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CLIMATE CHANGE (TECHNICAL FOCUS)

Title: Enhancing Groundnut Production Under Climate Change in North Bank Region (The Gambia)

Presented By

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Submitted on 22nd March 2024.

DECLARATION

STUDENT’S DECLARATION

I, Jainaba Trawally, hereby declare that this thesis titled “Enhancing Groundnut Production Under Climate Change in North Bank Region, The Gambia” is my original work to the best of my knowledge and it has not been submitted to any other university or published for the award of a degree. I also declare that all the information, materials, and results from other works presented in this thesis have been duly cited and recognized as required by academic rules and ethics.

Name: Jainaba Trawally

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SUPERVISOR’S DECLARATION

I, Dr. Khaldoon A. Mourad, hereby declare that I supervised the preparation of this Master thesis submitted therein per the guidelines on supervision of the Master thesis laid down by the Pan African University Institute of Water and Energy Sciences, Algeria.

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Date: 20/03/2024

Signature:

DEDICATION

I thank Almighty Allah for giving me the strength to undergo this program. I also dedicate this work to my parents, Isatou Sowe and Modou A. Trawally for their continued support and prayers towards my education, siblings, friends, and loved ones for giving me words of encouragement and support during this program.

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ABSTRACT

Rising temperatures and erratic rainfall have had a significant impact on food production in Africa including The Gambia. To enhance groundnut production, this thesis aims to examine the impact of temperature and rainfall on groundnut productivity in the North Bank Region in The Gambia. Thus, the potential impacts of climate change on groundnut production were assessed by comparing the baseline (1971-2000) with RCP 4.5 (2020-2039) in the near future and RCP 8.5 (2060-2079) mid-term future using the Cropwat model. The findings showed that the linear regression analysis between temperature and rainfall against groundnut yields for the period of 1990-2020 was positive and negative respectively, indicating that the decline in groundnut yield is not rainfall whilst temperature rise has a minimal influence on the yield. In addition, the simulated result for the baseline (1971-2000) in the Cropwat model showed that the Crop Water Requirement (CWR) of groundnut was met because the rain efficiency was 87.6%. While Irrigation Water Requirement (IWR) was minimal (19.1mm) which was only required at the end of the maturity period. Under RCP 4.5 (2020-2039) in the near future, CWR of groundnut will not be met due to a decrease in the rain efficiency to 66.0%, an additional irrigation supplement of 301.2mm will be required throughout the growth stages for optimal groundnut growth. Under RCP 8.5 (2060-2079) in the mid-term future, the CWR of the groundnut will not be met due to a reduction in rainfall, with irrigation necessary throughout the growing season. The rainfall efficiency will be 60.5% and an additional IWR of 405mm will be needed for optimal growth. Furthermore, a farmers' perception survey was conducted on the challenges facing groundnut production due to climatic and non-climatic factors, which show that farmers are facing three major challenges namely storage problems, pest infestations, and soil fertility decline. Based on the survey, 80% of the respondents, reported that they have observed a decline in rainfall and an increase in temperature. Thus, to foster groundnut resilience to climate change some adaptation measures such as irrigation planning, storage facilities establishment, pest control, and soil fertility are needed, which can be implemented by national stakeholders and policymakers in The Gambia.

Keywords: Food production; CROPWAT model; Rainfall efficiency; Crop Water Requirement; Irrigation Water Requirement

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
AR5	-	Fifth Assessment Report
AR6	-	Sixth Assessment Report
AU	-	African Union
CDKN	-	Climate and Development Knowledge Network
CH_4	-	Methane
CIAT	-	International Centre for Tropical Agriculture
CMIP	-	Coupled Model Intercomparison Project
CO_2	-	Carbon-dioxide
CWR	-	Crop Water Requirement
FAO	-	Food and Agriculture Organization
FC	-	Field Capacity
GBOS	-	Gambia Bureau of Statistic
GCCPC	-	Gambia Competition and Consumer Protection Commission
GDP	-	Gross Domestic Product
GHGs	-	Greenhouse Gases
H_2O	-	Water
HFCs	-	Hydrofluorocarbons
ICRISAT	-	International Crops Research Institute for the Semi-Arid Tropics
IFAD	-	International Fund for Agricultural Development
IPCC	-	Intergovernmental Panel on Climate Change
IWR	-	Irrigation Water Requirement
LGA	-	Local Government Area
LULC	-	Land Use and Land Cover
MAE	-	Mean Absolute Error
MOA	-	Ministry of Agriculture
MoFA	-	Ministry of Foreign Affairs
N_2O	-	Nitrous oxide
NOAA	-	National Oceanic and Atmospheric Administration

PFCs - Perfluorocarbons

RCP - Representative Concentration Pathways

RMSE - Root Mean Square Error

SDGs - Sustainable Development Goals

SF_6 - Sulfur hexafluoride

SSPs - Shared Socioeconomic Pathways

SWAT - Soil and Water Assessment Tool

TAW - Total Available Water

UNCCS - United Nations Climatic Change Secretariat

UNFCCC - United Nations Framework Convention on Climate Change

USDA - U.S. Department of Agriculture

USGS - U.S. Geological Survey

WFP - World Food Programme

WP - Wilting Point

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CHAPTER ONE

1.0 INTRODUCTION

1.1. Background of the Study

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) stressed that more than a century's worth of energy use, land use changes, lifestyle choices, and patterns of production have resulted in net greenhouse gas (GHG) emissions that are caused by anthropogenic activities (IPCC, 2023). The world's temperatures are rising due to climate change. The industrial revolution has significantly worsened the climatic catastrophe (IPCC, 2022; Massey, 2023). United Nations Framework Convention on Climate Change (UNFCCC) acknowledges that "many of the challenges brought about by climate change are beyond the capabilities of developing countries" (UNFCCC, 2021). As a result, the Paris Agreement highlights the necessity of developing nations' growing capacity for climate change and calls on all wealthy nations to bolster their backing for initiatives in underdeveloped nations (UNFCCC, 2021).

Rising global temperatures are predicted to alter precipitation patterns and amounts, increasing the likelihood of natural disasters like heat waves, fires, floods, and droughts (IPCC, 2018). Extreme weather events such as heatwaves, heavy precipitation, droughts, and tropical cyclones have been seen in locations across the world due to human-induced climate change (IPCC, 2021). Rapid, wide-scale changes in the ecosystem are already being influenced by these extreme events (Dasgupta, 2021).

More than 60% of Africans are employed in the agriculture sector than any other, contributing 35% of Africa’s GDP, but it is extremely susceptible to changes in precipitation and temperature (African Development Bank, 2019). Climate change is becoming the most threatening issue affecting the livelihood of subsistence farmers (Ali, 2021). Africa's economy, infrastructure investments, food and water systems, public health, agriculture, and livelihoods are all at risk from exponential collateral harm, which might reverse the continent's meager development progress and slide into higher levels of extreme poverty despite having contributed the least to global warming and having the lowest emissions (African Development Bank, 2019).

Africa's ability to meet the United Nations Sustainable Development Goals (SDGs) is seriously threatened by climate change. Temperature increases of more than 1.5°C have serious repercussions, particularly for Africa (IPCC Report 2018). Africa is anticipated to be greatly affected by climate change since some of the continent's agricultural regions rely heavily on rain. Hence, current trends indicate that Africa's water demand considerably outpaces its supply, endangering the lives and livelihoods of those who live there and rely on agriculture for a living (Castells-Quintana et al., 2018; Serdeczny et al., 2016).

On the other hand, crop modeling is a contemporary technique for simulating or forecasting plant growth and yields in the field and greenhouses. A crop model is defined as a numerical computing procedure that forecasts plant growth, biomass, and yield, producing outcomes related to crop interactions and the environment (Wang et al., 2017). Numerous crop models have been employed up to this point to replicate important crops like bananas, rice, corn, cassava, and green beans (Gao et al., 2021).

Crop models come in various forms. Statistical models (also known as empirical models) use mathematical relations between the different variables. The main disadvantage of statistical models is that their development and parameterization were based on observable data, making them unsuitable for use in locations or applications that were not involved in the process. Additionally, they cannot forecast values in unpredictable situations (such as the effect of climate change on crop growth) (Jones et al., 2017).

Solely mechanistic models (also known as process-based models) depend on the simulation of biophysical processes. Instead of being based on mathematical equations that only link two variables, as in statistical modeling, they are based on mathematical equations that explain physiological processes. If the procedure has been stated, it can be obtained even without actual data. Mechanistic models can be deterministic, meaning that for a given set of inputs, the outcome will always be the same. This is achieved by eliminating random changes from the model and equations. (Basso et al., 2015). Mechanistic models can also be stochastic, meaning that even with consistent inputs, outputs will vary between simulations due to random effects included in the models and equations.

Since models can simulate a variety of complicated processes, they are also helpful tools in the field of agro-environmental studies. They help to estimate variables that are difficult, costly, or time-consuming to measure, models might be employed as a proxy. Crop development, environment, management, and genetic aspects are all considered in models. To ascertain how these factors affect crop growth or to measure ecosystem services, there is therefore a great deal of interest in employing crop modeling. Therefore, crop models are system-based models that aim to promote the connections between "soil–plant–atmosphere–management." (Wallach et al., 2019).

To achieve these, multidisciplinary methods are required, and crop models can consider biological, physiological, ecological, physical, or economic factors. The incorporation of these methodologies into crop modeling has resulted in the creation of extensive crop models, such as APSIM (Holzworth et al., 2014), CropSyst (Stöckle et al., 2003), WOFOST (de Wit et al., 2019), DSSAT (Boote et al., 2019), AquaCrop (Steduto et al., 2009), STICS (Brisson et al., 2003), and CROPWAT (Smith, 1992). Crop models are descriptive instruments commonly employed in scenario testing. Asseng et al., (2018), for instance, employed an ensemble of crop models to comprehend the worldwide adaptability of wheat protein under climate change impacts.

Currently, the economy of The Gambia is among the least diverse and smallest in Africa, making it vulnerable to external shocks from the world economy. The economy is led by the service industry (58.2%), followed by the agriculture sector (25.7%) as of 2022 (GBOS 2023), which mostly relies on rain-fed agriculture. After growing slowly in the preceding years, the GDP expanded by 6.2% in 2019. Agriculture and tourism had a major role in the recovery (Republic of The Gambia, 2020b).

For most rural families in the Gambia, farming is the only source of income. The Gambia has a Sudano-Sahelian climate of (600-900 mm annual rainfall), meaning it has a lengthy dry season and a wet season (FAO, ICRISAT, CIAT, 2018). The wet season starts from June to October, and a lengthy dry season starts from May to November annually.

Groundnut is the major cash crop and one of the main exports of The Gambia. About 45% of the groundnut produced in the country is from the north bank region, although it may be grown practically anywhere in the country. It is one of the primary sources of revenue, foreign exchange, employment, and livestock feed for rural farmers (GCCPC, 2021).

The Gambia bears the heavy economic consequences of climate change and variability. It is well known that the average monthly minimum temperature in The Gambia has increased by 0.40 degrees Celsius during the past 40 years, and the country is extremely susceptible to any changes in its climate (Department of Agriculture, 2017).

In order, to achieve food security and increase groundnut productivity in a changing climate, climatic and non-climate factors that affect groundnut production should be considered. Therefore, this study examines the relationship between the different key climatic variables on groundnut production using the linear regression analysis, the CropWat Model to assess the potential climate impacts on groundnut irrigation water requirement. Additionally, the study conducted a comprehensive survey to capture the farmer's perceptions, and concerns regarding issues affecting groundnut production in the study area, and provided some recommendations.

