	234

One agricultural zone was selected in each of the states, to select the agricultural zones, the researcher did the following: Looked up the major agricultural zones for each state online, in cases where there were multiple zones, the researcher assigned random numbers to each zone and picked the zone with the lowest/first random number. For Taraba - Upper Benue River Zone, Borno - Lake Chad Basin Zone, Kogi - Central Agricultural Zone, Bauchi - Northern Guinea Savannah Zone, Benue - Benue River Zone, Enugu - Enugu-Awgu Zone, Kaduna - Southern Guinea Savannah Zone, Kwara - Central Agricultural Zone, Ogun - Forest Savannah Transition Zone, and Ekiti - Ekiti Zone

This gave a total of ten (10) zones. From each of the ten zones, one (1) local government area were randomly selected, giving a total of ten local government areas, one for each State. The local government areas were Taraba - Ardo Kola LGA, Borno - Kaga LGA, Kogi - Dekina LGA, Bauchi - Ningi LGA, Benue - Gwer West LGA, Enugu - Igbo Eze North LGA, Kaduna - Kauru LGA, Kwara - Ilorin West LGA, Ogun - Abeokuta South LGA, and Ekiti - Ikole LGA. From each of the ten (10) local government areas, four (4) farming communities were randomly selected, resulting in 40 farming communities. Finally, from each of the 40 farming communities selected, 10 farmers were randomly selected, giving 400 farmers for the survey. The selection and interviewing of farmers was done with the help of agricultural extension agents in the areas.

Measurement of Variables

The composition of each household was recorded, as well as the respondents' knowledge about climate change and how they've adapted to it. Farmers were asked if they had noticed significant changes in temperature or rainfall patterns where they live. Respondents were also asked to indicate their level of awareness about climate change by choosing options like "don't know", "know a little", "know to a reasonable extent", or "know to a great extent".

Farmers selected responses describing observed climate changes such as more frequent droughts, delayed rainfall onset, erratic rainfall patterns, hailstorms, or higher temperatures. The "normal" option meant no changes were noticed. Those who reported receiving climate change information were asked to specify the source. They also chose potential outcomes like declining or increasing crop yields, and food insecurity. Respondents indicated the actions they've taken to adapt to climate change. They answered yes or no to indicate which land management practices they use to address climate change, and provided the year each practice was started.

Respondents selected which land management practices addressed changes in rainfall and temperature. They also reported constraints to adapting to climate change. Costs and profits from growing cassava were ascertained. Survey details are in an Appendix. Socioeconomic attributes of sampled farmers are in Table 2. Qualitative data from surveys was coded and analyzed thematically to identify major themes around observed climate impacts and adaptation strategies. Gross margin analysis, descriptive statistics and a probit model were used to assess how climate factors predict agricultural outcomes. This helped answer research questions 1 and 3 about observed climate impacts and likelihood of farmers taking adaptive actions. The probit model is generally given as:

$$\mathbf{Pr(Y=1|) = \Phi\ (X'}\ \boldsymbol{\beta}),$$

Where Pr denotes probability, Φ is the Cumulative Distribution Function (CDF) of the standard normal distribution, and β is a vector of parameter estimates. The probit here is estimated in form of a latent variable model:

$$\boldsymbol{Y^{*}= X + \beta + \varepsilon}\ \textit{where}\ \varepsilon \sim N(0, 1).$$

Y* is the critical threshold level which, if exceeded, will indicate that the farmer employs the particular climate change cushioning effect, in this case, one (1) for those that employ and zero (0) otherwise. Thus, use of a cushioning effect against climate change Y=1 if the critical threshold is 1, zero otherwise.

A probit model was used to determine what factors influence a farmer's decision to adopt specific climate change adaptation practices. The analysis focused on the most commonly adopted practice used by over 30% of farmers. The explanatory variables included in the probit model are described. Additionally, a multinomial logistic regression was conducted to understand the determinants of involvement in different farm management adaptation practices. The practices examined were those employed by over 40% of farmers, such as: planting pest and disease resistant crops; using early maturing varieties; properly preserving seeds and seedlings; mixed farming; utilizing acclimatized varieties; increasing weed control; and paying attention to climate change information.

Farmers who did not adopt any adaptation practices were used as the base variable in the multinomial logistic regression model. In general, a multinomial logistic regression model for a categorical dependent variable with multiple levels (M levels) consists of M-1 separate equations. Each equation estimates the odds of being in one category relative to the base category. It includes an intercept as well as K predictor variables that may influence the odds. Therefore, in this case, the multinomial logistic regression model would contain separate equations for each adaptation practice compared to the base of not adopting any practices. Each equation estimates the odds of adopting that practice based on the intercept and K explanatory variables.

Assuming that the last or, Mth , category of the dependent variable is the reference category, the equations are of the form:

$$Log\ O1 = \alpha 1 + \beta 11\ X1 + \beta 21X2 + - - - \beta k1Xk$$

$$Log\ O2 = \alpha 2 + \beta 12X1 + \beta 22X2 + - - - + \beta k2Xk$$

$$Log\ Om\text{-}1 = \alpha\ m\text{-}1 + \beta 1\ m\text{-}1X1 + \beta 2\ m\text{-}1X2 + - - - \beta km\text{-}1Xk.$$

The Xs in the equation above are independent variables. As in logistic regression with binary response, parameters are estimated by maximizing the likelihood function for the sample responses on the dependent variable (Demaris, 1992). Also, the likelihood that the farmers use some land management practices to cushion the effect of climate change was also estimated using a probit model.

3.4.3 Methodological Limitations

This study was subject to some limitations due to time, resource, and capacity constraints. A key limitation was the inability to run the DSSAT 4 crop simulation model as planned. DSSAT 4 is an important tool for evaluating the vulnerability of cassava to climate change impacts and projecting implications of future climate scenarios. However, due to unresolved technical issues, I was unable to use the model to a completion within the thesis timeframe. The use of DSSAT 4 modelling could have provided a more robust evidence of climate change impacts on cassava production. However, as an alternative, a multiple linear regression analysis was conducted to cushion its effect for purposes of making future climate projections on cassava land use, production, and yield. While not a complete substitute, this helped provide context around expected impacts.

Operating under a tight timeline for this research, a simple random sampling was used for the selection of farmers. Also, important insights into varietal performance under changing conditions could not be carried out due to time constraint, which may limit recommendations for climate-resilient varieties.

4.0 RESULTS AND DISCUSSION

4.1 Mann–Kendall Test and Sen's Slope Method: Trend of Increasing Mean Temperature

The Mann-Kendall trend test was used to analyze trends in annual mean temperature from 1980 to 2021 (Table 1). The results of the Mann-Kendall test on the temperature data showed a statistically significant increasing trend ($z = 4.6391$, $p < 0.001$). The positive z-statistic value indicates an upward trend over time in annual mean temperature. The extremely small p-value provides strong evidence to reject the null hypothesis of no trend. This suggests that annual mean temperature has been increasing over the study period.

Sen's slope was also estimated to quantify the magnitude of the trend. The Sen's slope value of 0.0162069 degrees per year indicates that on average, annual mean temperature has been rising at a rate of 0.0162069 degrees annually over the past 42 years. The 95% confidence interval for Sen's slope ranged from 0.01033333 to 0.02181818. Since this confidence interval does not include zero, we can say with 95% confidence that the true slope of the trend is not zero, and therefore the increasing temperature trend is statistically significant.

Both the Mann-Kendall test and Sen's slope estimate provide robust evidence that there has been a statistically significant increasing linear trend in annual mean temperature from 1980 to 2021. On average, temperatures have risen by about 0.02 degrees every year over this study period. This has important implications for climate change impacts and adaptation planning in the region.

Therefore, the trend analysis detected clear warming trends in historical temperature data using distribution-free non-parametric tests, adding confidence to observed climate trends in the area.

Table 1: Trend analysis of Annual Mean Temperature (1980 – 2021)

Test	Statistics	P-Value	Slope Estimate	Confidence Interval
Mann Kendal Trend Test	**Z = 4.6391**	**P < 0.001**		
Sen's Slope			0.0162069 °C/year	0.01033333 to 0.02181818 °C/year

4.2 Assessment of the Variability in Cassava Land Use, Production and Yield in Nigeria between 1980 and 2021

The variability in CLU, production, and yield were studied for 42 years spanning 1980-2021. Results showed significant variations in CLU, production and yield over the last 42 years.. Figure 13 uses land area data from 1980 to 2021 to visualize how the amount of land devoted to cassava farming in Nigeria has changed significantly from year to year, almost doubling within that period (Figure 13). The horizontal x-axis represents the years, while the vertical y-axis measured the land area in hectares (ha). The blue data points indicate the actual land area devoted to cassava farming for each year. CLU fluctuated considerably from year to year, ranging from its minimum of 1.08 million ha in 1985 to its maximum of 9.98 million ha in 2021. The red line illustrates the line of best fit which showed a statistically significant ($p<0.01$) upward trend over time despite the yearly fluctuations. It shows a generally increasing pattern, with some variations. The land area for cassava production increased progressively from 1.2 million hectares in 1980 to 3.3 million hectares in year 2000 and to a peak of 9.98 million ha in 2021.

The variability in cassava production in Nigeria between 1980 and 2021 is shown in Figure 14. There was a highly significant increase ($p<0.01$) in cassava production between 1980 and 2000 (Figure 14a), and also within the last two decades (Figure 14b) due to increase in land area under cultivation with time. Both graphs show statistically significant increasing trends within the study periods with very high coefficient of determination (R2>0.85) implying greater than 85% linear association between production quantity and time, and that cassava production for the next 2-3 decades can be reliably predicted. Production varied widely from year to year and could have been influenced by exponential rise in Nigeria’s population from about 72.95 million in 1980 to over 200 million in 2021. The positive slope of the regression line suggests that for every unit change in year, average cassava production increased by 1 million tonne during these periods (Figures 14a,b).

The annual yearly variation in cassava yields are shown in Figures 15a (1980 – 2000) and Figure 15b (2001 – 2021). Figure 16a shows fluctuations in cassava yield with very slow rate of increase within the 20-year period. The regression line is nearly flat, indicating little overall change in average yields during this period despite an increase in cultivated area. The positive slope of the regression line suggests that average yields increased slowly but steadily over these two decades.

In contrast, there was a significant decline ($p<0.01$) in cassava yield between 2011 and 2021 after a steeply increase in yield between 2001 and 2010 (Figure 15b). Yields varied widely from year to year with an upward shift from 9583.3 – 9700.0 kg/ha (slow rise), 9601.2 – 12215.5 kg/ha (steep rise) and then a downward shift from 11210.8 – 5835.8 kg/ha (drastic decline) between the years 1980 and 2000, 2001 and 2010, and 2011 and 2021, respectively. On the average, the last two decades under review experienced a downward trend. The negative slope of the regression equation in Figure 15b implies that average yield of cassava decreased steadily within the last two decades. The decline in cassava yield per ha despite the increase in cultivated land area could be attributed to a number of factors including use of low yielding varieties, loss of soil fertility, pest and diseases, leaching of soil nutrients, poor management, poor access to improved planting materials like stem cuttings and fertilizers, and covid-19 pandemic and post covid-19 era (2019 – 2021) which recorded the lowest yields (Terry and Hahn, 1980; FAO, 2000).