1.2 Problem Statement

Climate change will adversely affect Africa more than other continents (Ndamani, 2016). Developmental challenges for the continent include the expected negative impact of climate change on agricultural productivity and livelihood (Yaro, 2013), which poses a danger to sustainable development, particularly in drier regions, and significant levels of social and physical vulnerability in certain areas (Ndamani, 2016; Yaro, 2013). The negative effects of climate change most severely affect farmers in poor nations (Ndamani, 2016). According to Aubert et al., (2012), farmers who rely on the weather and climate for their livelihoods face a great deal of uncertainty. To effectively handle the difficulties of climate change, agricultural policies and decisions should incorporate local experiences and empirical facts (Ndamani, 2016).

According to a study by Loum and Fogarassy (2015), The Gambia's climate is changing due to changes in rainfall, windstorm frequency, and frequency of cold spells and droughts. Food insecurity, malnourishment, and poverty have not changed in the Gambia as a result of reduced dietary nutrients, according to (FAO, 2017). The Gambia is a rain-fed agricultural nation that risks severe economic ramifications from climate change, primarily from rising temperatures that pose a threat to the agricultural sector, particularly to groundnut cultivation. The sustainability and production of groundnuts are seriously threatened by The Gambia's vulnerability to climate fluctuation.

Moreover, the trend of groundnut production has not been uniformed in the past years. Statistics from the Ministry of Agriculture (Department of Planning) have shown that groundnut production has increased from 1975 to 2001 with an annual increase rate of 5.5%. The average groundnut production between 1999 and 2001 was estimated at 137,000 metric tonnes. However, due to the extended dry spell experienced during the 2002 cropping season, groundnut production declined from 151,100 metric tons to 71,500 metric tons a reduction of 47.3% as shown in Figure 1.1. This decline has serious implications for the country's foreign exchange earning capacity as well as farmers' income thus reducing farmers' accessibility to essential food commodities (Ministry of Agriculture-Department of Planning, 2022).

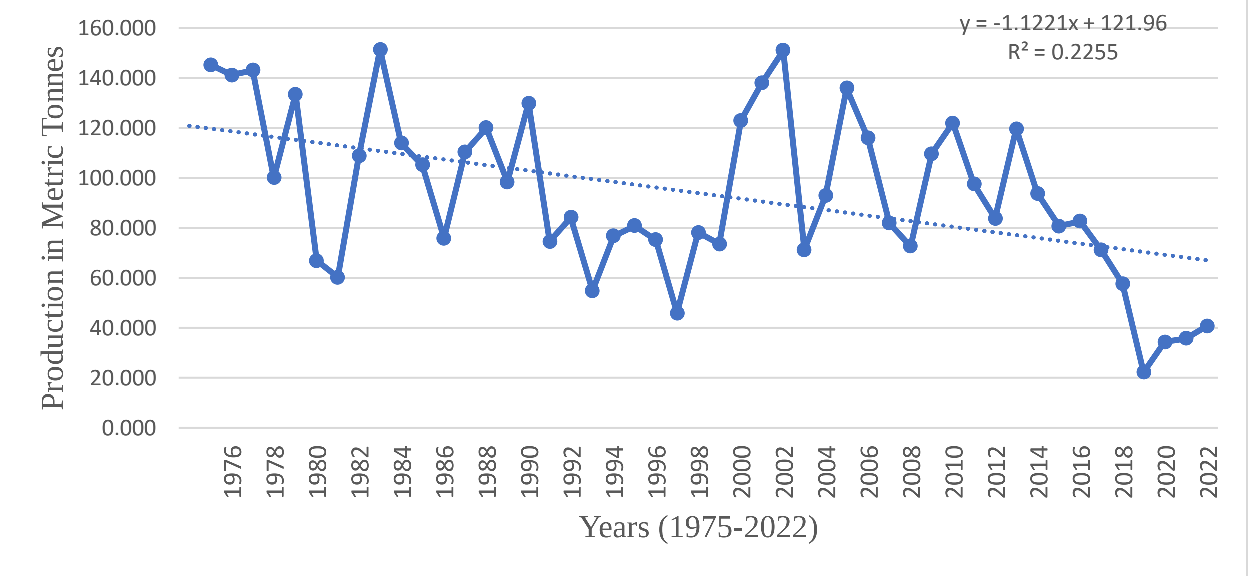


Figure 1.1: Groundnut Production (MT) in The Gambia

The area under cultivation from 1974 to 2001 was averaged. Between 2002 and 2012 it was high and then it started to decline from 2014 to 2022 due to population increase, Figure 1.2. Agricultural land areas started to be cleared for settlement by the building of schools, hospitals, and other recreational facilities.

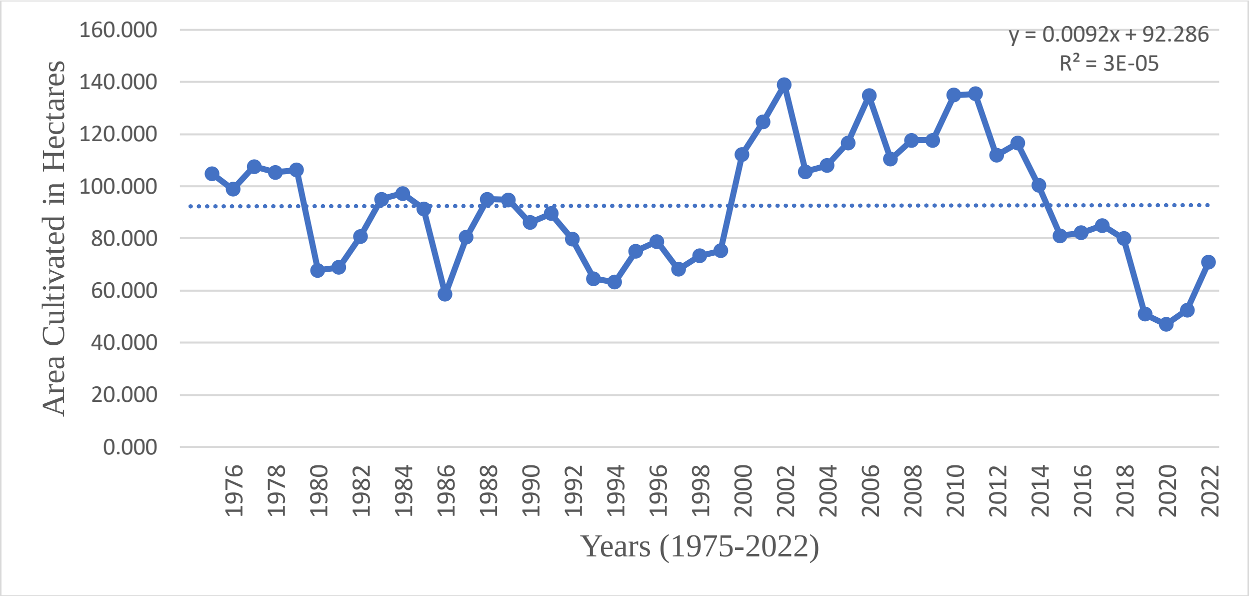


Figure 1.2: Area under cultivation (hectares) of groundnut in The Gambia

The yield of groundnut in metric tonnes from 1974 to 1990 was high due to the reason that the soil was very fertile and there were no impacts of climate change on the yield of groundnut. But from 1991 to 2022 the yield has declined due to the depletion of the soil and climate change impacts as shown in figure 1.3.

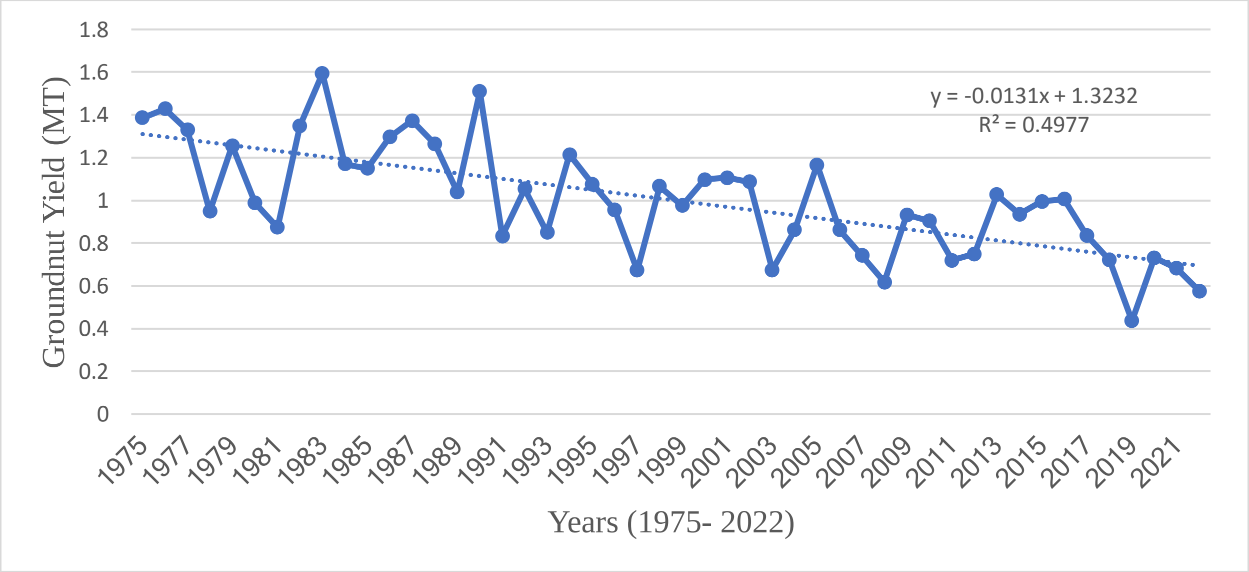


Figure 1.3: Groundnut Yield (MT) of The Gambia

Most of the studies conducted on groundnut production in The Gambia focus on non-climatic factors, no study has been conducted on both climatic and non-climatic factors. Furthermore, it is yet unknown how temperature variations caused by climate change will affect Crop Water Requirement (CWR) and Irrigation Water Requirement (IWR), which presents significant problems to agricultural water allocation, irrigation, and crop yield.

1.3 Relevance of the study

Groundnut in The Gambia serves as a major cash crop providing income for many farmers and contributing to the country's GDP. Groundnut crop is a valuable source of proteins and nutrients. Locally, they are consumed in various forms, providing a vital food source. It provides employment opportunities to many rural Gambians who are engaged in farming activities, and the processing and marketing of groundnut create additional jobs. Groundnuts and groundnut products are being exported to international markets. The revenue earned from these exports enhances the country's foreign exchange reserves and supports economic stability. Groundnut is often used in crop rotation, which helps to maintain soil fertility.

The findings from this study would help in the formulation of climate change policies and strategies that are relevant to groundnut production for the Government of The Gambia, and help in the attainment of SDGs 1- No poverty by increasing the productivity of groundnut to increase the economic standard, SDG 2 Zero Hunger by increasing crop yield to attained food security and SDG 13 Climate Action to formulate strong policies for both adaptation and mitigation plans.

This research is the first-ever comprehensive analysis of the effects of both climatic and non-climatic factors on groundnut production in The Gambia. Examining these diverse factors provides valuable insights for policymakers and stakeholders to develop strategies for sustainable and resilient groundnut production in the region.

1.4 Aims and Objectives

This research aims to enhance groundnut production under the changing climate in the North Bank Region of The Gambia.

To achieve the main objective, the following are the specific objectives of the study:

I. To establish the relationship between key climatic variables (temperature and rainfall) with groundnut yield from 1990-2020.

II. To assess the potential impacts of climate change on groundnut production in the north bank region (Kerewan station).

III. To examine farmers' perceptions of some of the challenges they face in groundnut production due to climatic, and non-climatic factors.

IV. To propose recommendations and measures to sustain groundnut production.

1.5 Research Questions

I. Is the relationship between the key climatic variables (temperature and rainfall) with groundnut yield for the duration of 1990-2020 positive or negative?

II. How do the impacts of climate change affect groundnut irrigation water requirements in the North Bank Region?

III. What are the main challenges facing groundnut farmers under climatic, and non-climatic factors in the study area?

IV. How can groundnut production be sustained under climate change in the study area?

1.6 Structure of the thesis

This thesis comprises five chapters, which are as follows:

Chapter One- Introduction: This chapter contains the background of the study, problem statement, relevance of the study, objectives of the study, and research questions.

Chapter Two- Literature Review: This chapter contains the literature review where previous research related to the topic is reviewed, to identify the gaps in existing knowledge that this research intends to fill.

Chapter Three-Methodology: This chapter explains the type of methods used to attain the results, the materials, data sources, sampling procedures, research design, models, and the explanation of the research approach.

Chapter Four- Result and Discussion: This chapter discusses the findings of the study using graphs, figures, and tables, comparing the findings from previous research, and addressing the research questions.

Chapter Five- Conclusions and Recommendations: This chapter summarizes the research findings and includes some recommendations to sustain groundnut production in The Gambia.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter provides a literature review on climate change and, the impacts of climate change on agricultural production; globally, in Africa, and in The Gambia. It involves the trend of groundnut production in Africa, Crop Modelling, CropWat, and questionnaires by reviewing existing research work and identifying key knowledge gaps.

2.2 Climate Change

Climate change is caused by greenhouse gas emissions which result in shifts in climate patterns. Climate scientists have selected a series of scenarios called Representative Concentration Pathways (RCPs) to provide a range of possible futures for the evolution of atmospheric composition (Moses et al., 2010). It is used in climate change scenarios to develop a comprehensive summary for policymakers and decision-makers. These scenarios describe the future concentrations of greenhouse gases and some of the possible changes in climatic factors. The IPCC Fifth Assessment Report (AR5) from 2014 employed four research and climate modeling pathways. These scenarios are RCPs 2.6, 4.5, 6.0, and 8.5 they are used to describe the future climate of the world (Boonwichai et al., 2018). Every scenario outlines the anticipated concentration of greenhouse gases. The numbers 2.6, 4.5, 6, and 8.5 represent the additional Watts of energy per m^2 of the Earth's surface due to the increased greenhouse gas concentrations compared to pre-industrial levels. RCP 2.6 is the lowest level of greenhouse gas concentration at 440 ppm CO_2 equivalent by 2100. RCP 4.5 is the second scenario which is more pessimistic as it describes the high concentration level of greenhouse gas at 570ppm CO_2 equivalent by 2100. RCP 6.0 is the medium-high emissions scenario where greenhouse gas emissions will continue to rise throughout the century with little or no mitigation efforts to reach 730 ppm CO_2 equivalent by 2100 and RCP 8.5 is the worst-case scenario emission where the greenhouse gas emissions will continue to rise rapidly throughout the century with little or no migration efforts plus the continued use of fossil fuels. Its extreme global temperature and high concentration of level of greenhouse gas will be at 1200ppm CO_2 equivalent by 2100 (Van Vuuren et al., 2011).

The main cause of global warming is as a result of the earth's atmosphere trapping more heat due to greenhouse gas emissions. Anthropogenic activities and natural processes are the primary sources of these emissions. Examples of natural disasters include forest fires, earthquakes, mud volcanoes, wetlands, permafrost, seas, and volcanoes (Yue & Gao 2018). The Intergovernmental Panel on Climate Change (IPCC) recently assessed that, to date, anthropogenic activities have led to an estimated 1.0 °C global warming above pre-industrial levels, with a likely range of 0.8 to 1.2 °C. Some examples of anthropogenic activities include pollution, deforestation, industrialization, changes in land use patterns, etc all lead to the increase in atmospheric concentrations of water vapor, methane, carbon dioxide, nitrous oxide, and other (-$GHGs_2$-) which will further exacerbate the rate of climate change (Stott et al., 2016).

On one hand, the greenhouse effect is a naturally occurring phenomenon that modifies the climate of the planet by producing an atmosphere that is comparatively warm and pleasant near the surface, thus providing sustenance for both people and other living things (IPCC, 2022). While on the other hand, anthropogenic activities are gradually raising the number of greenhouse gases (GHGs) due to carbon dioxide (CO_2), water vapor (H_2O), nitrous oxide (N_2O), methane (CH_4), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and other GHGs. This is causing an overall increase in the earth's temperature, which is known as global warming (Tripathi et al., 2016).

The first step in tackling climate change is realizing its dire consequences for ecological and human systems, as well as the risks and vulnerabilities they provide. This is an essential first step in realizing how urgent the current climate emergency is. An annual report, published in 2022 by the United Nations Climatic Change Secretariat (UNCCS), outlines trends in climatic indicators including temperature, precipitation, sea level rise, ocean acidification, and extreme weather occurrences. Heatwaves, wildfires, droughts, floods, hurricanes, severe storms, and landslides are a few of the climate risk events that are known to occur, according to UNCCS (2019). The IPCC (2018) projects that global warming will reach 1.5 °C between 2030 and 2052 if present emission rates persist.

2.3 Impacts of Climate Change on Agricultural Production Globally

The devastating environmental changes have had significant impacts on agricultural productivity, human health, and natural systems (Arunanondchai et al., 2018). There have been worries about the stability of the global environment, due to population growth and food security. The fertility of the soil, air pollution, and water availability all significantly affect agricultural output (Noya et al., 2018). Due to the direct and indirect effects of abiotic stressors, the adverse effects on plant productivity are intensifying with sudden environmental changes.

The demand for food production rises as the world population increases. By 2050, the world's population is expected to reach 9.73 billion people, and the increase will continue until it reaches 11.2 billion by the year 2100 (FAO, 2017). Many obstacles, such as soil salinity in arid regions, hinder agricultural output and reduce crop productivity (Hammam & Mohamed, 2018; Mohamed et al., 2019b; Said et al., 2020; Abdel-Fattah et al., 2020). Furthermore, climate influences crop yield and quality and may make soil more susceptible to desertification (Abdel-Fattah et al., 2021). Food production is already being impacted globally by climate change and global warming in comparable ways (FAO, 2019b). Also, there is a significant increase in crop damage that will result from increasingly frequent and severe natural disasters like floods, droughts, and forest fires. According to the most recent IPCC report (IPCC, 2019), changes are expected in regions that are good for freshwater, food production, and biodiversity. More than 70% of the world's ice-free land surface is impacted by human activity. Predicting the behavior of food and feed production is challenging, particularly at the local level. As an illustration, the effects on pollinators (Kehrberger & Holzschuh, 2019), such as bees, are already under great pressure from habitat loss and intensive agriculture. The same is true for pests and diseases that affect livestock or crops due to global warming (Kebede et al., 2018; Zayan, 2019). Figure 2.1 summarizes the impact of climate change in agriculture and food security. Hence, Africa is one of the continent’s most severely impacted by climate change (Leal Filho et al., 2015).

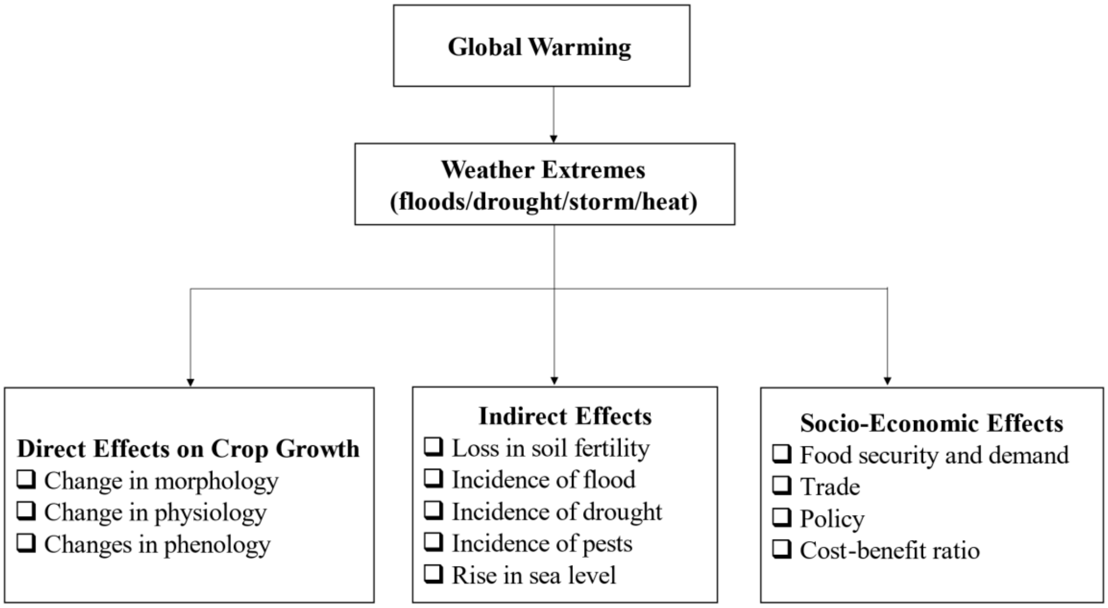


Figure 2.1: Impacts of climate change on agriculture and food security

2.4 Impacts of climate change on Agricultural Production in Africa

The Mediterranean Sea, Red Sea, Indian, and Atlantic oceans encircle Africa, making it the second-largest continent in the world. It is located between 37°21′N and 34°51′15′S in latitude and between 51°27′52′E and 17°33′22′W in longitude (National Geographic Society, 2023). According to predictions from Worldometer (2023), there will be 1.4 billion people living in Africa. Figure 2.2 illustrates that as of 2019 (Statista 2019), its agricultural land area amounted to 1119 million hectares. Although six of these nations have very low starting points, Africa's GDP is among the ten fastest-growing in the world. For many Africans, the main sources of food, fiber, and money are agriculture and fishing. According to Statista (2022), 43% of Africans of working age are employed in the agriculture sector.

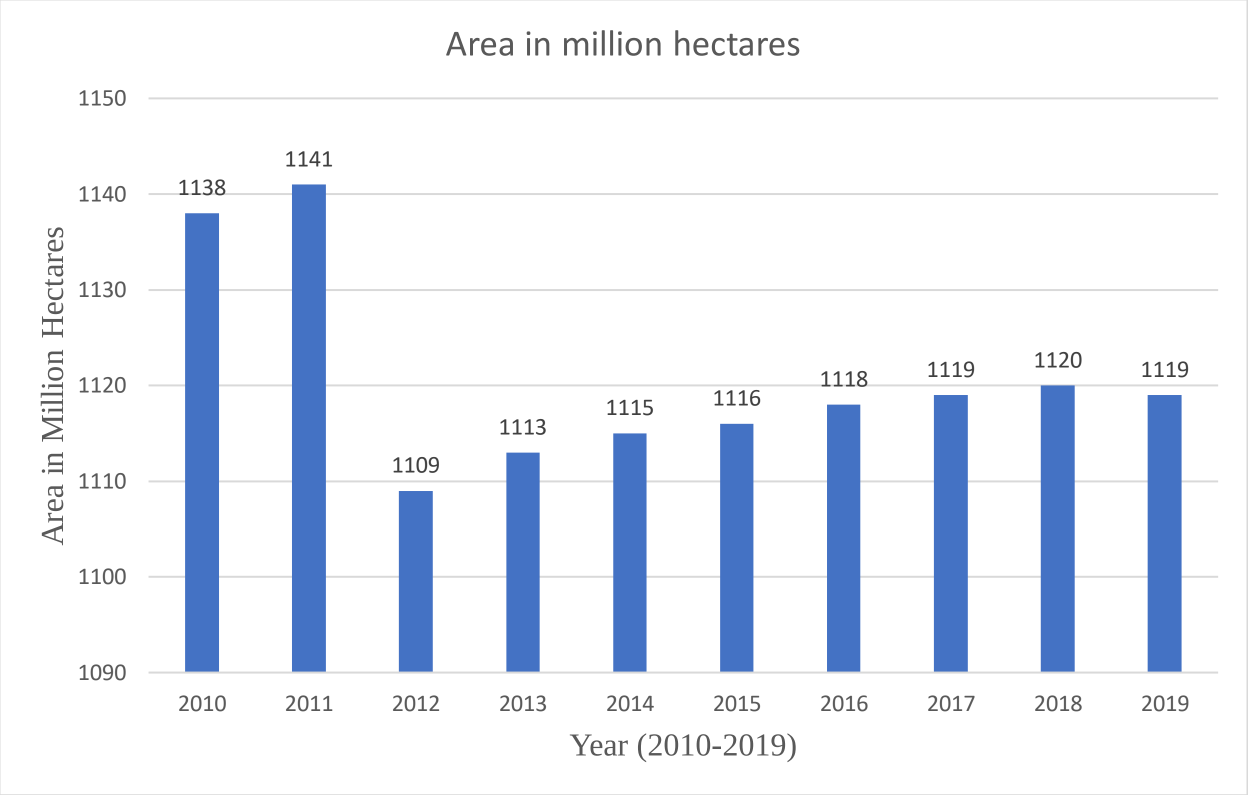


Figure 2.2: Statistic showing agricultural land distribution in Africa from 2010-2019