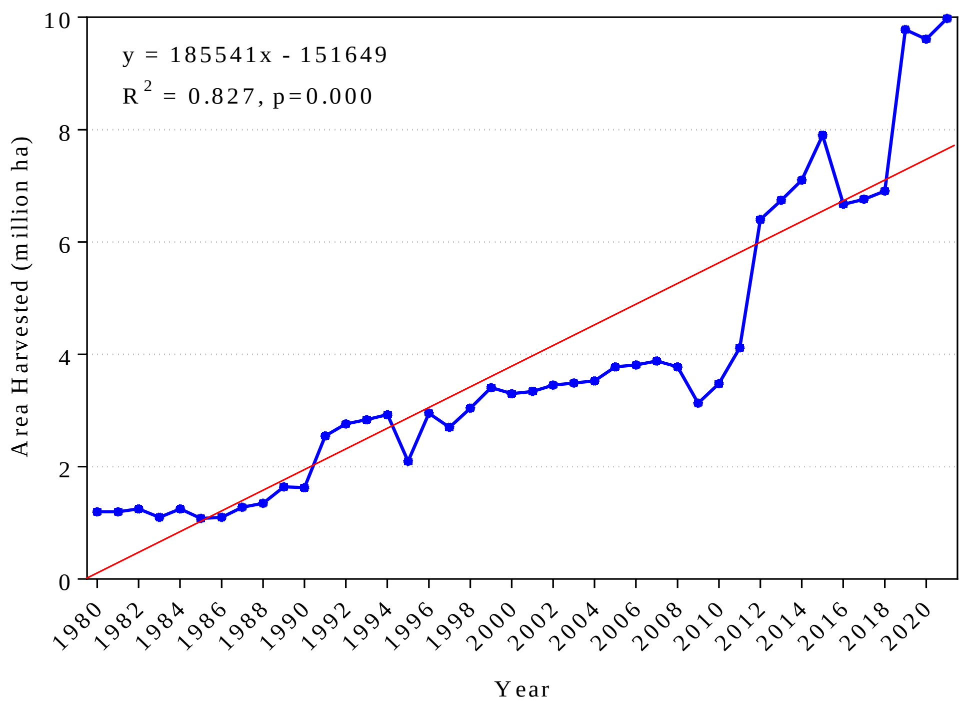

Figure 13: Variability in land use for cassava production between 1980 and 2021

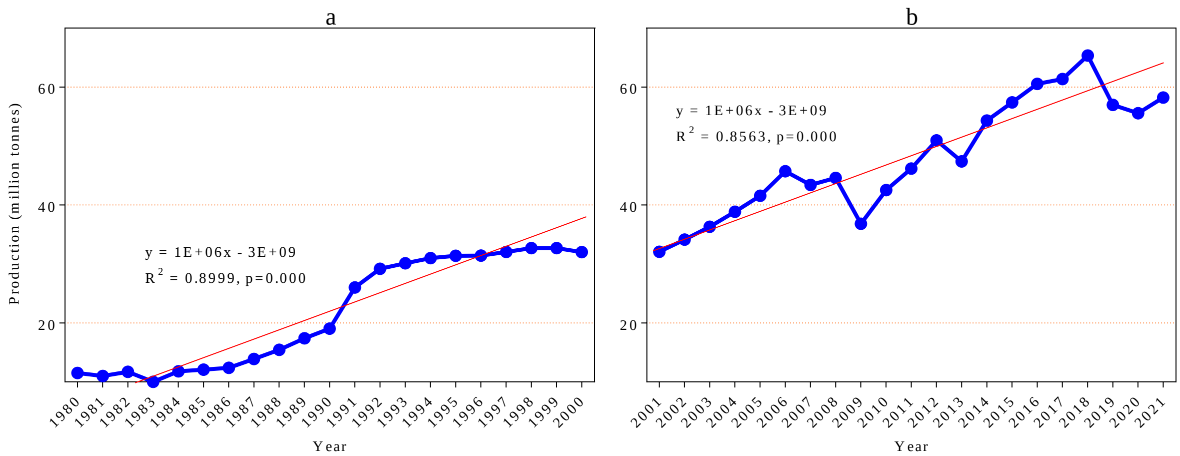

Figure 14: Variation in average annual production of cassava between 1980 and 2021. a: cassava yield between 1980 and 2000; b: cassava yield between 2001 and 2021

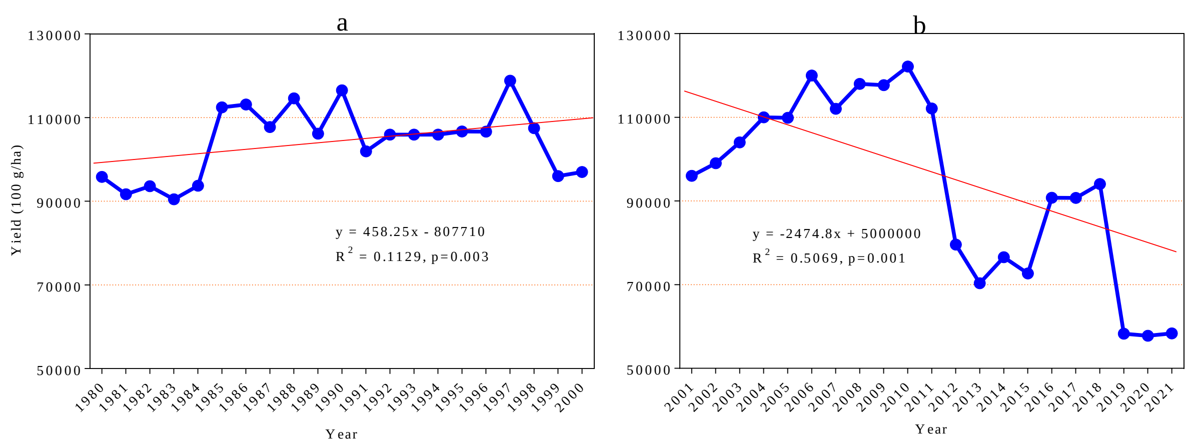

Figure 15: Variation in average annual yield of cassava between 1980 and 2021. a: cassava yield between 1980 and 2000; b: cassava yield between 2001 and 2021

4.3 Assessment of the Variability in Temperature and Rainfall in Nigeria between 1980 and 2021

Temperature variability in Nigeria within the 42 years under study is shown in Figure 16. The results showed a highly significant ($p<0.01$) increase in annual minimum (Figure 16a), maximum (Figure 16b), and average (Figure 16c) over the years. The lower limits ranged from 20.34 –

21.94 °C, the upper limits ranged from 32.49 – 33.83 °C, while the average temperature ranged from 26.39 – 27.86 °C. The lowest average annual temperature was recorded in 1989 (26.39 °C) while the highest was recorded in 2010 (27.86 °C). The slope of the regression line indicates that for every unit change in year, average annual temperature increases by 0.018 °C with about 48.28% linear association between year and temperature which indicates 48% predictability accuracy.

The trend analysis of the average annual variation in precipitation between 1980 and 2021 is shown in Figure 17. Each point represents the average annual precipitation for that year. Higher points indicate more rainfall while lower points indicate less rainfall. The linear regression line of best fit (red line) shows the overall trend of precipitation over time. The graph shows a statistically significant ($p<0.01$) increasing precipitation with time. X-axis (horizontal) represents the years from 1980 to 2021 and the Y-axis (vertical) represents the precipitation. Over the past 40+ years, average annual precipitation has been increasing progressively although the year-to-year variability is high. Some years see much higher rainfall than others. In particular, the highest amounts of precipitation were recorded in 1991 (1260.87 mm), 1999 (1263.55 mm), 2003 (1277.44 mm) and 2019 (1296.78 mm) respectively, while the lowest amount was recorded in 1983 (888.06 mm).

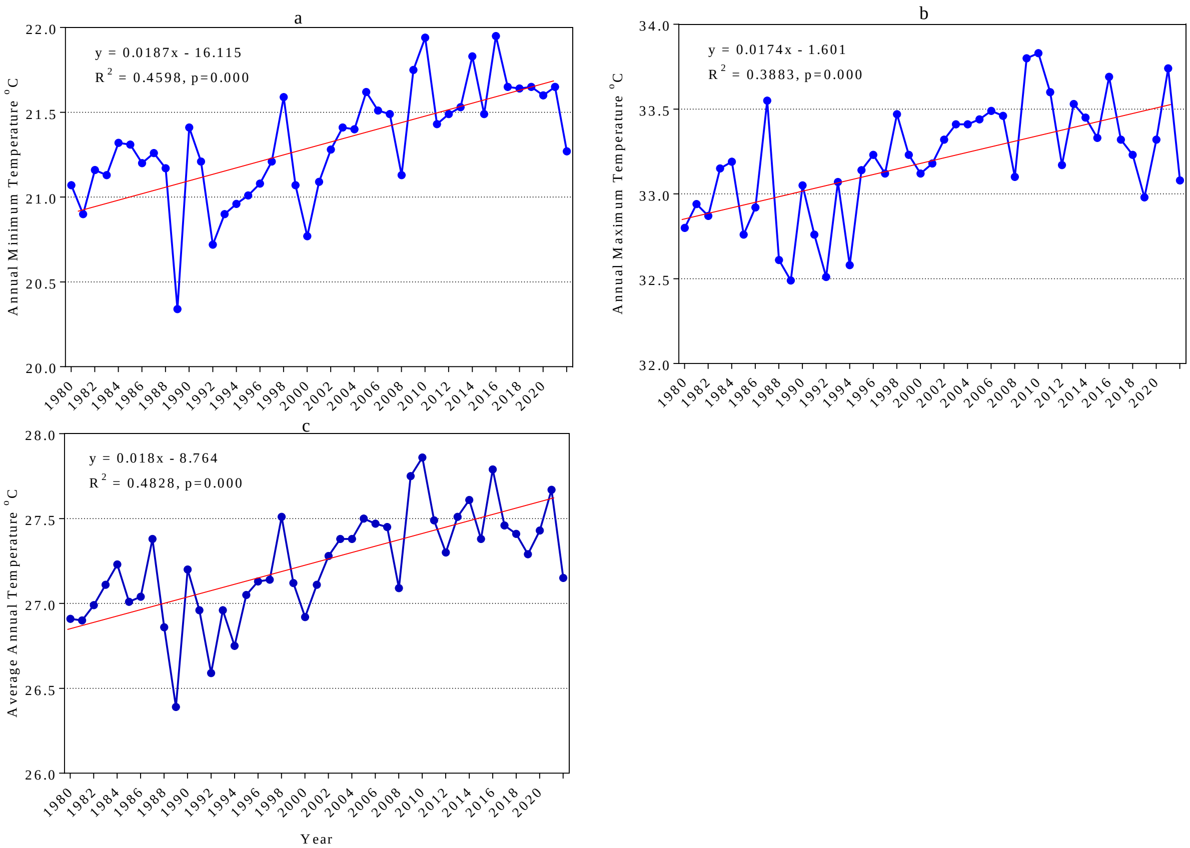

Figure 16: Variability in annual temperature between 1980 and 2021.

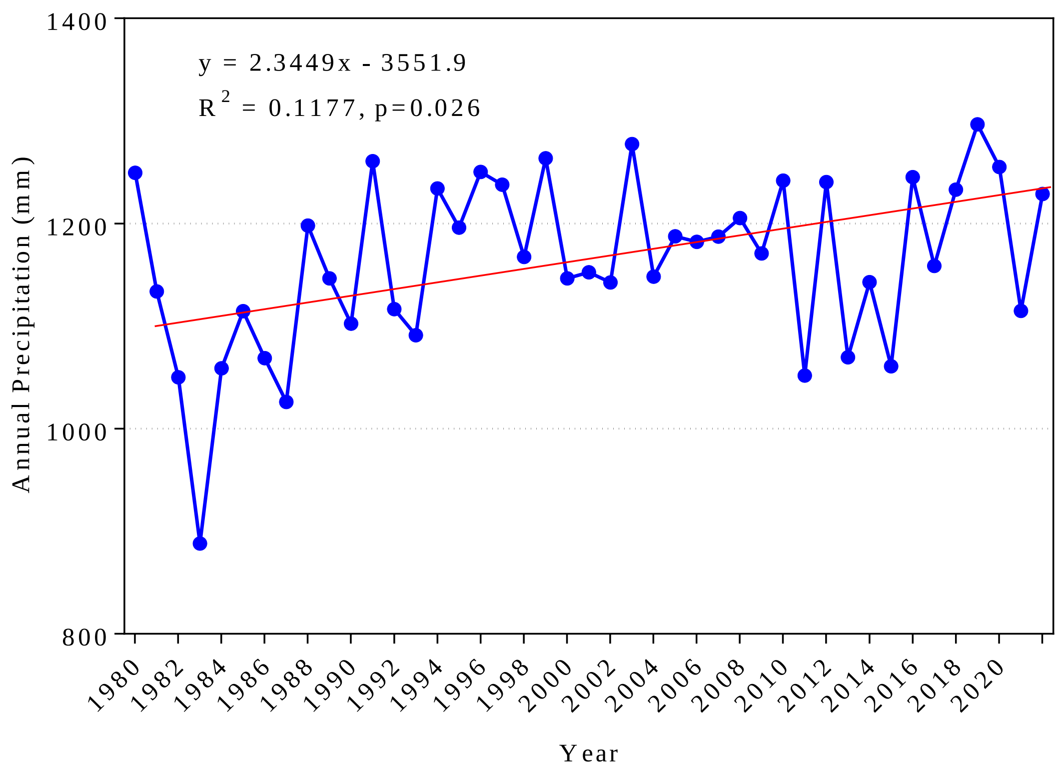

Figure 17: Variability in average annual precipitation of cassava between 1980 and 2021.

4.4 Assessment of the Impact of Climate Variables on Cassava Land Use in Nigeria between 1980 and 2021

The impact of climate predictor variables on CLU response is illustrated in Figures 18 and 19. A notable effect ($p<0.01$) of temperature on CLU was observed, showing a linear correlation of approximately 29.2% between the two. The positive regression coefficient of 4.26 indicates that for every unit change in temperature, area used for cassava farming increased by 4.26 million ha (Figure 18). In addition, the significant impact of temperature on CLU implies that CLU could be forecasted based on temperature with accuracy of around 29.2%. Conversely, the influence of precipitation on cassava land use was insignificant ($p>0.05$) although a positive trend with very low coefficient of determination (8.43%) which implies that land use for cassava production cannot be reliably predicted from precipitation data (Figure 19). Tolerance value nearing 1 and VIF value below 10 indicate that the predictors are distinct and satisfactory (Table 2). This result suggests that temperature plays a crucial role in predicting cassava land use patterns, highlighting the importance of considering climatic factors in land use planning and management strategies. Further research could explore how variations in temperature might impact CLU over different time scales and geographical regions, providing valuable insights for sustainable agricultural practices and resource allocation.