Climate change has a serious influence on Africa (Leal Filho et al., 2015). Higher sea levels, increased variable rainfall, and higher temperatures are all effects of climate change (CDKN 2014). Furthermore, trends in Africa's economy and population suggest that the consequences of climate change will only get worse. Growing populations, for example, will increase the need for food and water, yet prolonged extreme occurrences, such as droughts, would put further strain on already scarce water supplies and reduce agricultural production (CDKN, 2014). There are already risks to food production in the region, and these risks could get worse if the climate changes. In scenarios where global warming approaches 4°C, there would be a grave risk to food security in Africa, and there would be little chance of risk reduction through adaptation (Niang et al., 2014). Enhancing the economic performance of agriculture is essential to accomplishing the (-SDGs-) and fulfilling the needs of food security and nutrition for the growing population of the continent, which will also result in the realization of AU Agenda 2063. The situation has gotten worse because of its geographic characteristics, which include most of its land being in the warming tropics, as well as its comparatively low ability for social, economic, and human adaptation to the effects of climate change.

African agriculture is vulnerable to climate change because its agricultural systems are rainfed. The majority of African farmers operate on small-scale farming or subsistence agriculture and have little financial resources, scant access to infrastructure, inconsistent information availability, and low dependence on technology. This makes African agriculture particularly vulnerable to the effects of climate change. According to Shackleton et al., (2015), the continent's inability to adapt to climate change is further attributed to persistent poverty and social inequality, low levels of development, limited economic capacity, and governance issues. The region's agriculture, fisheries, and food security are predicted to be severely harmed by new climate change concerns, which will also feed back into development and undermine progress in reducing poverty and inequality (Shackleton et al., 2015).

2.5 Impacts of Climate Change on Agricultural Production in The Gambia

The Gambia’s progress towards the 2030 Agenda and (SDGs) has not been materializing because of the exogenous shocks from climate change. These factors have led to widespread rural-urban migration, increased rates of poverty, and food and nutrition security. Agriculture is a significant industry and economic engine that employs many smallholder farmers and contributes around one-quarter of the country's GDP. About 70% of the workforce in The Gambia is employed in agriculture, rice, groundnuts, millet, and sorghum are the principal crops farmed in the area. Roughly half of the population's food demands are met by imports due to low agricultural productivity (WFP Annual Report, 2021).

The Gambia is one of the poorest nations as 21.3% of its people live close to the multidimensional poverty line, while 57.2% of people are "multidimensionally" poor. Low productivity is intimately linked to food insecurity, malnutrition, and rural poverty, especially in the rain-fed sector. Poverty levels have not significantly altered, and the projected 3.5 percent GDP growth rate per year is insufficient to do so. For most rural residents and households living below the poverty line, agriculture is their primary source of income. Though it only makes up 24% of the GDP, it employs almost 70% of the people. The majority of arable land is farmed by rain, with 3% thought to be farmed by irrigation. The Gambia is one of the nations that is at risk of climate change. It has suffered from severe drought in 2011 and 2014, which has previously resulted in a 50% decrease in production. Saltwater intrusion has grown to 150–200 km inland due to the accelerated effects of climate change, which also impact production. These consequences are attributed to rising sea levels and decreased rainfall (IFAD, 2021).

2.6 Linear Regression

The linear regression method is a non-parametric test that determines the relationship between a single dependent variable and an independent variable that has a causal link. In the concept of statistical solving, simple linear regression is an empirical approach and it can solve the tasks by considering the historical data set of the climate values or parameters. Simple linear regression will be represented as follows:

$$Y= \alpha+\beta X \qquad \text{Equation 2.1}$$

Where Y= dependent variable, X= independent variable, α, β = regression coefficients

In simple linear regression, it is implemented by calculating the slope and intercept because it will be like a mathematical equation of slope, and intercept line. The regression coefficient formula can be used to evaluate the direction and degree of the correlation between the two variables. Similar to this, different correlation coefficient formulas can also be found in statistical and mathematical evolution processing. The formula for r is as follows:

$$r = \sum(x_i - \bar{x})\,(y_i - \bar{y}) / \sum(x_i - \bar{x}) \qquad \text{Equation 2.2}$$

2.7 CROPWAT Model

CROPWAT is a crop water requirement and irrigation water requirement model that was developed by FAO under the land and water division in the year 1992 (Smith, 1992) to enhance crop water productivity and irrigation water requirement in agricultural production (Aravind et al., 2021). It has fewer parameters, is easier to use, more accurate, and has lower error probability than other models (Kang 2009). It is especially successful in locations where water is a constraint (Chisanga et al., 2022). The main uses of the CROPWAT model include estimation of crop water requirement, scheduling of irrigation activities, water productivity assessment, and assessing the potential impact of climate change on crop water requirement. It is an empirical decision-support tool that is used for calculating crop water and irrigation needs by inputting variables such as crop data, soil data, crop patterns, rainfall data, and climate data (Tibebe et al., 2016). CROPWAT uses the FAO-modified Penman-Monteith method to estimate crop water requirements and evapotranspiration (Ali et al., 2022).

Additionally, CROPWAT can be used in conjunction with the FAO's CLIMAT 2.0 database files, which compile climate data for simulations from roughly 5000 agro-meteorological stations worldwide. Monthly averages of the climate from 1971 to 2000 are included in the database. Moreover, CROPWAT contains certain experimental crop and soil data that are helpful in situations where a modeler lacks enough information. To achieve dependable model outputs, it is strongly advised that this data be calibrated and validated using field data collected from the study region.

Most of the literature on the Cropwat model makes analysis based on CWR, IWR, irrigation scheduling, net irrigation, crop evapotranspiration, and reference evapotranspiration calculation. Some of the research was conducted by (Moseiki et al., 2020; Song et al., 2015; Nivesh et al 2019; Madhusudhan et al., 2021; Moseiki et al.,2019) on the CWR of some crops namely rice, groundnut, sesame, cotton, etc. shows that CWR of crops is higher in the dry season than raining season, different crops have different CWR, it varies based on the growth stages (initial, development, mid-season and late season) and season to season. According to Vadde et al., (2017), IWR is the additional amount of water required by a crop when there is insufficient rainfall to meet the CWR. It further indicates that irrigation demand is higher during the dry season and lower during the wet season, while the average water demand closely resembles that of normal situations. Meanwhile, (Roja et al., 2020) state that irrigation scheduling is done to help the farmer apply the right amount of water to the crop at different periods by stressing that injudicious application of the groundwater would lead to the depletion of the groundwater table. Net irrigation was defined by (Vadde et al 2017; Surendran et al., 2015) as the amount of water needed to bring the soil to field capacity. It can be lost through percolation, run-off, and seepage. Evaporation normally takes place during the irrigation application of water. The net irrigation requirement is the amount of water that is not effectively provided by rainfall (NIR = ET_c – Effective rainfall). It further buttressed that the net irrigation requirement is highest during dry conditions and lowest during wet conditions. Furthermore, (Moseki et al., 2020; Abdrabbo et al., 2015) use the RCPs to project future impacts of climate on CWR and IWR.

2.8 Questionnaires

Questionnaires or surveys are valuable tools that are used for obtaining primary data from respondents. It has been used in climate change studies to obtain important information in the field based on the researcher's objectives. Different types of surveys are used in climate change studies but the most prominent ones are; perception surveys, vulnerability assessments, and adaptation and mitigation surveys.

(Agwu et al., 2018; Arku et al., 2017) conducted a farmers' perception survey on the impacts of climate change on crop production, the findings show that most of the respondents understood climate change as a prolonged dry season and changes in rainfall patterns, but the impacts on productivity were not clear.

The importance of the perception survey over the other climate change surveys cannot be overemphasized because it helps climate change researchers obtain people's subjective views, and beliefs regarding climate change through the administration of questions. It can be used to find possibilities and obstacles to climate change action, and it encourages a participatory approach that involves the communities which can help to build trust and collaboration leading to a more impactful and sustainable outcome. Hence, this study decided to use it because it addresses the objective of this study which is to examine farmers' perceptions of some of the challenges, they face in groundnut production due to climatic, and non-climatic factors.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This chapter covers all the techniques and methods that have been used for conducting this research. This section describes the methodology that was followed in the study to answer the research questions.

3.2 Study Area

The North Bank Region, one of The Gambia's five administrative regions, is the study area of this research. It is located at longitude -16.09382390 W and latitude 13.49547950 N. Kerewan is its capital. Later, it was reorganized into the Kerewan Local Government Area (LGA) without changing the area it covered. As of the 2013 census (GBOS, 2013), it had 221,054 residents, giving it a population density of 98 inhabitants per km^2.

The region's vulnerability to drought has increased during the 20th century. This pattern, like the Sahelian region overall, witnessed relatively high rainfall until the late 1960s, then severe droughts in the 1970s and early 1980s, and a scant recovery in the 1990s and 2000s (Dietz et al., 2004; The Gambia Department of Water Resources, 2003).

The North Bank Region is part of the Sudan-Sahelian zone, which receives 600–900 mm of rain each year. The area saw less rainfall in 29 of the 40 years from 1972 to 2011 than the country as a whole (Yaffa, 2013). According to the Department of Agriculture (2005) states that the two most common soil types in the area are clay-loam and sandy-clay-loam, both of which have low fertility and poor soil structure. Additionally, the area is more vulnerable to harsh weather because it has less vegetation than the rest of the nation (Gibba, 2002).

The shape files of Africa, The Gambia, and the study area (North Bank Region) were obtained from the Diva-gis website (https://www.diva-gis.org/). It was then exported to the ArcGIS Desktop 10.6 to analyze it to obtain the study area map.