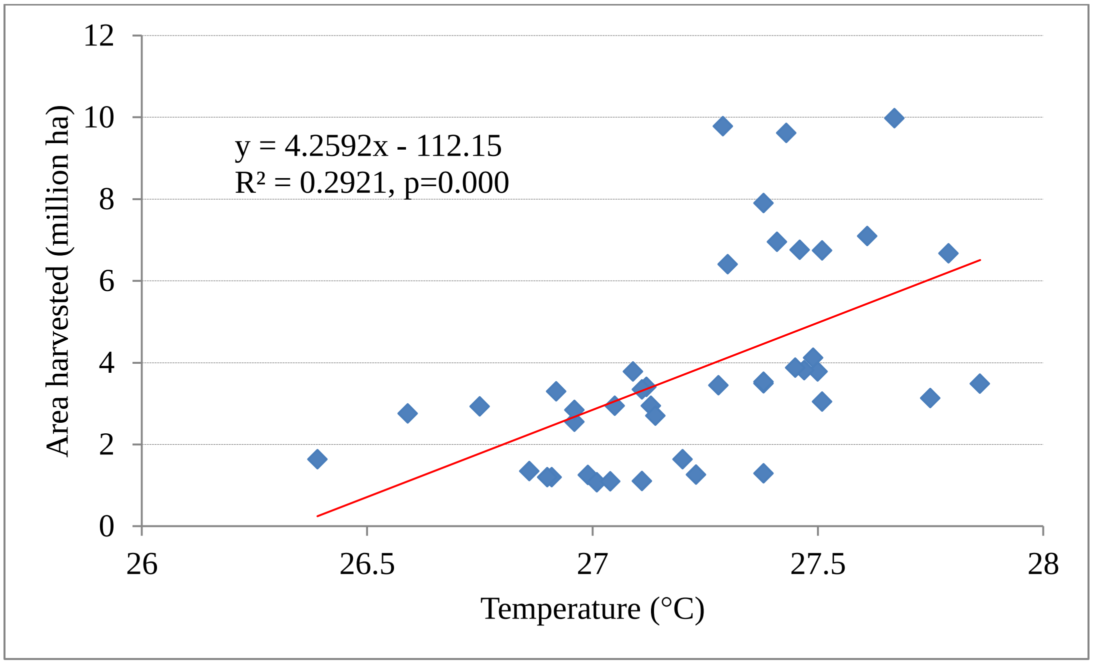

Figure 18: Effect of temperature variation on cassava land use between 1980 and 2021

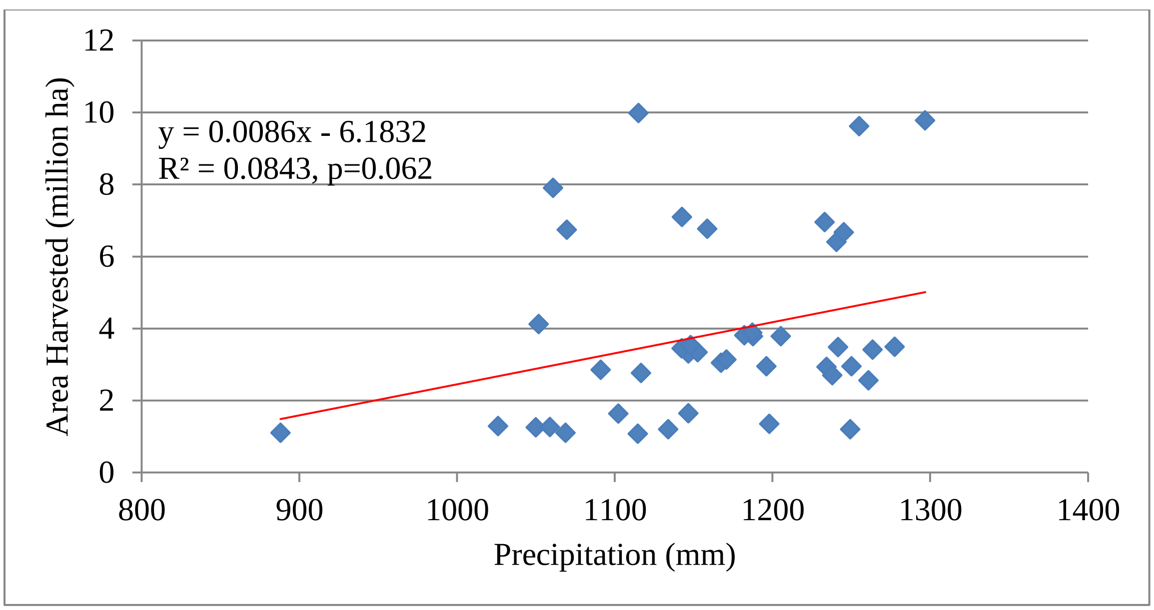

Figure 19: Effect of precipitation variability on cassava land use between 1980 and 2021

Table 2: Regression analysis of climate variables on land use for cassava (1980-2021)

	Precipitation	Temperature
a.	–6183189.40±5234481.97	–1121500196±28554412.70
b.	8630.56±4196.79	4259175.80±1048476.70
R^2	0.084	0.292
R	0.290	0.540
Tolerance	1	1
VIF	1	1
p-value	0.062	0.000

a: constant; b: regression coefficient; R^2: coefficient of determination; R: correlation coefficient

4.5 Assessment of the Impact of Climate Variables on Cassava Production in Nigeria between 1980 and 2021

The impact of temperature and precipitation on cassava production over the years showed significant variability. Temperature had a greater impact on cassava production ($p=0.000$, R2=0.402) (Figure 20) than precipitation ($p=0.013$, $R^2=0.146$) (Figure 21) within the 42 years under investigation, with both factors showing significant effects ($p<0.05$). The positive regression coefficient recorded in both factors indicates an increasing upward trend over time, such that a unit change in average annual temperature will cause a significant increase of 32.67 million tonnes in cassava production. Likewise, a unit change in precipitation will cause cassava production to increase by 74 268 tonnes. The results suggest that temperature and precipitation play crucial roles in influencing cassava production, as indicated by the low p-values of 0.000 and 0.013 respectively. In addition, higher coefficient of determination was recorded in temperature (40.20%) in contrast to precipitation (14.60%) which further emphasizes the greater impact of temperature on cassava production. Higher R^2 values indicate higher linear relationship between cassava production and temperature than with precipitation. Overall, both temperature and precipitation are important factors to consider in understanding and predicting cassava yields in Nigeria. Tolerance (1) and VIF (1) values showed that the variables were reliable (Table 3).

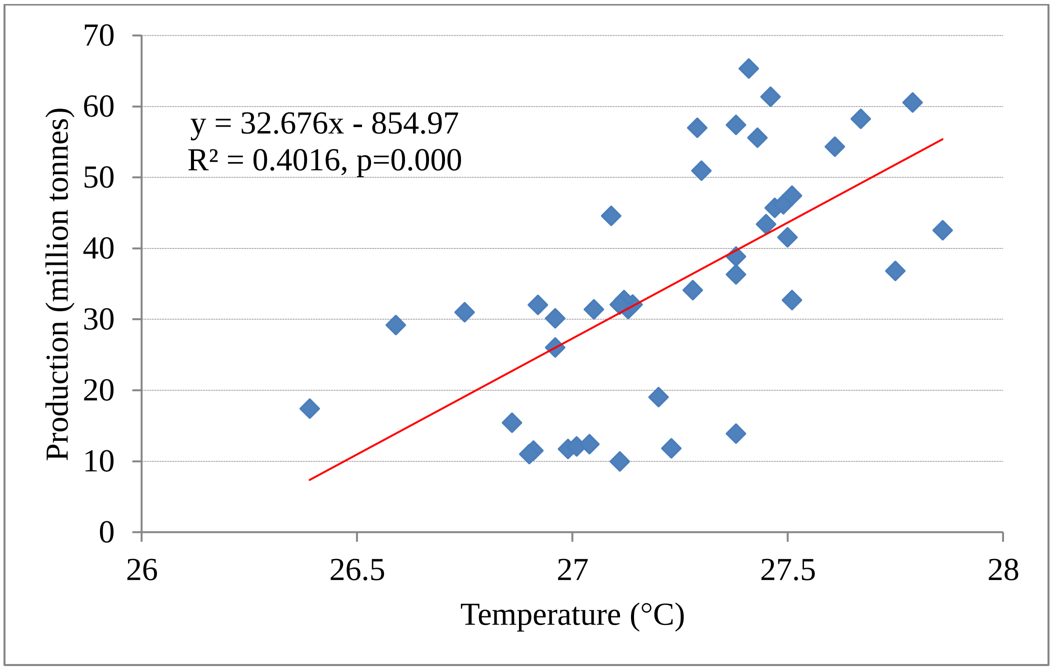

Figure 20: Regression analysis between annual temperature and cassava production between 1980 and 2021

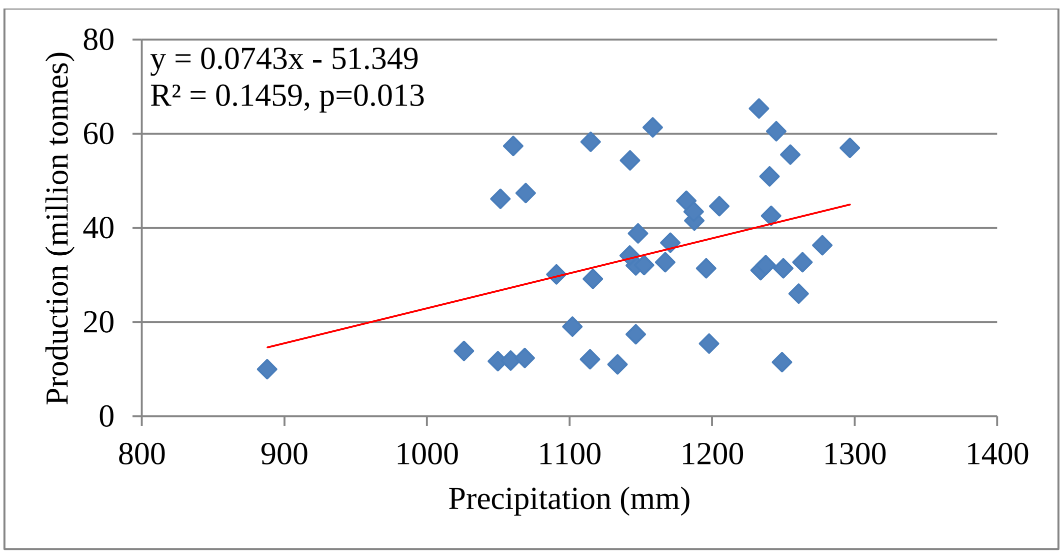

Figure 21: Regression analysis between annual precipitation and cassava production between 1980 and 2021

Table 3: Regression analysis of climate variables on cassava production (1980-2021)

	Precipitation	Temperature
a.	–51349071.87±33076907.65	–854968600.90±171767519.90
b.	74268.58±28415.40	32676188.12±6307054.52
R^2	0.146	0.402
R	0.382	0.634
Tolerance	1	1
VIF	1	1
p-value	0.013	0.00

a: constant; b: regression coefficient; R^2: coefficient of determination; R: correlation coefficient

4.6 Assessment of the Impact of Climate Variables on Cassava Production in Nigeria between 1980 and 2021

The impact of climate predictor variables on cassava yield response were illustrated in Figures 22 and 23. Temperature and precipitation showed no significant impact on cassava yield ($p>0.05$), indicating that cassava yield cannot be forecasted based on either temperature or precipitation. However, the trend analysis showed a non-significant decrease in cassava yield with increase in temperature. This suggests that other factors not considered in this study may play a more critical role in determining cassava yield (Figure 22). The trend analysis between precipitation and yield showed a non-linear relationship between them (R^2 = 0.000) with a flat line of best fit (Figure 23). Tolerance and VIF values were also consistent with earlier reports (Table 4). Further research is needed to identify and understand these additional variables that influence cassava yield implying that cassava yield is a complex factor. By gaining a more comprehensive understanding of the factors affecting cassava yield, researchers and farmers can develop more effective strategies to improve cassava productivity and ensure food security in the face of changing climatic conditions.

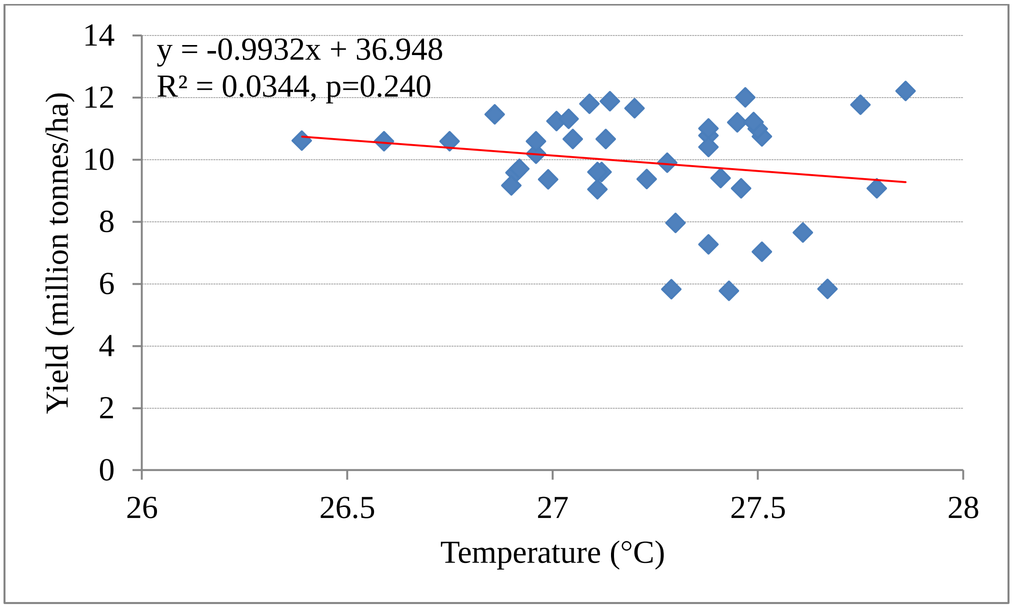

Figure 22: Impact of mean annual temperature on cassava yield in Nigeria (1980-2021)

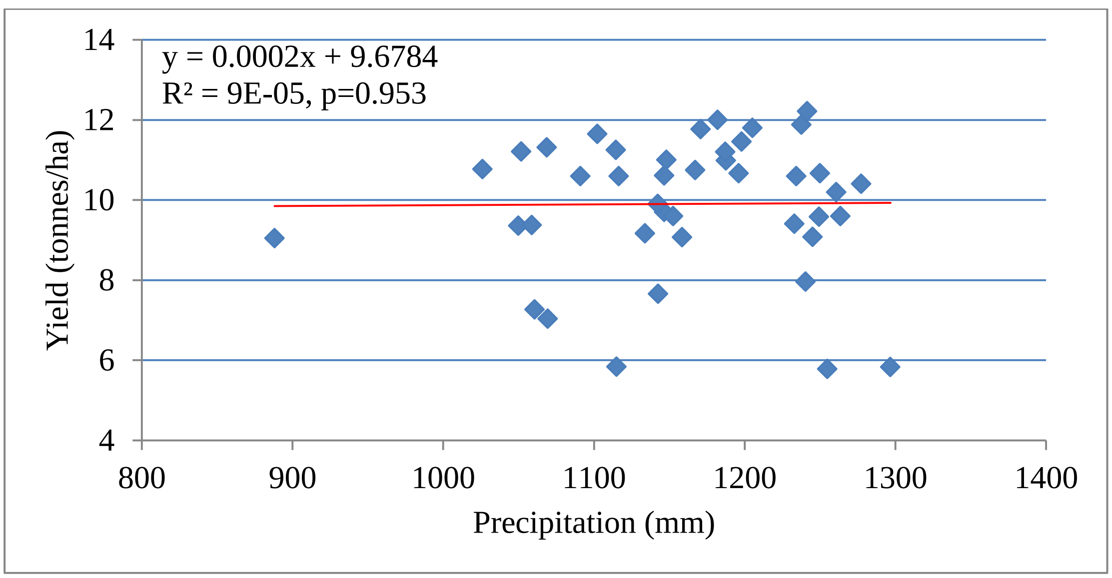

Figure 23: Impact of mean annual precipitation on cassava yield in Nigeria (1980-2021)

Table 4: Regression analysis of climate variables on cassava yield (1980-2021)

	Precipitation	Temperature
a.	96784.24±37172.87	–369480.12±226630.60
b.	1.913.00±31.934	9932.09±8321.55
R^2	0.000	0.034
R	0.009	–0.185
Tolerance	1	1
VIF	1	1
p-value	0.953	0.240

a: constant; b: regression coefficient; R^2: coefficient of determination; R: correlation coefficient

4.7: Assessment of correlation matrix among cassava production and climate variables

Correlation analysis among climate variables and cassava land use (CLU) yield, and production is shown in Table 5. Land use for cassava cultivation in terms of area harvested had significant positive linear relationship with production quantity ($p<0.01$, $r=0.905$), temperature ($p<0.01$, $r=0.540$), and precipitation ($p<0.031$, $r=0.29$). In contrast, it had highly significant negative correlation ($p<0.01$, $r= -0.748$) with cassava yield. This analysis suggests that an increase in either of land area for cassava cultivation, temperature, or precipitation will result in an increase in the tonnage of cassava produced. In contrast, an increase in land area under cultivation will result in reduced yield per hectare due to a number of factors such as reduced efficiency in management personnel, increased cost per unit stand, rationing of farm inputs, increased build-up of pest and diseases etc. In addition to been negatively correlated to CLU, cassava yield was also negatively correlated with production quantity ($r= -0.439$, $p=0.002$) and temperature ($r= -0.185$, $p=0.120$) but had a weak positive but non-significant correlation with precipitation ($r=0.009$, $p=0.476$). The notable negative correlation with cassava yield highlights a potential trade-off between maximizing production quantity and achieving high yields per unit area. The insignificant negative relationship between yield and temperature suggests that yield per hectare decreases with increase in temperature, although, this cannot be reliably predicted. However, previous studies have implicated increase in temperature above optimal to reduced tuberization and yield (Tengi et al., 2022). These findings shows the complex relationship between climate variables and cassava land use decisions, emphasizing the need for targeted strategies to optimize both production and yield in cassava farming systems.

4.8: Assessment of the combined effect temperature and precipitation on CLU, production and yield

The combined effect of temperature and precipitation on CLU, production, and yield is presented in Table 6. CLU was notably influenced by the combined effect of temperature and precipitation (p=0.000, R^2=0.354). Likewise, cassava production was also significantly impacted by the combined effect of temperature and precipitation (p=0.000, R^2= 0.513). Contrarily, cassava yield was not significantly affected (p=0.50, R^2=0.035) by the interaction of temperature and precipitation within the 42 years of the study. These results suggest that while CLU and cassava production are strongly influenced by the interaction of temperature and precipitation, cassava yield does not show a significant response to these environmental factors which could be implicated on a number of factors including the persistent decline in soil fertility over time (Akamigbo, 2000; Yakubu and Mallo, 2019), pest and diseases outbreak (Eni et al. 2021), poor agricultural inputs like fertilizer, manure, high cost of improved planting materials, destruction of farm produce by the dreaded Fulani herders (Ezeh et al. 2021). The highly significant combined effects of both climates variables on CLU and cassava production implies that both variables are useful in making future projections in CLU and production using the multiple linear regression equations:

$$CLU = 7431.56P + 4106604.72T - 116623693$$

$$CP = 65118.48P + 31339295.59T - 894168834.10$$

Where: CLU is cassava land use, P is annual precipitation, T is annual temperature, and CP = cassava production.

Table 5: Correlation matrix among cassava land use and climate variables

	Land Use	Yield	Production	Temperature	Precipitation
Land Use	1	-0.748**	0.905**	0.540**	0.290*
Yield		1	-0.439**	-0.185	0.009
Production			1	0.634**	0.382*
Temperature				1	0.072
Precipitation					1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 6: Combined effect of climate variables on cassava land use, production and yield (1980-2021)

	Area Harvested	Production	Yield
a.	–116623693	–894168834.10	366565.21
bP	7431.561±3836.031	65118.48±21794.24	4.84±31.863
bT	4106604.72±1017209.13	31339295.59±5779233.45	–10031.49±10031.50
R^2	0.354	0.513	0.035
R	0.595	0.716	0.187
Tolerance	0.996	1.006	0.994
VIF	1.006	0.994	1.006
p-value	0.000	0.000	0.50

a: constant; bP: regression coefficient for precipitation; bT: regression coefficient for temperature; R^2: coefficient of determination; R: correlation coefficient

4.9 QUALITATIVE ANALYSIS

4.9.1 Scenarios of Climate Change in Cassava Production: Challenges in Nigeria

The survey found that on the average, the farmers practicing cassava based cropping systems were 51.71 years old. The typical household size for these farming households was 7.14 people. The farmers had spent an average of 8.84 years in formal schooling or education. The average farmer in the sample was in their early 50s, came from moderately large households of over seven people, and had primary education equivalent to nearly 9 years of schooling.

Table 7: Value means and standard deviation of the variables used in the model

Variable	Mean	Standard Deviation	Minimum	Maximum
Age of household head	51.71	14.34	14	98
Age2	2879.30	1500.30	196	9604
Number of years in school	8.84	5.37	0	24
Household Size	7.14	3.38	1	28
Males over age 15	2.42	1.36	0	7
Gender of respondent household head– Malesb	0.84	0.37	0	1
Agric Production c	0.50	0.50	0	1
Amount lost due to climate change	164,318.8	290,761.6	400	2700000
Access to information on climate change	0.806	0.396	0	1
Occupation (1 if agriculture, 0 otherwise)	0.505	0.500	0	1

Source: Field survey data
a 1 if land management score is greater than 50%; 0 otherwise.
b 1 if Gender is male ; 0 otherwise (female)
c 1 if involved in agric production activity (crop and livestock); 0 otherwise

4.9.2 Knowledge and Adaptation to Climate Change by Cassava Farmers

Based on the survey results, the majority (over 90%) of respondents noticed significant changes in both temperature and rainfall. Most (over 96%) respondents had also heard of climate change prior to being interviewed. However, as shown in Figure 24, among those who had heard of climate change before, nearly half (45.71%) reported knowing only a little about climate change. While awareness of climate change was high, the survey suggests knowledge levels about climate change remain relatively low, even for those who had heard of the concept previously. The farmers were aware climate changes were occurring but the majority reported having only surface-level knowledge about the phenomenon of climate change itself.

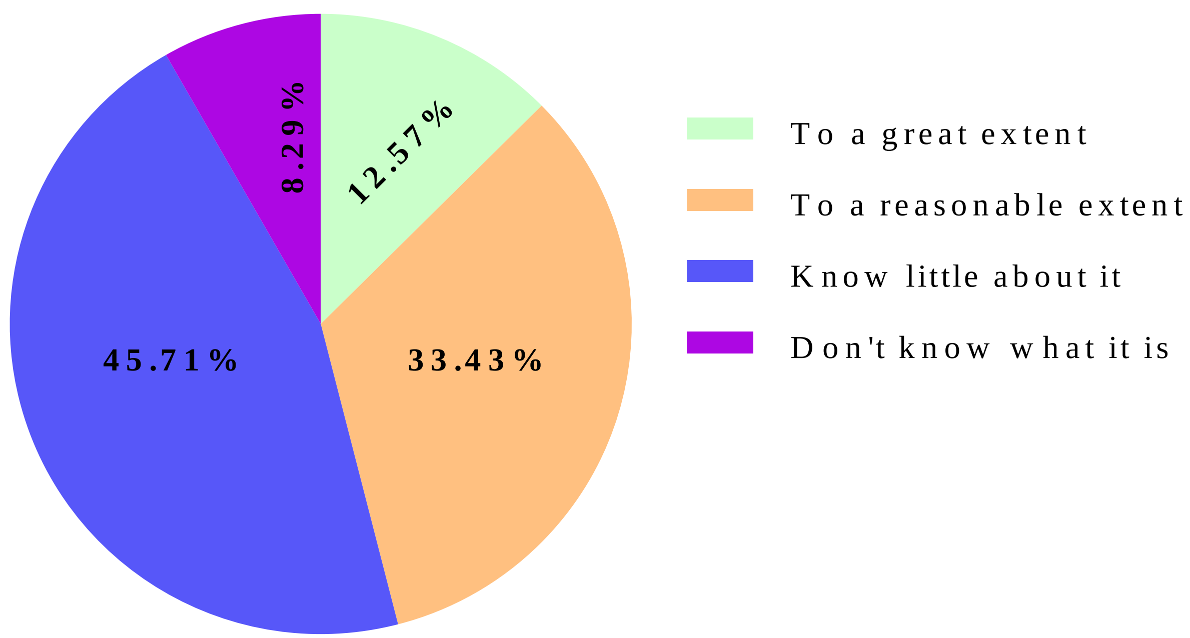

Figure 24: Extent of knowledge of climate change by respondents who have heard about it

The majority (80.56%) of respondents reported obtaining information about climate change. Only 19.44% said they do not get information about climate change. Figure 25 shows the different channels through which farmers receive climate change information. Most farmers are accessing information about climate change, and the primary pathways or sources they rely on to receive information and updates regarding climate change were illustrated in Figure 25.