The Map of the Study Area North Bank Region- The Gambia

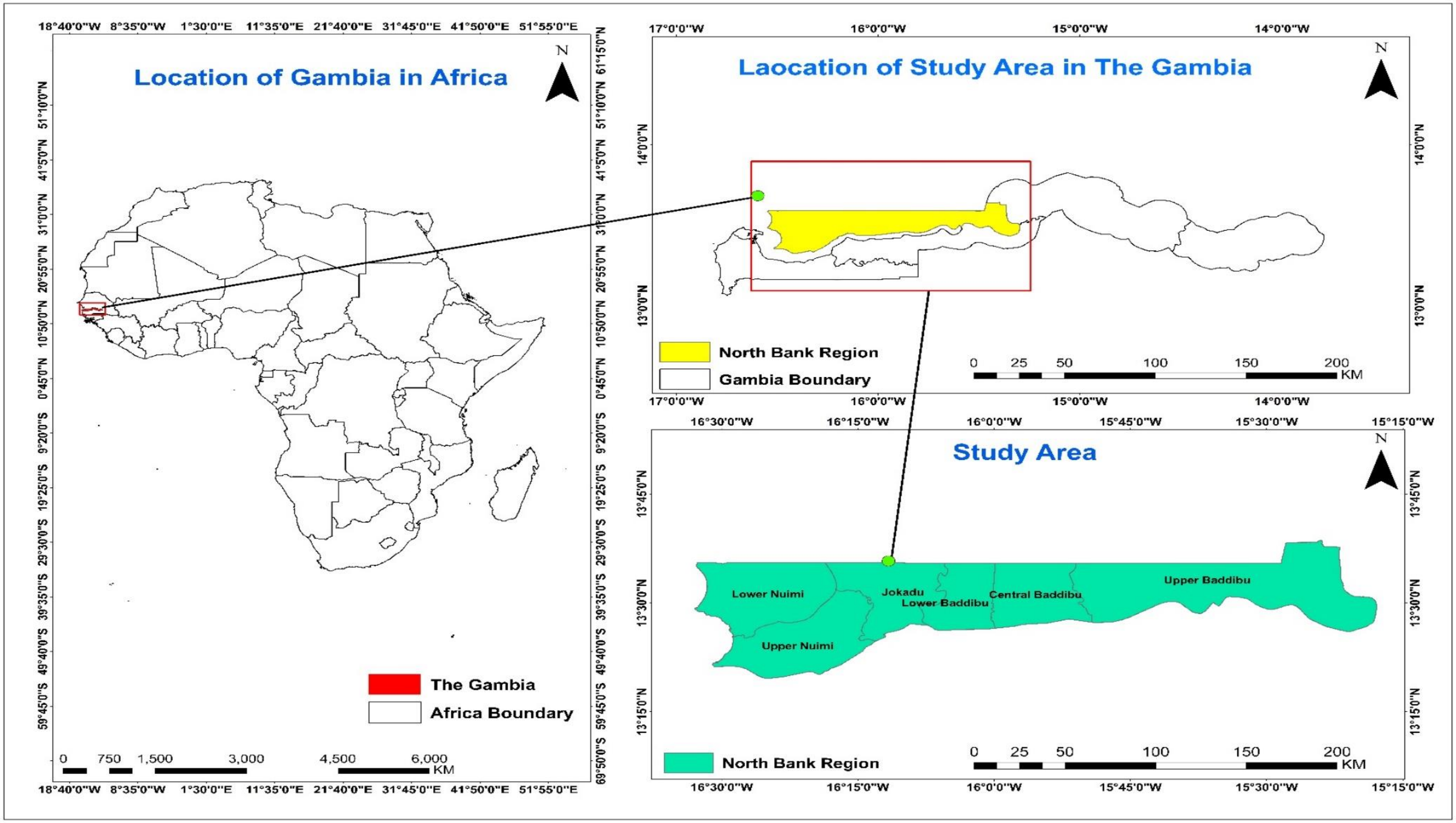


Figure 3.1: Geographic location of the study area

3.3 The seasonal calendar of The Gambia

Groundnut is sown from June-July, harvested from the second week of November to February and the lean season is from May to September.

Table 3.1: The Seasonal Calendar of The Gambia

The Gambia	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Rainy season												
Flood						▨	▨	▨	▨			
Drought	▨					▨	▨	▨	▨	▨	▨	
Sowing/planting					Maize	Maize, Rice, Sorghum, Millet, Groundnuts	▨					
Harvesting	Groundnuts	▨							Maize	Maize, Rice, Sorghum, Millet	Groundnuts	▨
Lean season					▨	▨	▨	▨	▨			

Source: The Ministry of Agriculture (MOA), 2015.

3.4 Choice of crop and model

The model and crops chosen for this study are determined by several factors.

A. Crop: The study area is home to a large number of crops. Horticultural crops like tomatoes, okra, peppers, cabbage, and pumpkins, as well as tuber crops like cassava, carrots, and sweet potatoes, cereals like maize and millet, and oil crops like groundnuts, are the most often grown crops in the area. Groundnuts are the sole crop examined in this study. The following factors are some of the criteria that are used for the selection of groundnuts:

For this study, only one crop (groundnut) is studied. The selection of groundnut is based on the following reasons:

1. In the research region, groundnuts are the most widely produced crop and a significant cash crop.

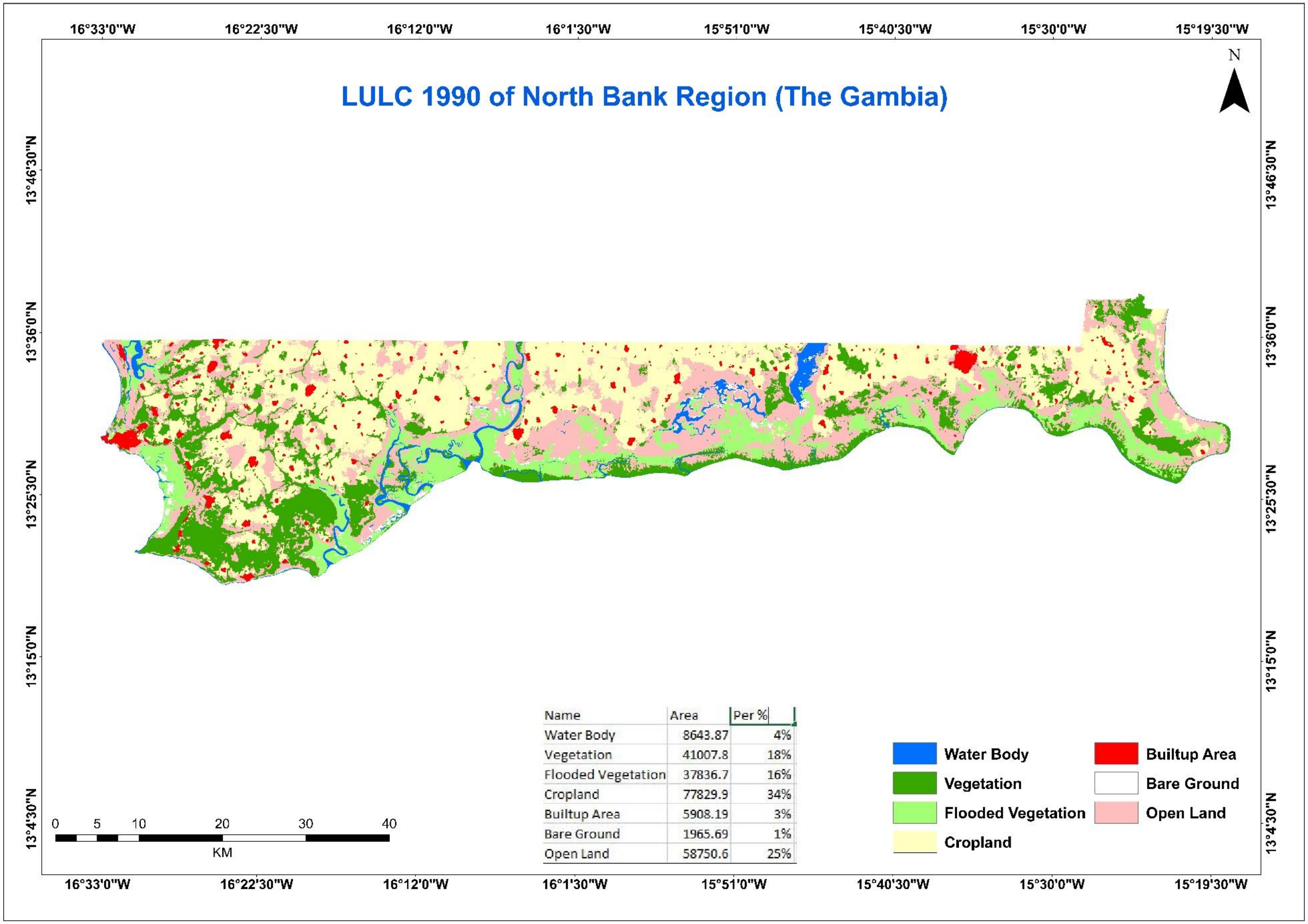
2. Data on groundnuts are accessible for the research region.
3. It contributes to preserving the research area's soil fertility.
4. Through the sales of groundnuts to the neighboring countries, either raw or processed, it provides revenue for the farmers.
5. The exports of groundnuts and groundnut products, generate foreign exchange for the government.
6. Since the Gambia's agriculture is rainfed, it is vulnerable to climate change due to the delayed rainfall and high temperatures.

B. Model- There are many crop models in the world but the biggest challenge is which model best works for specific research. The choice of crop model is made based on data availability, the researcher's background of the study, and the specific objectives. Thus, the CROPWAT model was chosen for the following reasons:

1. CROPWAT is a soil-water balance model that can accurately simulate daily water balance, to calculate the reference evapotranspiration and crop water requirements under different climatic conditions, soil, and management practices.
2. The CROPWAT model is user-friendly and it requires relatively small input data to produce a reliable output result than other models.
3. The CROPWAT model aligns with the research objectives and the researcher's area of specialization, which is climate change.
4. It is a water-driven crop model that is used for stimulating crop growth and development which is more suitable for climate change studies by taking into account evapotranspiration, rainfall, and irrigation.
5. It has been widely validated around the world since its inception in 1992 under various climatic conditions and when evaluating the effects of climate change on crop and irrigation water requirements, it has demonstrated the ability to yield accurate results.

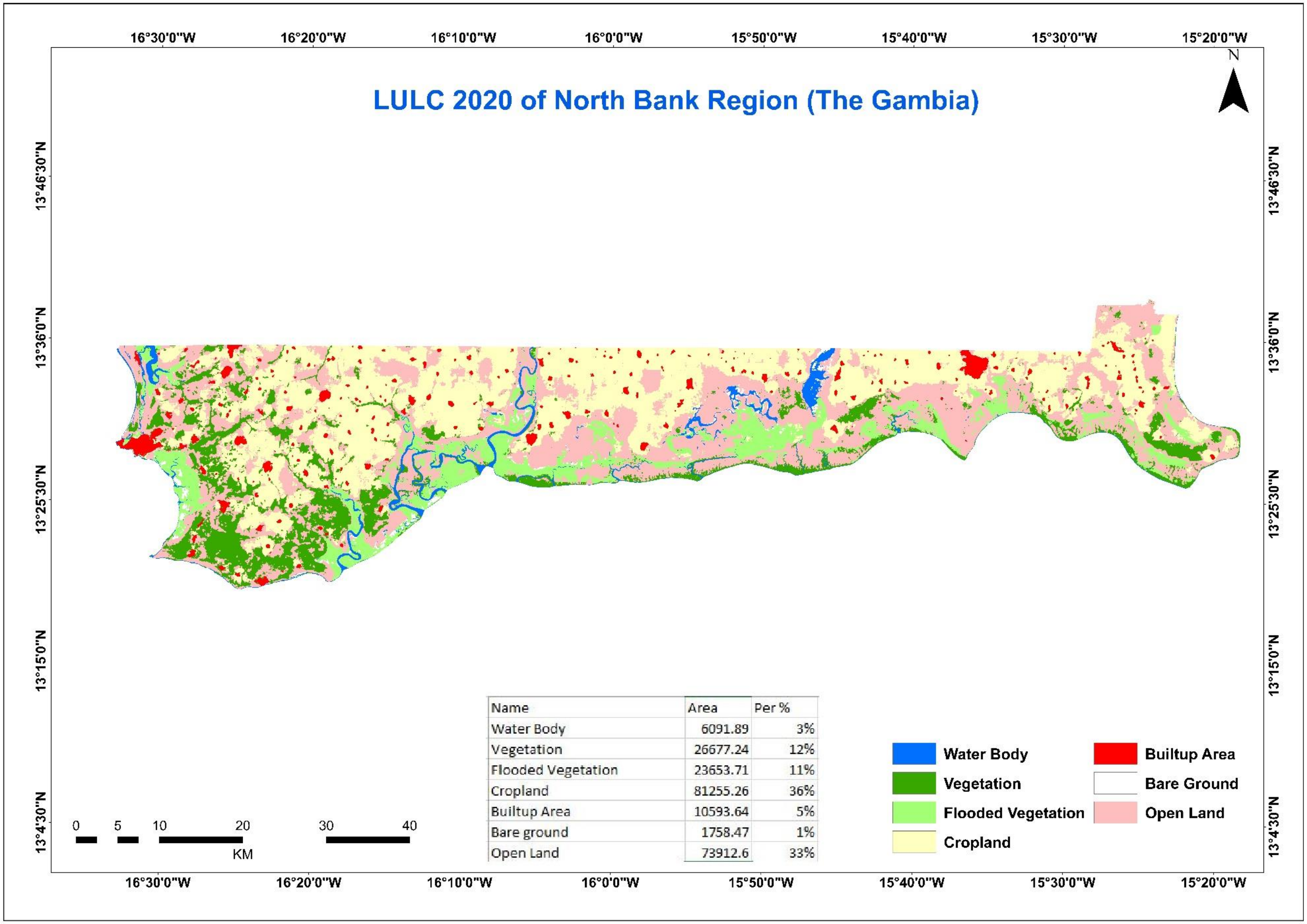
3.5 Land Use Land Cover Map of the Study Area (North Bank Region)