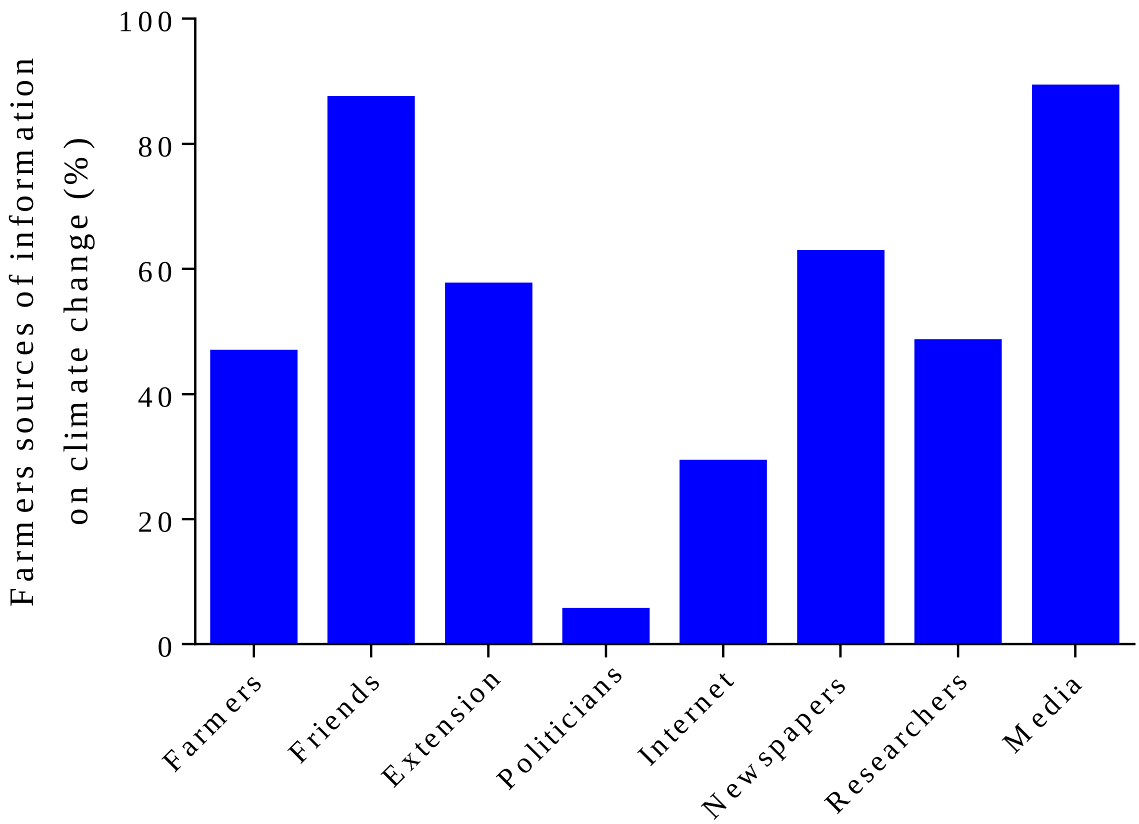

Figure 25: Famer's Sources of Information on Climate Change

The majority (88.74%) of farmers obtain climate change information through media agencies. The second most common source is friends, with 86.89% getting information that way. Agricultural extension workers are also a major source, providing information to 58.07% of farmers. Politicians are the least utilized source of climate change information, reaching only 4.06% of farmers. Media and interpersonal networks like friends are the primary channels farmers use to learn about climate change. Extension workers also play an important role, while politicians have very little influence as an information source on this topic for these farmers. The vast majority (96.27%) of farmers observed delayed onset of rains, over two-thirds (68.81%) reported experiencing too much rain, 66.29% observed higher temperatures (Figure 26). Only a very small minority (2.24%) reported no changes in climate conditions. The farmers overwhelmingly perceived and reported changes in key climate variables like rainfall patterns and temperatures. Delayed rains were nearly a universal observation, while the majority according to the survey results also experienced excessive rainfall and warming temperatures.

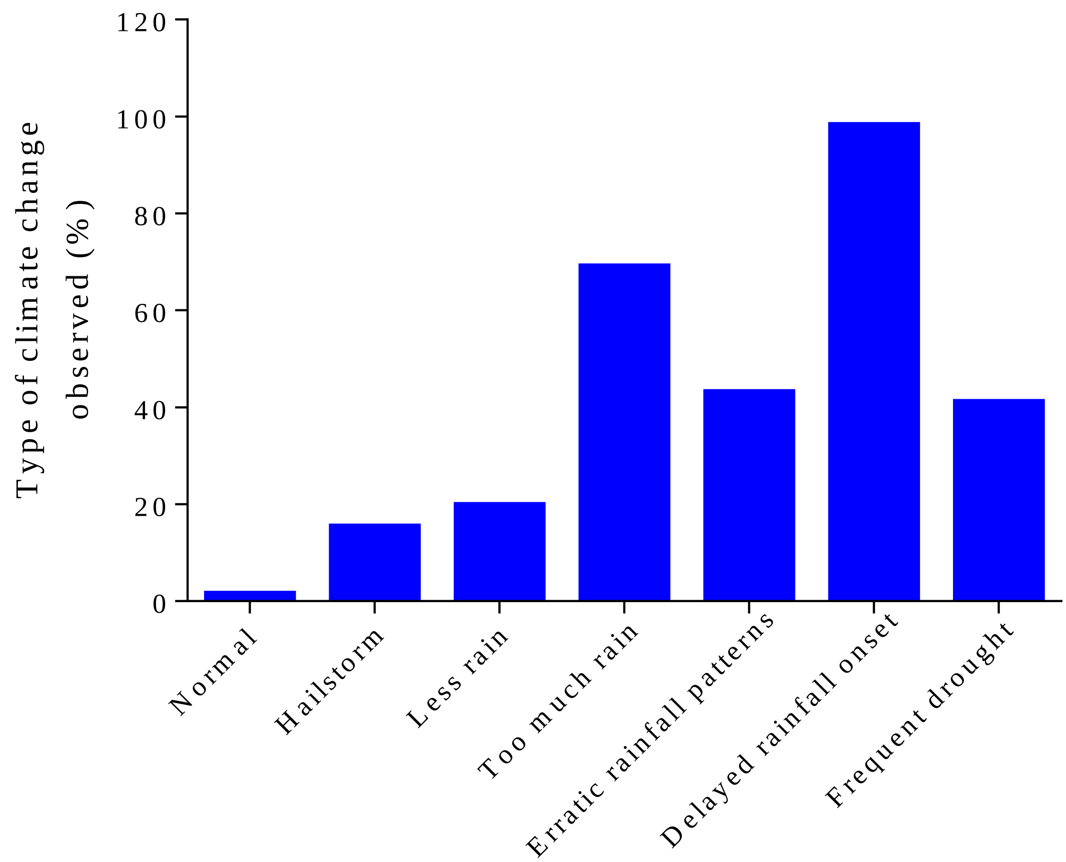

Figure 26: Type of Climate Change Observed

The major negative outcomes reported from climate change were flooding (70.29%), decrease in crop yields (64.1%), food price increases (61.87%), and food shortages/insecurity (58.92%). Very few farmers (3.48%) observed any positive impacts like increased crop yields (Figure 27). The category of people mostly affected by climate change is shown in Figure 28. The overwhelming majority of the respondents (77.34%) opined that all categories of people are affected by climate change. The farmers perceived significant negative impacts on agriculture and food security from climate change, including reduced production, higher prices and shortages. Figure 29 indicates that climate change effects cut across all demographics according to most respondents. Very few observed any beneficial outcomes from observed climate trends.

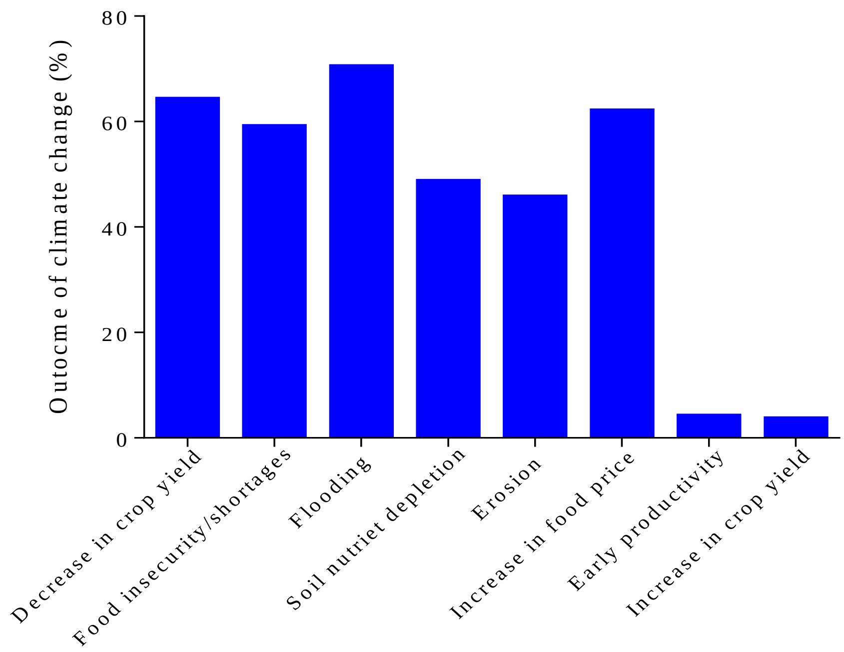

Figure 27: Outcome of Climate Change

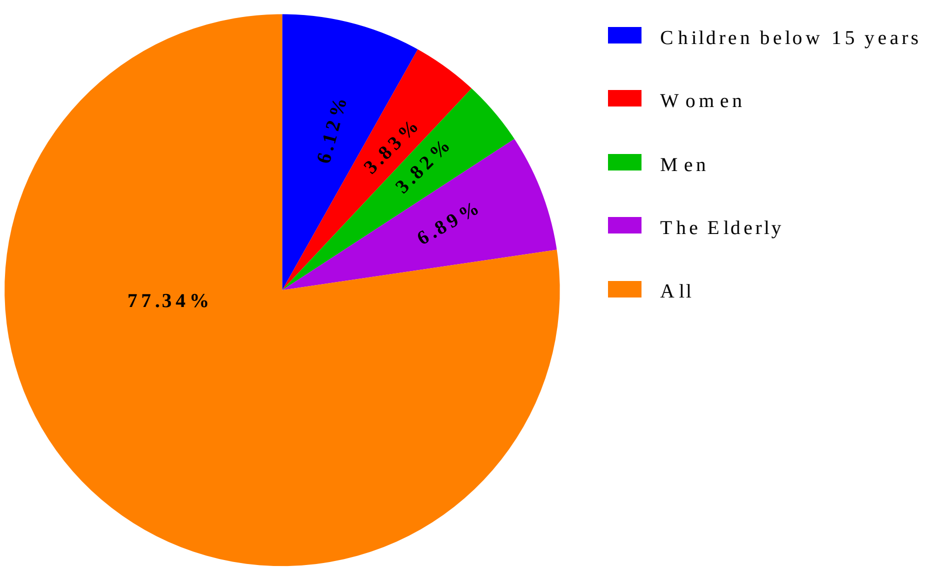

Figure 28: Category of People Mostly Affected by Climate Change

The largest proportion of farmers (45.05%) bought food to cope with climate change effects. The second most common action was starting new farm management practices, adopted by 37.62% of farmers. About 29.95% of people started non-farm activities as another adaptation strategy. Very few (0.99%) participated in food-for-work programs. Purchasing food was the most widespread coping mechanism, while changing agricultural practices and diversifying income sources through non-farm work were also commonly utilized adaptation responses based on the results in Figure 29. Participation in food assistance programs was minimal (1.98%).

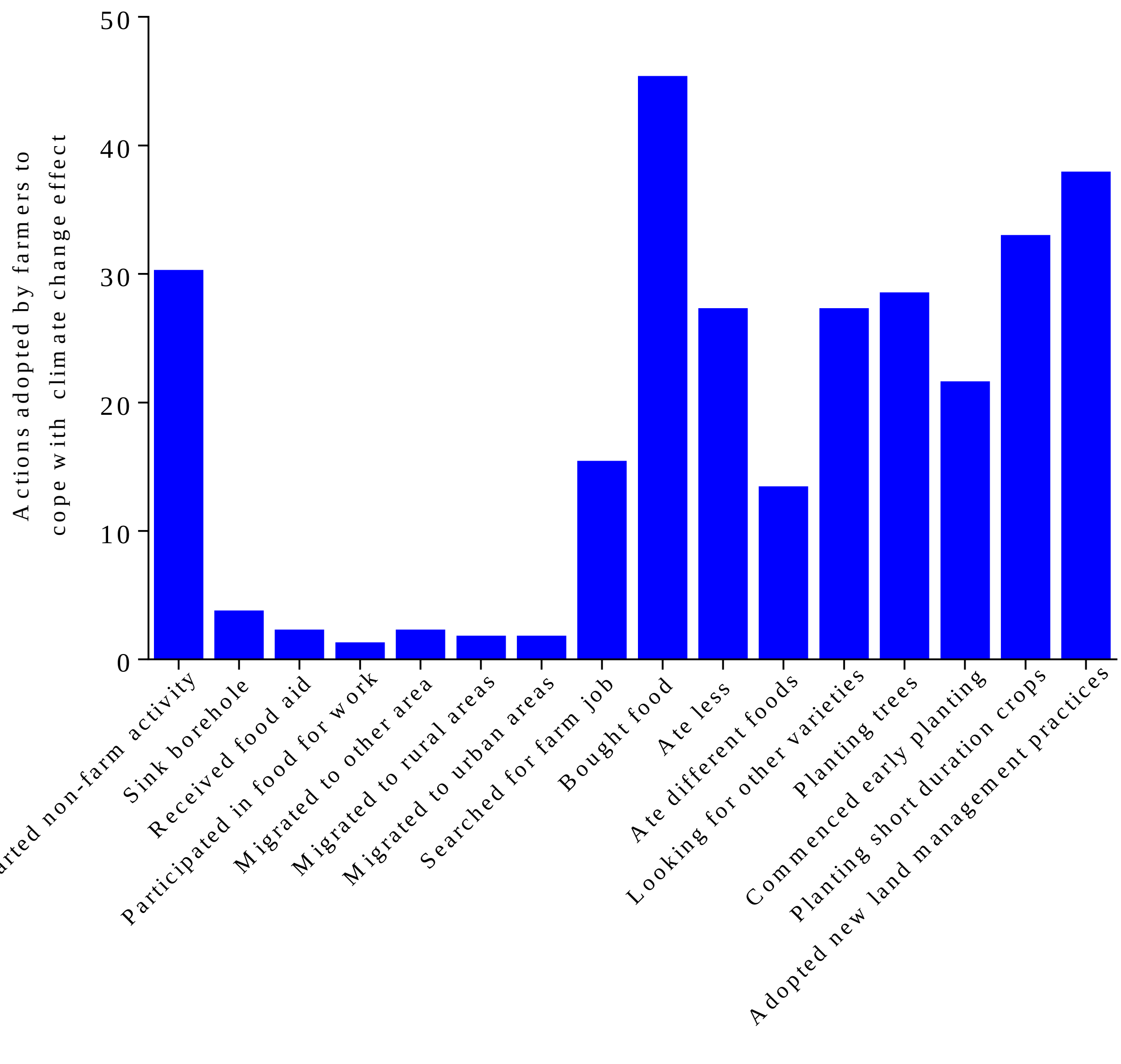

Figure 29: Actions taken by the farmers to cushion the effect of climate change

4.9.3 Adaptive Farm Management Strategies Used by the Farmers in Cushioning the Effects of Climate Change in Cassava Farming

The major farm management adjustments made by farmers include planting pest- and disease-resistant crop varieties (56.68%), using crop varieties that are well-acclimatized to local conditions (48.27%), proper preservation of seeds and seedlings for planting (49.75%), mixed farming/intercropping practices (49.01%), sourcing information about climate change impacts and responses (47.03%) (Table 8). The top adaptations were centered on using improved crop varieties that can better withstand stresses, maintaining high quality planting materials, diversifying production systems, and staying informed on climate topics. These represent the major farm management adjustments made by farmers (Table 8).

Table 8: Adaptive Farm Management Strategies Used by the Farmers in Cushioning the Effects of Climate Change in Cassava Farming

S/No	Adaptive Strategies	% of farmers using the practice
1	Planting pest and disease resistant crops	56.68
7	Use of early maturing crop varieties	50.50
9	Proper preservation of seeds and plant seedling used for planting	49.75
12	Mixed farming practices	49.01
2	Use of crops varieties that are well acclimated	48.27
6	Increase in number of weeding of cropped land	47.28
15	Listening to information about climate change	47.03
5	Use of chemicals like herbicide, insecticide	38.61
8	Protection of water sheds and mulching	34.90
17	Changing harvesting dates	32.18
13	Change of planting date	31.93
19	Processing of crops to minimize post-harvest losses	31.93
16	Changing the timing of land preparation	30.69
14	Use of recommended planting distance	26.73
11	Reducing access to eroded and erosion prone area	25.99
4	Reforestation/Afforestation	25.25
20	Use of windbreaks/shelter belts	21.04
10	Use of weather-resistant variety	20.05
3	Use of irrigation system/water storage	8.91
18	Out migration from climate risk areas	2.48

Table 9 provides more specific information about the land management practices adopted by the 38% of farmers who reported utilizing land-based adaptation strategies in response to climate change impacts. The majority of farmers (74.34%) keep their land under fallow as an adaptation strategy. Most farmers (83.55%) also mulch or use surface cover on their land. Intercropping is another widely used approach, practiced by 72.37% of farmers. Using farm yard manure on fields is another common adaptation, adopted by 60.53% of farmers. The results show that keeping land fallow, mulching/surface covering, intercropping, and applying manure are the land management practices used by the highest proportions of farmers as a means of coping with climate change impacts according to the data presented.

Table 9: Percentage of Farmers Using Different Types of Land Management Practices to Adapt to Climate Change

S/No	Land management practice	% of farmers using the practice
1	Mulching/surface cover	83.55
19	Fallowing	74.34
12	Intercropping	72.37
10	Crop rotation	63.16
6	Increased Fertilizer	62.50
9	Cover crops	61.84
5	Farm yard manure	60.53
16	Erosion control	39.47
14	Removal of unwanted bush	38.16
8	Agroforestry	36.84
15	Soil improvement	35.53
4	Composting	34.87
11	Crop rotation with legumes (nitrogen fixing)	34.21
17	Replenishing soil fertilizer	26.32
18	Border cropping	7.24
13	Enclosure of the land	2.63
2	Trash line	1.97
7	Water harvesting	1.97
3	Infiltration ditches	1.32

4.9.4 Constraints to Climate Change Adaptation

Lack of information, reported as a very great constraint by the highest proportion (53.30%) of farmers. No subsidies for agricultural inputs, which 40.66% said constrained adaptation to a very great extent. Irregularity of extension services, seen as a very great constraint by 30.69% of farmers. Lack of access to improved crop varieties, cited by 30.87% as a major limitation. Poor government attention to climate change problems, identified by 31.55% as constraining adaptation to a very great degree. The most significant barriers according to the largest shares of farmers were insufficient information, lack of input subsidies, irregular extension, limited seed access, and inadequate government support for climate issues.

Table 10: Constrains to Climate Change Adaptation

S/No	**Problems**	**VGE**	**GE**	**TSE**	**LE**	**NE**
1	Lack of information	53.30	26.65	8.12	11.42	0.51
2	Ineffectiveness of indigenous strategies	21.43	40.56	24.49	10.46	3.06
3	Irregularity of extension services	30.69	27.62	19.69	16.11	5.88
4	No subsidies for inputs	40.66	33.50	15.35	7.16	3.32
5	Lack of access to improved crop varieties	30.87	29.59	31.63	5.10	2.81
6	Absence of water management techniques	23.77	32.30	21.71	17.05	5.17
7	Poor government attention to climate problems	31.55	30.03	26.46	8.14	3.82
8	Low awareness level	26.48	33.42	29.82	5.66	4.63
9	Limited knowledge on adaptation measures	22.16	27.58	35.57	11.86	2.84
10	Cultural influence	14.10	14.36	18.21	24.10	29.23
11	Taboos	9.04	9.30	21.45	22.48	37.73
12	Inability to give up traditional values	8.46	20.00	23.59	21.28	26.67
13	Low institutional capacity	20.67	18.86	33.59	17.31	9.56
14	Absence of government policy on climate change	19.74	28.83	33.25	13.51	4.68
15	Others, specify	22.22	18.52	14.81	22.22	22.22

VGE: very great extent; GE: great extent; TSE: to strong extent; LE: less extent; NE: no extent

4.9.5 Determinants of Adaptation Strategies Used by Farmers to Cushion the Effect of Climate Change

The study analyzed actions taken by cassava farmers to cope with climate change impacts. It first determined the percentage of farmers taking different actions and then used probit analysis to identify variables influencing adaptation actions. Tables 11 and 12 present the results of the probit analysis. Table 11 shows the parameter estimates, while Table 12 shows the marginal effects. The adaptation actions considered were those practiced by approximately 30% of farmers. The specific actions analyzed were: starting non-farm activities, buying food, planting early-maturing crops, and using new land management practices. Probit analysis was used to determine what variables significantly influenced farmers' likelihood of adopting each of these four main adaptation responses to climate change. The study employed probit regression to identify factors affecting cassava farmers' decisions to undertake the key climate coping actions of non-farm work, food purchases, early varieties, and land techniques.

Table 11: Parameter Estimates of the Probit Model of Determinants of Actions Taken by Farmers to Cushion the Effects of Climate Change

Explanatory Variable	**Coefficient**			
	Started non-farm activity	Bought food	Planted early maturing crops	Started new land management practices
Age of Household head	0.028 (0.026)	0.040 (0.030)	0,151 (0.042)***	0.056 (0.030)*
Age2	0.0003 (0.0003)	-0.0005 (0.0003)	-0.0016 (0.0004)***	-0.0004 (0.0003)
Number of years in school	0.040 (0.015)***	0.038 (0.015)***	0.056 (0.015)***	0.059 (0.014)***
Household Size	0.036 (0.021)*	0.066 (0.021)***	0.064 (0.023)***	0.009 (0.021)
Occupation	0.016 (0.143)	0.043 (0.141)	-0.102 (0.150)	-0.212 (0.141)
Gender – Males	0.140 (0.214)	-0.307 (0.210)	0.024 (0.231)	-0.283 (0.206)
Grows cassava or otherwise	-0.076 (0.157)	0.667 (0.156)***	0.549 (0.171)***	0.297 (0.156)*
Constant	-0.564 (0.640)	-1.822 (0.668)	-5.226 (1.042)***	-2.388 (0.737)***

*, **, *** implies significance at 10%, 5% and 1% probability levels respectively, standard errors in parenthesis

Table12: Marginal Effects of the Probit Model of Determinants of Actions Taken by Farmers to Cushion the Effects of Climate Change

Explanatory Variable	**Coefficients**			
	Started non-farm activity	Bought food	Planted early maturing crops	Started new land management practices
Age of Household head	-0.010 (0.009)	0.016 (0.011)	0.052 (0.014)***	0.021 (0.011)*
Age2	0.00009 (0.00009)	-0.00019 (0.0001)*	-0.00053 (0.00014)***	-0.00017 (0.00011)
Number of years in school	0.014 (0.005)***	0.015 (0.006)***	0.0.19 (0.005)***	0.022 (0.0054)***
Household Size	0.013 (0.007)*	0.026 (0.008)***	0.022 (0.008)***	0.0032 (0.0079)
Occupation	0.005 (0.049)	0.017 (0.056)	-0.-35 (0.051)	-0.080 (0.053)
Gender – Males	0.047 (0.069)	-0.122 (0.083)	0.0085 (0.079)	-0.109 (0.081)
Grows cassava or otherwise	-0.076 (0.157)	0.667 (0.156)***	0.549 (0.171)***	0.297 (0.156)*
Constant	-0.564 (0.640)	-1.822 (0.668)	-5.226 (1.042)***	-2.388 (0.737)***

Source: Calculations from field survey data. *, **, *** implies significance at 10%, 5% and 1% probability levels respectively, standard errors in parenthesis.

The results indicate that certain factors significantly impacted the likelihood of farmers taking specific actions to mitigate and adapt to the effects of climate change. The number of years spent in school and household size significantly influenced the probability of a farmer starting a non-farm job or activity. This suggests farmers who were in school for much longer, and thus had more education, were more likely to employ adaptive and mitigative practices. This also applies to farmers with larger household sizes. As shown in Table 11, the marginal effect demonstrates that the number of years a farmer spent in school influences the probability of them starting non-farm work as a way to cope with climate change impacts.

4.9.6 Determinants of Farm Management Practices Used by Farmers to Cushion the Effects of Climate Change

The survey also sought to determine the factors influencing the farm management practices utilized by farmers to adapt to climate change. The dependent variable was the selection of specific farm practices listed as explanatory variables in Table 13. These practices included: planting pest- and disease-resistant crop varieties, using early-maturing crop varieties, properly preserving seeds and seedlings for planting, employing mixed farming practices, utilizing crop varieties well-suited to the local climate, increasing weed removal on cropped land, and paying attention to information about climate change. Farmers who did not practice any of these adaptations served as the base variable for comparison.

Table 13: Description of Farmers' Adaptive Farm Management Practices

S/No	Adaptive farm management practices	Number of Farmers
1	Did Nothing	58
2	Planting pest and disease resistant crops	52
3	Use of early maturing crop varieties that are well acclimated	41
4	Proper preservation of seeds and plant seedling used for planting	45
5	Mixed farming practices	48
6	Use of crops varieties that are well acclimated	53
7	Increase in number of weeding of cropped land	69
8	Listening to information about climate change	38

4.9.7 Determinants of Level of Land Management Practices Used by Cassava Farmers to Cushion the Effect of Climate Change

Part of the survey aimed to identify the factors influencing farmers' use of specific land management practices under cassava cropping systems to mitigate climate change impacts. First, the number and percentage of land management practices employed by farmers was determined. Then, a probit analysis was conducted to uncover the variables that affected adoption of different land management practices. The marginal effects are displayed in Table 14. Only practices used by over 50% of farmers practicing land management were included in the probit analysis. The land management practices considered were: mulching/surface cover, farmyard manure application, increased fertilizer use, cover crops, fallowing, crop rotation, and intercropping.