Land use and land cover (LULC) are terms often used interchangeably, yet they have different meanings. Land use refers to the way and manner people are using land for development such as agricultural activities, settlement, or recreational purposes, whereas land cover refers to the physical land type such as how much of the region is covered by forests, impervious surfaces, wetlands, and open water (NOAA, 2015). There are many reasons why land use and land cover are changing regularly. These include natural causes like climate variability or climate change causing floods and droughts, or anthropogenic causes like industrialization and urbanization.



Name	Area	Per %
Water Body	8643.87	4%
Vegetation	41007.8	18%
Flooded Vegetation	37836.7	16%
Cropland	77829.9	34%
Builtup Area	5908.19	3%
Bare Ground	1965.69	1%
Open Land	58750.6	25%

Figure 3.2: The land use/land cover map of 1990 of the study area



Name	Area	Per %
Water Body	6091.89	3%
Vegetation	26677.24	12%
Flooded Vegetation	23653.71	11%
Cropland	81255.26	36%
Builtup Area	10593.64	5%
Bare ground	1758.47	1%
Open Land	73912.6	33%

Figure 3.3: The land use/land cover map of 2020 of the study area

Figure 3.2 and Figure 3.3 show maps of LULC of the study in 1990 and 2020, respectively, which were downloaded from the USGS website free to access at https://earthexplorer.usgs.gov/. The downloaded satellite images for the year 1990 were acquired using Landsat 4-5 TM C2 L1 and for the year 2020 were acquired using Landsat 8-9 OLI/ TIRS C2 L1 and then it was transferred to the ArcGIS 10.8 to do the analysis using the analyst tool. The training samples were selected and then the supervised classification was run to get the LULC classes. The LULC area figures were calculated by using the geometry calculation and then the area figures were imported into MS Excel to get the percentage of each LULC class.

The percentage for the water body in 1990 was 4% and in 2020 it is 3%, showing a decrease of 1% because of low rainfall due to climate change and high evaporation rate. The percentage of vegetation was 18% in 1990 and in 2020 it is 12%, showing a decrease of 6% because of an increase in built-ups and also clearing of land for farming purposes. The percentage of flooded vegetation in 1990 was 16% and in 2020 it is 11%, showing a decrease of 5% because of mangrove dieback and anthropogenic activities such as cutting the mangrove for roofing. The percentage of cropland in 1990 was 34% and in 2020 it is 36%, which shows a 2% increase because people in the region are now focusing more on farming activities. The percentage of the built-up area in 1990 was 3% and in 2020 it was 5% which shows a 2% increase due to an increase in population and settlement. Both in 1990 and 2020 the percentage of bare land was 1%, with no changes. The open land in 1990 was 25% and in 2020 it is 32% which shows an increase of 7% due to deforestation.

3.6 Soil Texture of North Bank Region

Soil texture plays a significant role in agricultural production. It is the relative proportions of different particle sizes in soil, specifically sand, loam, and clay. Each soil type has different properties that can impact agricultural production in various ways: water retention and drainage, nutrient retention and availability, aeration, and root development.

The soil data of the study area was downloaded from the FAO soil portal website. It was then exported to ArcGIS 10.8 for analyses using the analyst tools. The SWAT model 2012 was used to classify the soil. Soil texture of the study area has four different types of soils namely clay-loam, loam, sandy-loam, sandy-clay-loam, and water. Sandy-clay-loam is the most predominant soil in the study area as shown in Figure 3.4. According to a 2022 report from the Ministry of Agriculture-

Department of Soil and Water Conservation, groundnut production performs well in sandy-loam soil. The soil map data was validated with data obtained from the National Agricultural Research Institute- Soil Department for the study area.

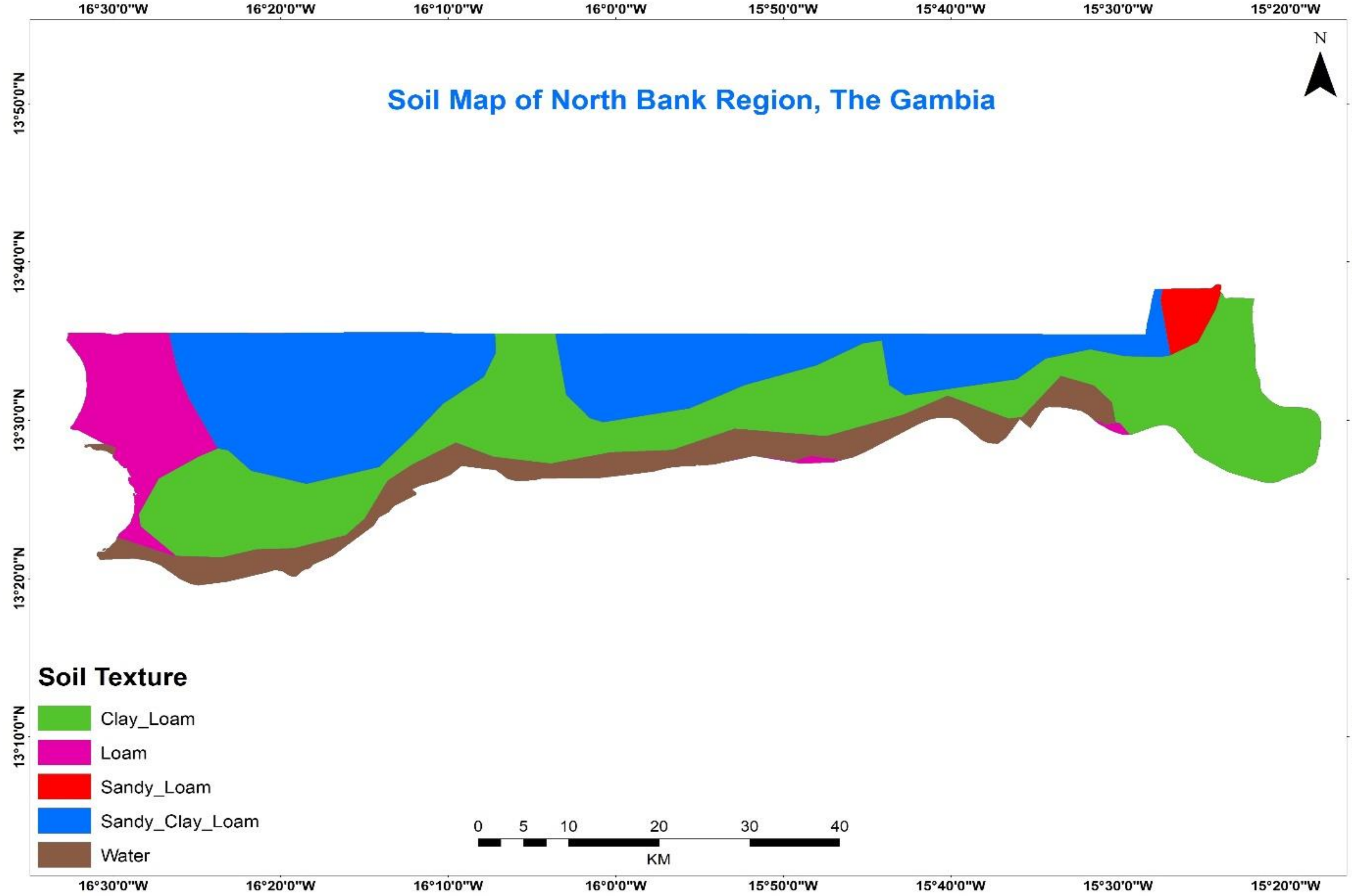


Figure 3.4: The soil texture of the North Bank Region (The Gambia)

3.7 Data Sources

The Climate data (temperature and rainfall) for 30 years from 1990-2020 was obtained from the Ministry of Water Resources under the metrological unit and the groundnut yield data for 30 years from 1990-2020 was also obtained from the Ministry of Agriculture-Department of Planning.

Agroclimatic data were obtained from the CLIMWAT, which is a database that allows, the calculation of crop water requirements, irrigation supply, and irrigation scheduling for various crops for a wide range of climatological stations worldwide. CLIMWAT 2.0 offers observed agroclimatic data for over 5000 different stations around the world in the years 1971-2000. So, the Kerewan station (North Bank Region) data from 1971-2000 was used in the CROPWAT model to stimulate the result for the baseline. For the future climate scenario, the data was obtained from the climate knowledge portal 2.0 administered by the World Bank and is free to access at https://climateknowledgeportal.worldbank.org/country/gambia/cmip5 at the same time the multi-model ensemble was used because it incorporates expert model's opinions from multiple different sources, to provide a more comprehensive understanding on the potentials impacts of climate change, which was used in the generation of CMIP 5 IPCC fifth assessment report (AR5) under RCP 4.5 2020-2039 near future and RCP 8.5 2060-2079 mid-term future. Additional climate variables, such as wind speed, relative humidity, and radiation, were gathered from current climate data.

Farmers' perception data was obtained through a survey using semi-structured questionnaires. The questionnaires were used to interview the groundnut farmers on some of the challenges that they are facing on their farms and focus group discussions were also conducted too to get a better understanding of the challenges that they faced.

3.8 Methods

Objective one was analyzed using the linear regression method. The rainfall data from 1990-2020 was used against groundnut yield data from 1990-2020 to determine the relationship between the two. The temperature data from 1990-2020 was also used against groundnut yield data from 1990-2020 to determine the relationship between the two. The ANOVA table would further be used to break down the components of the variation in the data into variations between treatments and errors or residual variations. The purpose of using the ANOVA table in this research is to determine if the linear regression model best fits the data and if the independent variables in the model have a significant effect on the dependent variable because the ANOVA table helps to test the null hypothesis and the alternative hypothesis. This information can help determine the reliability and validity of the model.

Objective two was analyzed by using the CROPWAT model latest software version of 8.0, which requires relatively little input data and the results are satisfactory (Vozhehova et al., 2018). The CROPWAT model was used in conjunction with the CLIMWAT to obtain the simulated result for the baseline and to obtain the future scenarios the CROPWAT model was also used.