Table14: Marginal Effects of the Probit Model of Determinants of Actions Taken by Farmers to Cushion the Effects of Climate Change

Explanatory Variable	**Marginal Effects (dy/dx)**						
	Planting pest and disease resistant crops	Use of early maturing crop varieties crop	Proper preservation of seeds	Mixed farming practices	Use of crops varieties	Increase in number of weeding	Listening to information about cc
Age of Household head	-0.00038 (0.0004)	-0.0006 (0.010)	0.0158 (0.0143)	-0.042 (0.015)***	-0.0159 (0.0164)	0.0209 (0.0208)	0.0043 (0.0051)
Access to information on cc	-0.0018 (0.0029)	-0.0193 (0.082)	0.0282 (0.1008)	0.0011 (0.1307)	0.0074 (0.1451)	0.148 (0.110)	-0.0493 (0.0779)
Number of years in school	-1.154x10-6 (0.00009)	-0.0060 (0.0056)	0.0043 (0.0067)	-0.0118 (0.009)	-0.0106 (0.009)	0.0281 (0.0097)***	0.0021 (0.0028)
Age2	4.19x10-6 (0.00000)	0.00003 (0.0001)	-0.0002 (0.0002)	0.00046 (0.000016)***	0.00016 (0.00017)	-0.00018 (0.00022)	-0.00005 (0.000006)
Gender – Males	0.0287 (0.0221)	-0.031 (0.081)	0.077 (0.060)	0.192 (0.0678)***	0.0935 (0.1011)	-0.325 (0.164)**	-0.046 (0.0818
Agric production or other business	0.00097 (0.0015)	0.0130 (0.053)	-0.054 (0.0595)	0.0812 (0.0877)	0.0397 (0.0867)	-0.093 (0.0876)	0.0066 (0.0221)
Amount of loss	7.82x10-9 (0.00000)	-1.68x10-7 (0.0080)	8.20x10-8 (0.00000)	-2.12x10-8 (0.00000)	4.35x10-7 (0.00000)**	-4.95x10-7 (0.00000)	-1.44x10-8 (0.00000)
Household size	-0/0003 (0.0003)		-0.0203 (0.0094)**	-0.0142 (0.0122)	0.0054 (0.0123)	0.0517 (0.0142)***	-0.0017 (0.0031)

*, **, *** implies significance at 10%, 5% and 1% probability levels respectively, standard errors in parenthesis

This helped determine the drivers of adoption for the most commonly utilized land management strategies.

The results in Table 14 show that household size had a positive and significant influence on the likelihood of households adopting all the land management practices under consideration. The results also indicate that household heads with more education are likely to have greater experience with land management. Additionally, access to climate change information positively and significantly impacted the use of increased fertilizer and crop rotation. The age and squared age variables significantly (at a 10% probability level) influenced the likelihood of the household head practicing crop rotation. Given that age was included as both a linear and quadratic term, the results show that age had a negative effect on the probability of a household doing crop rotation until age 40 (where $\beta 1$ = -0.158 and $\beta 2$ = 0.002), after which the effect became positive. These findings generally align with those of Deressa et al (2008), who reported that socioeconomic factors influenced how people cope with extreme climate events.

The results in Table 15 generally imply that government policies and investment strategies are needed to better support land management practices that help cushion the effects of climate change in the region. Specifically, policies and strategies should focus on:- Providing and facilitating access to education, as household heads with more education were more likely to engage in land management. Ensuring access to information on climate change and adaptation measures, as this positively influenced use of practices like increased fertilizer and crop rotation. Supporting measures that provide labor, as larger household size (more available labor) had a positive association with adopting land management practices. Overall, the results suggest government interventions around education, information dissemination, and labor availability would be necessary to promote improved land management for adapting to climate change effects in the studied region.

Table 15: Parameter Estimates of the Probit Model of Determinants of Different Land Management Practice

Explanatory Variable	**Coefficients**						
	Mulching/surface cover	Farm yard manure	Increased Fertilizer	Cover crops	Fallowing	Crop rotation	Inter cropping
Age of respondents	-0.459 (0.089)	0.065 (0.066)	0.104 (0.075)	0.038 (0.074)	0.118 (0.070)	-0.158* (0.091)	0.0005 (0.078)
Age2	0.0004 (0.0008)	-0.0005 (0.0006)	-0.0008 (0.0007)	-0.0006 (0.0007)	-0.001 (0.0007)	0.002* (0.0009)	0.0001 (0.0007)
Number of years in school	0.016 (0.036)	0.067** (0.032)	0.186*** (0.043)	0.088*** (0.033)	0.044 (0.032)	0.044 (0.033)	0.050 (0.039)
Household Size	0.123** (0.060)	0.079* (0.047)	0.179*** (0.062)	0.206*** (0.058)	0.092* (0.050)	0.186*** (0.057)	0.328*** (0.077)
Number of household member aged 15 with primary education	-0.471*** (0.170)	-0.219 (0.151)	-0.287 (0.182)	0.022 (0.151)	0.141 (0.167)	-0.070 (0.146)	-0.063 (0.171)
Number of household member aged 15 with secondary education	0.115 (0.150)	-0.301** (0.118)	-0.550*** (0.163)	-0.128 (0.123)	0.207 (0.146)	-0.053 (0.127)	0.388 (0.183)
Number of household member aged 15 with university	-0.054 (0.142)	-0.194 (0.118)	-0.510*** (0.159)	-0.191 (0.124)	-0.083 (0.129)	-0.222* (0.128)	-0.211 (0.152)

education							
Males over age 15	-0.141 (0.168)	0.81 (0.140)	0.286 (0.172)	0.134 (0.149)	-0.095 (0.158)	0.123 (0.156)	-0.115 (0.182)
Gender – Males	0.716 (0.465)	0.198 (0.405)	-0.584 (0.526)	0.144 (0.448)	-0.371 (0.455)	0.111 (0.478)	-0.211 (0.571)
Agric trading business activity	-	-	-	-0.304 (0.602)	-0.383 (0.568)	0.088 (0.608)	0.173 (0.813)
Non-agric trading business activity	-0.800 (0.547)	-0.426 (0.512)	0.233 (0.574)	-0.605 (0.510)	-1.230** (0.521)	-0.581 (0.531)	-1.247** (0.596)
Public sector employment	-0.100 (0.411)	0.062 (0.334)	0.220 (0.449)	-0.445 (0.364)	0.201 (0.379)	0.282 (0.371)	-0.222 (0.431)
Artisan	-0.328 (0.714)	0.722 (0.723)	0.780 (0.940)	-1.077 (0.713)	-0.640 (0.705)	-0.047 (0.654)	0.819 (0.969)
Formal private employment	-1.179 (0.766)	-0.347 (0.704)	-0.947 (0.771)	0.004 (0.805)	-1.544** (0.688)	-0.675 (0.771)	-1.814** (0.898)
Access to climate change information	-0.501 (0.352)	0.308 (0.284)	0.942*** (0.328)	-0.224 (0.303)	0.049 (0.319)	0.641** (0.296)	0.382 (0.339)
Constant	1.537 (2.227)	-2.464 (1.662)	-5.153*** (1.985)	-2.016 (1.838)	-2.944* (1.735)	2.060 (2.202)	-2.209 (1.956)

*, **, *** implies significance at 10%, 5% and 1% probability levels respectively, standard errors in parenthesis.

Table 16: Marginal Effects from Probit Model of Determinants of Different Land Management Practice

Explanatory Variable	**Marginal Effects (dy/dx)**						
	Mulching/surface cover	Farm yard manure	Increased Fertilizer	Cover crops	Fallowing	Crop rotation	Inter cropping
Age of respondents	-0.009	0.025	0.035	0.013	0.033*	-0.055*	0.0001
Age2	0.00009	0.-0.0001	-0.0003	-0.0002	-0.0003	0.0005*	0.00002
Number of years in school	0.003	0.026**	0.062***	0.031***	0.012	0.015	0.011
Household Size	0.263**	0.031*	0.059***	0.072***	0.026*	0.064***	0.075***
Number of household member aged 15 with primary education	-0.100***	-0.084	-0.096	0.008	0.039	-0.024	-0.014
Number of household member aged 15 with secondary education	0.0245	-0.116**	-0.184***	-0.044	0.058	-0.018	0.088**
Number of household member aged 15 with university education	-0.011	-0.075	-0.170***	-0.066	-0.023	-0.077	-0.047

Males over age 15	0.030	0.031	0.095*	0.047	-0.026	0.043	-0.026
Gender – Males	0.196	-0.074	-0.168	0.051	-0.092	0.039	-0.044
Agric trading business activity	-	-0.168	-	-0.112	-0.121	0.029	0.035
Non-agric trading business activity	-0.236	0.023	0.073	-0.231	-0.444	-0.220	-0.416*
Public sector employment	-0.022	0.023	0.071	-0.161	0.541	0.094	-0.053
Artisan	-0.082	-0.237	0.196	-0.409*	-0.218	-0,016	0.119
Formal private employment	-0.386	-0.137	-0.360	0.001	-0.557**	-0.o258	-0.625**
Access to climate change information	-0.097	0.119	0.333***	-0.076	0.014	0.232**	0.093

*, **, *** implies significance at 10%, 5% and 1% probability levels respectively, standard errors in parenthesis.

CHAPTER FIVE

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The study analyzed the impact of climate change on Land use, cassava production and yield in Nigeria.

5.1 Summary: findings and reflections on objectives and questions

5.1.1 Summary of findings

Key Findings:

1. Temperatures increased significantly at 0.016-0.022°C annually, intensifying heat waves and water stress.
2. Rainfall increased significantly from 1980 to 2021 which may increase flood risks.
3. Cassava production expanded to meet rising demand, doubling cultivated area.
4. Yields increased slowly pre-2000, increased steeply from 2001 to 2010, and fell drastically post-2010 due to soil degradation, poor access to improved farming materials, pest and diseases, poor management, intermittent rainfall pattern and rise in temperature.
5. Farmers observed delayed rains, excess rain, higher temperatures and associated impacts on crops.

The study of farmers' adaptation to climate change was conducted using data from 400 farmers randomly selected from ten States in Nigeria. A multiple linear regression analysis was conducted for purposes of making future climate projections on cassava land use, production, and yield. The results of the study show a strong statistical evidence that annual mean temperatures have been increasing over the past 42 years from 1980 to 2021 in the region which leads to a significant upward warming trend. On average, temperatures have risen by 0.016-0.022 degrees every year over this period based on the Sen's slope estimate. This shows the rate and magnitude of temperature rise.

Warming trends are important to consider for climate change impact assessments and adaptation planning. Higher temperatures will exacerbate issues like heat waves, water stress, impacts on agriculture/livelihoods etc. Adaptation strategies need to be formulated and implemented to build resilience of natural and human systems to actual and projected climate risks. This could include measures in areas like agriculture, water resources, infrastructure etc. Continued monitoring of temperature trends is important to track climate change progression and update adaptation responses based on most recent data.

Over the past 40+ years, average annual precipitation has been increasing significantly. This suggests the climate in Nigeria may be getting wetter overall. However, the year-to-year variability is high. Some years see much higher rainfall than others. So the increase in rainfall is a gradual long-term trend, not a consistent pattern from one year to the next. With climate change, many parts of the world are expected to see more extreme precipitation events - both heavier rainfall and longer dry periods. A wetter climate overall could impact factors like agriculture, infrastructure, water resources and flooding risk over the long run if the trend continues. More rainfall means more runoff and potential for floods.

Technological advances in cassava farming like improved varieties, irrigation, and fertilizers likely helped stabilize and boost yields after 2000, reduced vulnerability to weather factors and more consistent productivity gains over time. Food security and incomes of cassava farming communities would have benefited from higher average yields. Continued agricultural research and investment in cassava production could help further increase yields and incomes in coming years. However, challenges from climate change impacts like droughts or floods still remain a threat to stability, and needs addressing. From the data used in this study, cassava yields improved steadily after 2000 likely due to agricultural technologies while yields fluctuated widely before 2000 due to weather dependency.

Improved cassava varieties and farming techniques helped increase and stabilize yields after 2000. This led to consistently higher production levels. Increased production would have benefited food security as well as livelihoods of resource-limited farmers dependent on cassava. Continued investment in cassava sector R&D, extension services and rural infrastructure can help sustain production growth. Higher and more reliable production is important as cassava demand is projected to rise with population growth. Climate change impacts still pose risks and adaptive measures are needed to ensure future production stability and food/income security for farmers. In this study, cassava production fluctuated widely before 2000 but increased steadily after 2000 likely due to improved yields driven by agricultural technology development.

Cassava production has become an increasingly important agricultural activity and food crop in Nigeria over the past 4 decades based on the expansion of land area devoted to its cultivation.

While yearly fluctuations occur depending on various factors like weather, the overall long-term trend of increasing land area indicates growing demand for and production of cassava in the country. Peak land areas approximating 3.8 million hectares in late 2000s and 9.98 million hectares recently, suggest the significant role cassava occupy as a strategic food security crop, given Nigeria's large population. The exponential rise in land area from 1.2 million hectares in 1980 to about 9.98 million hectares now demonstrates major scaling up of cassava farming systems and livelihood opportunities in rural areas. Continued growth in land area will be needed to meet projected increases in domestic and export demand for cassava and its products from a growing population and economy.

Sustaining high yields on expanded lands will require investments in improved varieties, soil/water management, mechanization, rural infrastructure to boost productivity and farmer incomes. Rising cultivation reflects cassava's comparative advantages but also raises issues of sustainable intensification and impacts on natural resources/environment if not properly managed. Increasing land allocation signals the strategic importance of cassava agriculture in Nigeria's food system and rural economy over the long-term.

The survey results on farmers' adaptation show that the majority (92.29% and 96.76%) of respondents have observed a significant temperature and rainfall change. Additionally, most (90.20%) were aware of climate change before the interview; however, the largest portion (45.71%) of those familiar with it have limited knowledge. Common climate change effects noted by crop farmers include delayed rains (97.97%), excessive rainfall (68.81%), and higher temperatures (65.59%). Major outcomes of climate change were flooding (71.29%), reduced crop yields (65.1%), higher food prices (62.87%), and food shortages (57.92%). Farmers reported an average loss of N164,318.8 naira due to climate change. To mitigate its impact, the majority (45.05%) purchased food, while 37.62% adopted new farm practices and 29.95% engaged in non-farm activities. Regarding land management practices, most farmers employed fallow periods (74.34%), mulching (83.55%), intercropping (72.37%), and using farmyard manure (60.53%).

Additionally, planting pest- and disease-resistant crops (56.68%), utilizing well-acclimated crop varieties (48.27%), proper preservation of seeds and plant seedlings for planting (49.75%), implementing mixed farming practices (49.01%), and staying informed about climate change (47.03%) were among the adaptation strategies employed by yam and cassava farmers. The level of education and household size significantly impacted the likelihood of diversifying into non-farm activities to mitigate the impact of climate change. Therefore, initiatives supporting non-farm ventures and offering alternative livelihoods should prioritize educated farmers. It is anticipated that elderly individuals, farmers with higher education, and those from larger households will opt for early-maturing crops to mitigate the effects of climate change. Policy interventions promoting education access, particularly for the elderly and large households, should promote the cultivation of these early-maturing crops.

5.1.2 Restating the research objectives: a summary of how they were achieved

Earlier in the introduction of this thesis, two specific objectives were stated. These objectives have been achieved in this thesis in the following ways:

- To assess the effects of climate change on cassava land use, production, and yield from 1980 to 2021: This objective was achieved by regressing temperature and rainfall predictor variables on cassava land use, production, and yield data from 1980 to 2021. Significant increase in rainfall amount over the period was positively and significantly correlated with cassava land use and production. In contrast, temperature increase was negatively correlated with cassava yield.
- To assess the current adaptation and coping strategies adopted by farmers in Nigeria in response to climate change impacts: This objective was achieved through qualitative data from 400 randomly selected respondents. The major adaptation and coping strategies adopted by farmers to cushion the effect of climate change were: planting resistant varieties, planting varieties that are well acclimated to local conditions, proper preservation of seeds and seedlings for planting, adopting mixed cropping system, and seeking out information about climate change impacts and responses.

5.1.3 Restating the research questions: a summary of how they were answered

Two corresponding specific research questions were also investigated in the bid to achieve the objectives of this thesis. These two specific research questions have been answered in the following ways:

1. What are the effects of climate change on cassava land use, production, and yield in Nigeria from 1980 to 2021? This research question was answered in sections 4.2 to 4.9.2. The effects

include: expansion of cultivated area with a corresponding increase in total cassava production at the expense of yield, as a consequence of increased temperature and precipitation. Other effects reported were delayed onset of rainfall, frequent drought, too much rain, and erratic rainfall pattern.

2. What are the current adaptation and coping strategies adopted by farmers in Nigeria in response to climate change impacts? This research question was answered in section 4.93. (Table 8).

5.2 Conclusion

This mixed-methods study provides compelling quantitative and qualitative evidence of the impacts of climate change on cassava production systems in Nigeria over the past four decades. Quantitative analysis of meteorological and survey data revealed significant increasing temperature trends, fluctuations in rainfall patterns, and changes in cassava yields and production areas over time. Qualitative data from farmer focus groups provided rich contextual understanding of their direct observations of climatic changes negatively affecting crops and livelihoods. It also shed light on the adaptation strategies currently employed on farms.

While technological advances after 2000 helped stabilize cassava yields between 2001 and 2010, cassava yield continued to decline after 2010 due to inclement weather, poor management, pest and diseases, poor access to improved materials, soil degradation etc. which was corroborated by the farmers' qualitative report delayed onset of rainfall, unpredictable weather conditions, frequent droughts, lack of improved varieties. Both the quantitative trends and qualitative perceptions show the need for continued monitoring of climate risks and proactive implementation of comprehensive adaptation measures. Coordinated multi-sector policies and investments in climate-resilient technologies, diversification of livelihoods, and education outreach can help build the adaptive capacity of vulnerable farming communities and strengthen the resilience of Nigeria's important cassava production systems into the future.

5.3 Limitations of the study

Here are some limitations of the study that could give rise to further studies:

- Survey data was cross-sectional and captured farmers' perceptions at one point in time. A longitudinal study following the same farmers over many years could better show impacts of climate trends.

- Qualitative data from focus groups provided context but views may not be generalizable across all farming communities. Larger and more diverse samples could strengthen understanding of adaptation challenges.
- Yield data prior to 2000 had more fluctuations potentially due to inconsistent record-keeping. More recent yield trends may be more reliable indicators of climate impacts.

- The study did not assess socioeconomic factors like market access, input costs, education levels which also influence production levels and adaptive capacity.
- Regression analysis established correlations but could not prove causation between climate drivers and yields. Experimental studies could provide stronger evidence of impacts.
- Language barriers may have limited farmers' full expressions of their experiences in focus groups and surveys. Using local facilitators could address this.
- The scope was limited to cassava and did not consider impacts on other key staple crops in the region. A broader assessment is needed.

5.4 Recommendations

Here are some recommendations from this study :

Strengthen the national meteorological monitoring network to improve collection of climate data, especially in rural areas where farmers are located. This will enhance understanding and prediction of local climate impacts.

Develop climate information services to disseminate localized forecasts and advisories to farmers through various channels such as SMS, radio, extension agents. This will help farmers make informed decisions about planting times and choices of crop varieties.

Establish demonstration farms showcasing climate-resilient cassava varieties and integrated soil and water management techniques. This hands-on approach can help promote wider adoption of adaptation best practices.

Provide financial support through government subsidies or microloans for farmers to access climate-resilient technologies such as drought-tolerant cassava stems, irrigation equipment, post-harvest storage and processing facilities.

Launch mass awareness campaigns using local languages to educate farmers and communities about climate change risks and how to build household resilience through livelihood diversification, income sources, nutrition and health.

Strengthen coordination between researchers, extension services, policymakers and farmers to facilitate two-way sharing of climate information and ensure science-based solutions meet end-user needs on the ground. This can promote co-creation of knowledge.

Develop gender-sensitive adaptation programs as women play a vital role in cassava production but often have less access to resources and information. Addressing their specific vulnerabilities and empowering them is key to effective climate action.

CHAPTER SIX

6. REFERENCES

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Appendix

Research Study: Analysis of Impact of Climate Change on Growth and Yield of Cassava and Adaptation Strategies by the Crops Farmers in Southern Nigeria

Name of Enumerator: …………………………………………………………………..

State: ………………………………………………………………………………………

Location: ……….…. Name: …………. Code: ……………

SECTION A: HOUSEHOLD COMPOSITION

PID	**Name of hh member above 14 years old**	**Age**	**Relationship to household head1(HH)**	Gender **1=male 2=Female**	**Level of education2**	**Primary Activity3**	**Number of years in school**
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

* PID = Personal identification number

1 Relationship to head: 1=head, 2=spouse, 3=child, 4=siblings, 5=other family member, 6=non-family member, 99=others

2 **Level of education:** 1=no formal education, 2= adult literacy training, 3=some primary education, 4=completed primary education, 5=some secondary education (incl. junior secondary school), 6=completed secondary education, 7=post-secondary education, 8=Koranic education, 99=others

SECTION B: KNOWLEDGE AND ADAPTATION TO CLIMATE CHANGE

Have you noticed a significant temperature change yes --------- No-----------

Have you noticed a significant change in rainfall yes ---------- No -------------

Have you heard of climate change before now? Yes ( ) No ( )

8. If yes, to what extent do you know about climate change? (a) Don't know what it is ( )

(b) Know little about it ( ) (c) To a reasonable extent ( ) (d) To a great extent ( )

9. From your understanding how will you describe it to a friend?

____

Sources	Yes	No
Extension Workers		
Friends		
Farmer’s cooperatives		
Politicians		
Internet		
Newspapers		
Radio/Television		
Researchers		
Others (Specify)		

11. Type of climate change observed: (i) More frequent drought --------------------------- (ii) Delayed on-set of rainfall --------------------------- (iii) Erratic rainfall patterns ------------------- (iv) Hailstorm ---------------------

(v) Too much rain ---------------- (vi) Less rain ---------------- (vii) Higher temperatures -------------------------- (viii) Normal ----------------- (ix) Others (specify) ---

12. What has been the outcome from climate change (i) Decline in crop yield -------------------- (ii) Increase in crop yield (iii) Food shortage/insecurity---------------------------------- (iv) Food price increase ------------------- (v) Early productivity --------------------- (vi) Flooding -------------------- (vii) Erosion hazard ---------------------- (viii) Soil nutrient depletion -------------------------- (ix) Others (specify) --

13. Who has been the most affected by climate change (i) children (below 15 yrs) ----------------- (ii) Women ----------------------- (iii) Men ------------------------- (iv) the elderly ------------------------ (v) All -----------------------

14. What action have you taken (i) Started non-farm activity ------------- (ii) Started using new land management practices ---------------- (iii) Received food aid ----------------------- (iv) Participated in food for work ----------------- (v) HH head migrated to other rural area --------------- (vi) HH head plus other migrated to rural area ----------------------- (vii) Migrated to urban area ------------------- (viii) Sought off-farm employment ----------------------------- (ix) Bought food --------------------- (x) ate less ------------------ (xi) ate different foods ---------------- (xii) looking for

other varieties --------------------- (xiii) Planting trees --------------- (xiv) Started planting early ----- ------------ (xv) planting early maturing crops ------------------- (xvi) Sink borehole ----------------

15. Amount of loss due to climate change (Naira) ---

16. What (if any) land management practices have you used to address climate change:

S/No	Land Management Practice	Response(yes/No)	Year respondent started using the practice
1	Mulching/Surface cover		
2	Trash line		
3	Infiltration ditches		
4	Composting		
5	Farm yard manuare		
6	Fertilizer		
7	Water harvesting		
8	Agroforestry		
9	Cover crops		
10	Crop rotation		
11	Crop rotation with legumes (nitrogen fixing)		
12	Intercropping		
13	Enclosure of the land		
14	Removal of unwanted bush		
15	Soil improvement		
16	Erosion control		
17	Replenishing soil fertilizer		
18	Border cropping		
19	Fallowing		

17. Type of climate change addressed by above management practice

S/No	Land Management Practice	Response(yes/No)	Year respondent started using the practice
1	Mulching/Surface cover		
2	Trash line		
3	Infiltration ditches		
4	Composting		
5	Farm yard manuare		
6	Fertilizer		
7	Water harvesting		
8	Agroforestry		

9	Cover crops		
10	Crop rotation		
11	Crop rotation with legumes (nitrogen fixing)		
12	Intercropping		
13	Enclosure of the land		
14	Removal of unwanted bush		
15	Soil improvement		
16	Erosion control		
17	Replenishing soil fertilizer		
18	Border cropping		
19	Fallowing		

18. Adaptive Farm Management Strategies Adopted by the Respondents in Cushioning the Effects of Climate Change on Cassava Farming

S/No	Adaptive strategies	Used	Year started
1	Planting pest and disease resistant crops		
2	Use of crops varieties that are well acclimatized		
3	Use of irrigation system/water storage		
4	Reforestation/Afforestation		
5	Use of chemicals like herbicide, insecticide		
6	Increase in number of weeding of cropped land		
7	Use of early maturing crop varieties		
8	Protection of water sheds and mulching		
9	Proper preservation of seeds and plant seedling used for planting		
10	Use of weather-resistant variety		

11	Reducing access to eroded and erosion prone area		
12	Mixed farming practices		
13	Change of planting date		
14	Use of recommended planting distance		
15	Listening to information about climate change		
16	Changing the timing of land preparation		
17	Changing harvesting dates		
18	Out migration from climate risk areas		
19	Processing of crops to minimize post-harvest losses		
20	Use of windbreaks/shelter belts		
21	Others specify		

SECTION C: CONSTRAINTS TO CLIMATE CHANGE ADAPTATION

Tick under the appropriate options, problems encountered in climate change adaptation.

KEY: 5: To A Very Great Extent (VGE), 4: To A Great Extent (GE), 3: To Some Extent (TSE), 2: To A Little Extent (LE) 1: To No Extent

S/No	Problems	VGE	GE	TSE	LE	NE
1	Lack of information					
2	Ineffectiveness of indigenous strategies					
3	Irregularity of extension services					
4	No subsidies on planting materials					
5	Lack of access to					

	improved crop varieties					
6	Absence of water management techniques					
7	Poor government attention to climate problems					
8	Low awareness level					
9	Inability to access available information					
10	Limited knowledge on adaptation measures					
11	Cultural influence					
12	Taboos					
13	Inability to give up traditional values					
14	Low institutional capacity					
15	Absence of government policy on climate change					
16	Others, specify					