3.8.1 Description of the Input Variables in the CROPWAT Model

The input variables in the CROPWAT model include the following:

A. Climate data

The CROPWAT model needs monthly rainfall data, monthly means of minimum temperature (0C), Maximum temperature (0C), air relative humidity (%), Sunshine duration (h), wind speed at 2m high (m/s), Potential evapotranspiration (Eto) measured or calculated with Pen-man-monteith (Umesh et al 2022).

A. Monthly rainfall data
B. Monthly means of Minimum temperature (^{0}C), and Maximum temperature (^{0}C),
C. Air relative humidity (%),
D. Sunshine duration (h),
E. Wind speed at 2m high (m/s),
F. Potential evapotranspiration (Eto) measured or calculated with Penman-monteith

The Penman-Monteith equation is used for calculating the evapotranspiration. The formula is seen below:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \qquad \text{Equation 3.1}$$

ET0 = Daily reference evapotranspiration (mm/day)

Δ = Slope of vapor pressure curve (kPa0/C)

Rn = Daily net radiation (MJ/m2)

G = Soil heat flux (MJ/m2)

γ = Psychometric constant (kPa0C.MJ/m^2)

Tmean = Daily air temperature (0C)

U2 = Daily wind speed at an elevation of 2m

es = Saturation vapor pressure, kPa

ea =Actual vapor pressure (kPa)

900 = Conversion Factor

B. Rainfall Data

The main source of water supply for Agriculture in most parts of the world is rainfall. It differs from place to place. An agriculturist's definition of effective rainfall is the amount of rain that directly meets crop water needs and also the surface runoff that can be utilized for crop production on the farms which is mostly pumped from ponds and wells. However, some parts of the rainfall are normally lost through percolation, evapotranspiration, and run-off. In the CROPWAT model, the USDA soil conservation service method is embedded in the model and it is used for estimating the effective rainfall through the following equations:

$$P_{eff} = \left[\frac{P_{dec} \times (125 - 0.6 \times P_{dec})}{125} \right] \quad \text{for } P_{eff} \leq 250/3 \text{ mm}$$ Equation 3.2

$$P_{eff} = \left(\frac{125}{3} \right) + 0.1 \times P_{dec} \text{ for } P_{dec} > 250/3 \text{ mm}$$ Equation 3.3

Where P_{eff} = Effective rainfall (mm)

Where P_{dec} = 10-day rainfall (mm)

C. Crop Data

The crop water requirement of a crop depends on the stage of growth, climatic factors, field management, and the varieties of the crop. The crop input variables are planting date, harvesting date, and duration of the growth season. The crop water requirement can be estimated using the following equation below (Ewaid et al., 2019).

$ET_c = ET_0 \times K_c$

Where:

ET_c = Crop evapotranspiration (mm/day)

ET_0 = Reference crop evapotranspiration (mm/day)

K_c = Crop Coefficient

Kc Crop coefficient (fraction) which describes the impacts of crop height, crop cover, canopy resistance, and soil evaporation = ETc Crop evapotranspiration (mm/day) and ET_0 Reference evapotranspiration (mm/day).

Kc values of different crops vary from place to place and season to season throughout the growing season due to the variation of the ET_o due to different growing stages of crop growth. Crop growing stages are the initial, development stage, mid-season, and late season (Allen et al., 1998).

D. Soil Data

Some of the soil parameters that are required as an input variable in the CROPWAT model are soil moisture, maximum rain infiltration rate, and maximum rooting depth.

E. Crop Pattern

Crop pattern refers to the cropping pattern of the crop its planting date, harvest date, rooting depth, crop co-efficient, Kc values (initial, development, mid and late growth stage), crop time duration, critical depletion, yield response factor and area of percentage cultivated are required to be inputted into the CROPWAT model, which has been taken from FAO irrigation and drainage paper 56. When a crop is faced with an evapotranspiration deficit, the yield reaction factor (Ky) measures how much the crop, weather, and soil combine to reduce crop yield relative to its potential yield. Dates for sowing and harvesting were chosen based on the recommendations given by the Department of Agriculture in the Gambia.

3.8.2 Calibration and Validation of Data in CROPWAT Model

The CROPWAT model stimulates crop water requirement, irrigation requirement, and irrigation scheduling based on climate data, rainfall, soil data, crop patterns, and crop data. Calibration and validation are very important processes in modelling. Calibration is the process of adjusting a model's input parameters to suitably stimulate outputs while Validation is the process of determining whether the model can effectively represent the real world.

For this research, six experimental crop data from 2014-2019 were obtained from the National Agricultural Research Institute (The Gambia) trial site. The data from the 2014-2016 groundnut growing season were obtained for calibration and 2017-2019 were obtained for validation. The information obtained from the research center was used for the calibration and validation of the cropwat model. Some of the crop parameters that were not obtainable from the research center and Ministry of Agriculture were obtained from the FAO guidelines manual 56 irrigation and drainage on Cropwat model. The monthly minimum and maximum temperature, rainfall, humidity, wind, and sunshine hours were all generated from the metrological stations in the study area from the period 2014 to 2019 which are all inputted in the cropwat model for the simulation.

The soil data includes: the total available soil moisture which can be estimated by subtracting the wilting point from the field capacity (FC-WP), maximum rain infiltration rate, maximum rooting depth, and initial soil moisture depletion (as % TAM), and initial available soil information were obtained from the Department of Soil (The Gambia) for the study area. During the model calibration, the data was inputted into the cropwat model to obtain the simulated result by fine-tuning the model through trials and error to ensure that the model accurately meets the real scenario in the study area.

The database of soil samples from the Department of Soil provided general information about the soil properties in the study area which are used in the model parameterization.

Table 3.2: Calibrated soil parameters for the simulation

Total available soil moisture (FC-WP)	130.0 mm/meter
Maximum rain infiltration rate	18 mm/day
Maximum rooting depth	60 centimeters
Initial soil moisture depletion (as %TAM)	30%
Initial available soil moisture	86.0mm/meter

The formula used for calculating the yield reduction is:

$$TA = 100 - (R_A \times 100) / RR \qquad \text{Equation 3.4}$$

TA is the yield reduction (%);
RA is the actual productivity (t/ha), and
RR is the potential productivity, and 5(t/ha) was used in this study.

Table 3.3: Percentage of observed yield reduction in the field

Year	Observed yield (t/ha)	Actual Productivity (t/ha)	Observed Yield reduction (%)
2014	1.00	4	0.2
2015	1.01	4.5	0.1
2016	0.84	3.5	0.3
2017	0.72	3	0.4
2018	0.44	2.5	0.5
2019	0.73	3.2	0.36

After the calibration, the validation process was performed to test the calibrated model. This was done by comparing the simulated yield reduction from the observed from 2017 to 2019. The Root Mean Square Error (RMSE), Mean Square Error (MSE), and coefficient of determination (R^2) are statistical indices that are used for measuring the performance of the validated model and to measure the fit between the simulated and the observed groundnut yield reduction.

Table 3.4: The statistical indices used for the evaluation performance of the Cropwat Model

Year	Observed Yield Reduction (%)	Simulated Yield Reduction (%)	R^2	RMSE (%)	MSE (%)
2017	0.4	0.5	0.94	0.084	0.0072
2018	0.5	0.6			
2019	0.36	0.4			

Wallach et al., (2006) states that working with RMSE (root mean squared error) is typically convenient because it has the same unit as the analyzed value, making it easier to understand. The evaluation yielded an RMSE value of 0.084%. Another method that prevents outcomes from being overestimated or underestimated, is mean square error, or MSE, and it is measured in the same unit as the analyzed value. This investigation yielded a value of 0.0072%. The R^2 coefficient, which measures the model accuracy, classifies the correlation between the observed and estimated values as very strong, with a value of 0.94, indicating that the simulated productivity followed the trend of the measured productivity when it increased or decreased. The accuracy of the model, as shown by the coefficient of determination (R^2), was 94%. In conclusion, validation for modeling the groundnut production was successful, exhibiting a high degree of prediction accuracy, together with outstanding performance and excellent indices metrics agreement.

3.8.3 Application of the CROPWAT

Excellent results have been obtained when estimating CWR and IWR for a variety of crops and locales using CROPWAT. The IWR for barley, wheat, tomatoes, and white corn in Iraq during different seasons could be precisely estimated using the CROPWAT model, according to Ewaid et al., (2019). Similarly, with the same results, the model was applied in India to determine CWR and IWR for maize, potatoes, wheat, castor beans, tomatoes, and soybeans (Memon & Jamsa, 2018; Shah, 2018).

With good results, CROPWAT has been used for irrigation scheduling, allowing farmers to schedule irrigation intervals, lessen water stress, and increase yields (Savva & Frenken, 2002). Additionally, future climatic data from climate models have been incorporated into the model to simulate future CWR and IWR for different crops, soil types, field management practices, and climate scenarios. The model produces outputs that can be used for planning purposes in the future (De Silva et al., 2007). According to Rahman et al., (2019), there has been a significant decrease in the water requirements for rice in Moulvibazar and an increase in Sylhet. Similarly, in Bangladesh, the effects of climate change on rice water requirements have been seen based on thirty years of meteorological data.

Despite its importance, CROPWAT has certain limitations. The model is sensitive to input parameters such as crop coefficients, soil properties, and crop rooting depths. Any small errors or uncertainties in these parameters can affect the accuracy of the model predictions. Furthermore, the model supports a wide range of crops, it may not include local cultivars, which might significantly differ in their water requirement to environmental conditions.

Objective three was achieved through the following:

3.8.4 Study Setting- The study was conducted in the north bank region which is divided into six districts, two districts namely Lower Baddibou and Upper Baddibou were chosen randomly based on their prominence in groundnut production, the representativeness of groundnut farmers, ecological circumstances, and socio-economic situations. Simple random sampling was employed to guarantee that every member of the target farmers has an equal and independent chance of being included in the sample, to select the three communities from each district. Kerr Ardo, Pallen Amdallai, and Torotyam were the communities that were selected from lower Baddibou. The communities selected from Upper Baddibou were Wallalan, Macca Farafenni, and Yallal Tankongali.

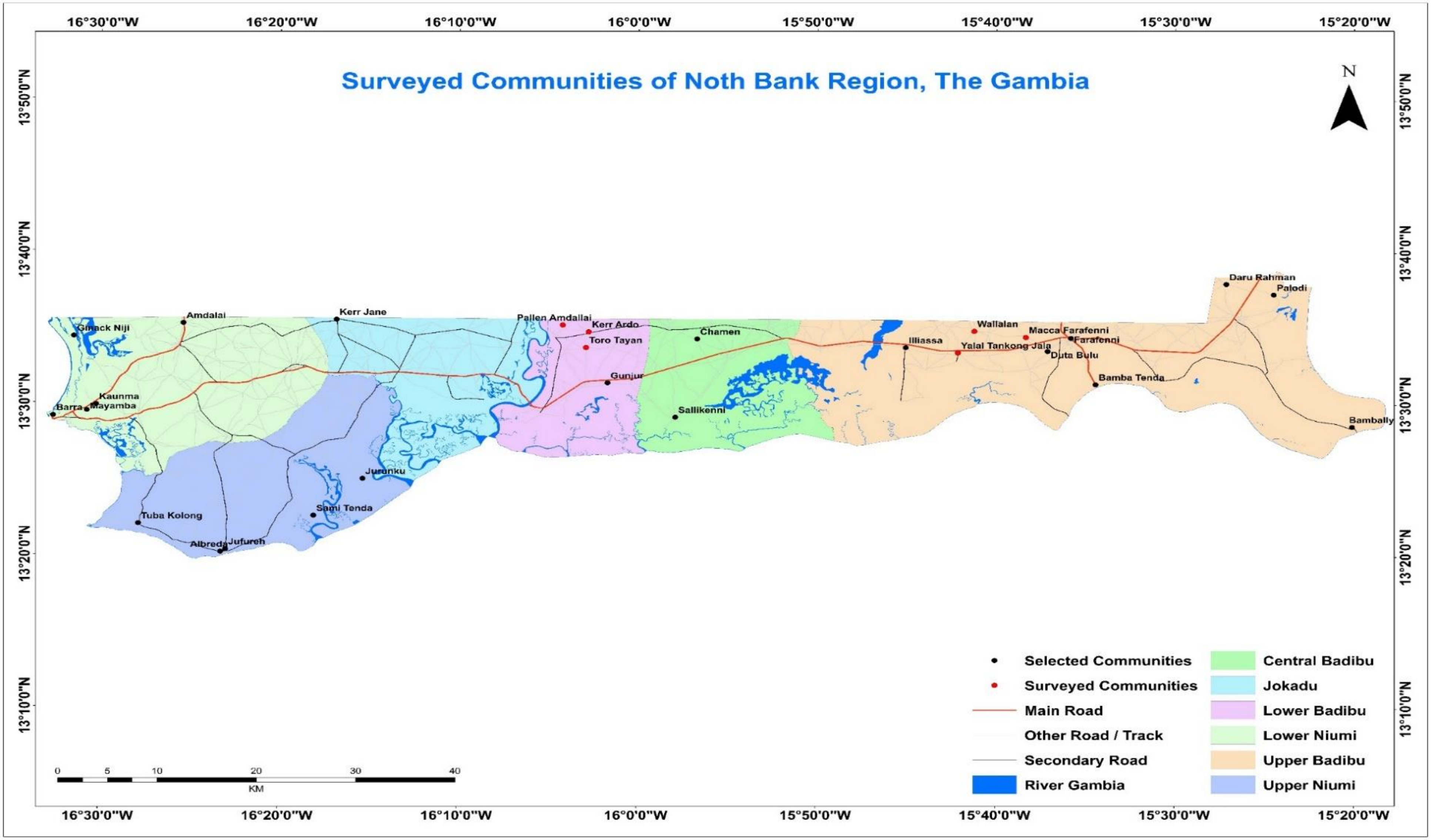


Figure 3.5: Surveyed communities of the study area

Table 3.5: Sample of the study area

Districts	Communities	No. of farmers interviewed	Percent (%)
Lower Baddibou	Kerr Ardo	23	21.30
	Pallen Amdallai	15	13.88
	Torotyam	10	9.26
Upper Baddibou	Macca Farafenni	20	18.52
	Wallalan	20	18.52
	Yalal Tankonjala	20	18.52
2 districts	**6 communities**	**108**	**100.0**

3.8.5 Research Design

This study used a qualitative research design. A qualitative approach was used during sampling, data collection, and analysis. At the data collection stage, farmers were interviewed using close-ended questionnaires on their opinions and ideas that they have had in groundnut production. They provided their responses based on the experience that they have for the past thirty years.

This study used a qualitative research design. A qualitative approach was used during sampling, data collection, and analysis. At the data collection stage, farmers were interviewed using close-ended questionnaires on their opinions and ideas that they have had in groundnut production. They provided their responses based on the experience that they have for the past thirty years.

3.8.6 Population and Sample Size

The North Bank Region of The Gambia was the study's location, and it was selected based on the criteria that it was more well-known for groundnut production than the other regions. The main importance of groundnut production in the region is that it provides income for the farmers, food for the population, and employment for the youths. Since it is a cash crop, the region even exports the groundnut to the neighboring countries. This study used sampling to obtain data from the field.

A sample of 108 farmers in the region was interviewed. The two districts known for groundnut production from the six districts were chosen with the help of the Regional Agricultural Directorate. From these two districts, three communities were selected from each districts making it six communities. The simple random sampling methods helped to make generalizations of the whole region due to the limited time for the research and resources. After the data collection, the following methods such as Microsoft Excel and graphs were used to analyze and present the data.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

This chapter discusses the study's findings using graphs, figures, and tables, comparing the findings from previous research, and addressing the research questions. Hence, this chapter will conclude by proposing a good policy framework that can be implemented in The Gambia.

4.1 Relationship between key climatic variables (temperature and rainfall) with groundnut yield from 1990-2020

The linear regression analysis of temperature and rainfall against groundnut yield for the years 1990-2020 is analyzed using the regression statistic and regression line.

4.2 Regression Statistic of temperature

The regression statistic of temperature refers to the trend analysis of the temperature against groundnut yield from 1990 to 2020.

Table 4.1: Linear regression analysis between temperature and groundnut yield from 1990-2020.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.41711138
R Square	0.1739819
Adjusted R Square	0.14549852
Standard Error	0.19473336
Observations	31

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.231629161	0.2316	6.10819	0.01957048
Residual	29	1.099711388	0.0379		
Total	30	1.331340549			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.4599858	1.366536858	-1.8002	0.082247	-5.25486752	0.3348959
Annual Temperature	0.12281398	0.049692582	2.4715	0.01957	0.02118124	0.2244467

From Table 4.1, it is shown that multiple R = 0.42, is the correlation coefficient value between temperature and groundnut yield. A value of 0.4 means that it has a low positive relationship.

The R square indicates the extent to which the independent variable accounts for the variance in the dependent variable. R Square = 0.17. So, to get the percentage it would be 0.17x100=17%. This means that 17% of the variance in temperature can be accounted for by the groundnut yield and the other 83% focuses on other factors.

The average gap between the observed values and the regression line is known as the standard error of the regression. So, the standard error is 0.19 indicating that the estimated value is exactly the true value and the standard error value would be 0.19mm from the regression line. The smaller the standard error, the more precise the linear regression model is and the value should always be 0 (or close to it).

In the ANOVA table the value of the significance F is paramount; it is also known as the P-value. To interpret the P-value it involves two scenarios the Null Hypothesis- There is no linear relationship between temperature and groundnut yield and the alternative hypothesis there is a linear relationship between temperature and groundnut yield. The laws of the p-value states that if the p-value is greater than 0.05 the hypothesis is Null and if the p-value is less than and equal to 0.05 the hypothesis is alternative. So, the p-value is 0.02 which is less than and equal to 0.05 meaning the hypothesis is alternative. It shows that there is a linear relationship between temperature and groundnut yield.

To interpret the p-value of the intercept of temperature, the p-value is 0.08. According to the law, the intercept or slope is equal to zero if the null hypothesis is true, while it is not equal to zero if the alternative hypothesis is true. So, the result shows that the hypothesis is alternative this means that temperature is a significant variable that impacts groundnut yield.

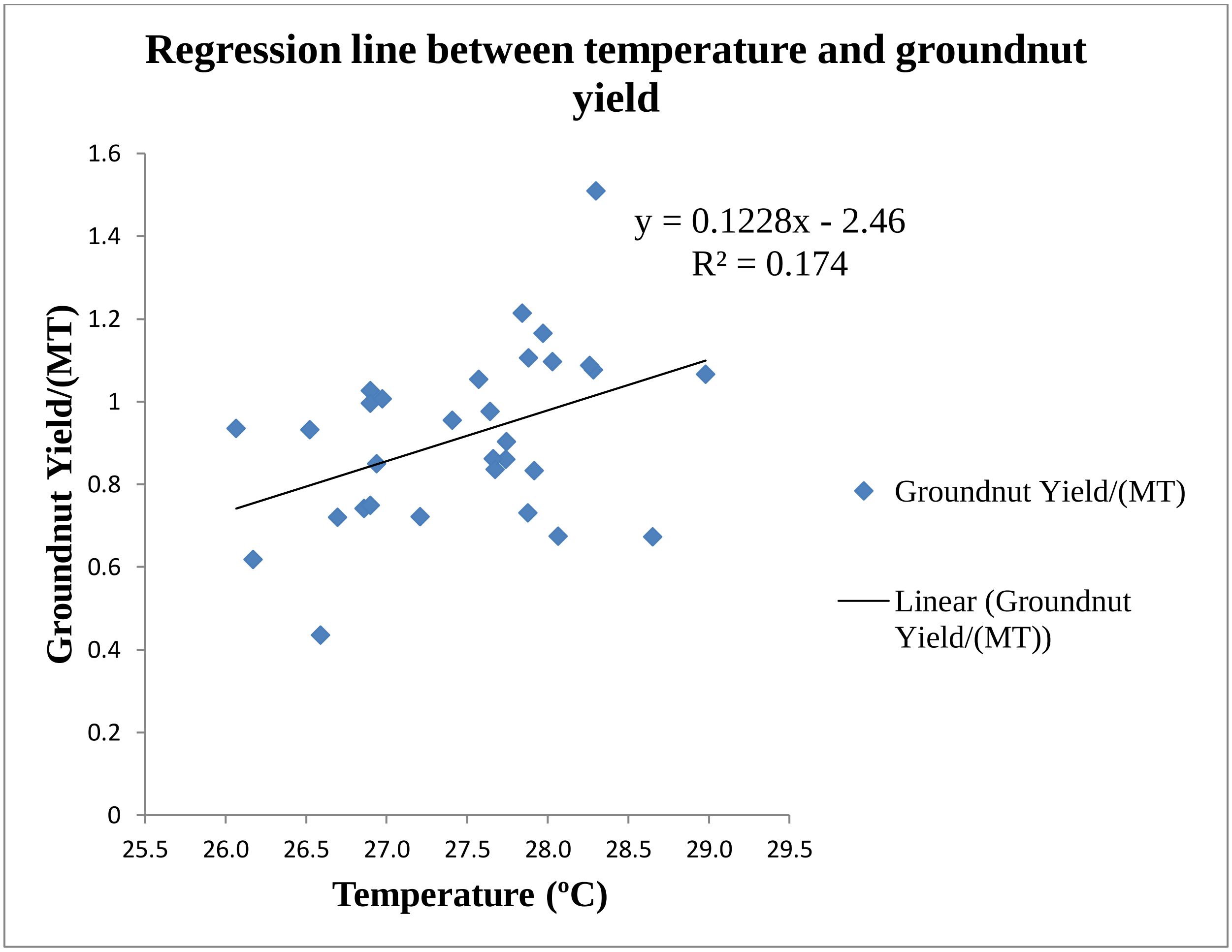


Figure 4.1: Regression analysis between temperature and groundnut yield

A positive coefficient was obtained from the regression analysis indicating a positive relationship which means that as the independent variable (temperature) increases, the dependent variable (groundnut yield) increases during the years 1990 to 2020. Hence, it is directly proportional.

4.3 Regression Statistic of Rainfall

The regression statistic of rainfall refers to the trend analysis of the rainfall against groundnut yield from 1990 to 2020.

Table 4.2: Linear regression analysis between rainfall and groundnut yield from 1990 to 2020.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.1046454
R Square	0.0109507
Adjusted R Square	-0.023154
Standard Error	0.2130858
Observations	31

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.014579047	0.01458	0.321084999	0.575316095
Residual	29	1.316761502	0.04541		
Total	30	1.331340549			

	Coeffi-cients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.0095415	0.168994559	5.97381	1.71149E-06	0.663908859	1.355174221
Rainfall (mm)	-0.000106	0.000187358	-0.5666	0.575316095	-0.000489354	0.000277024

From Table 4.2 shows that multiple R = 0.10, is the correlation coefficient value between rainfall and groundnut yield. A value of 0.1 means that it has a weak relationship.

The R square establishes the extent to which the independent variable may explain the variance in the dependent variable. R Square = 0.01. So, to get the percentage it would be 0.01x100=1%. This means that 1% of the variance in rainfall can be accounted for by the groundnut yield and the other 99% focuses on other factors.

The average separation between the observed values and the regression line is known as the standard error of the regression. So, the standard error is 0.21 indicating that the estimated value is exactly the true value and the standard error value would be 0.21mm from the regression line. The smaller the standard error, the more precise the linear regression model is and the value should always be 0 (or close to it).

In the ANOVA table the value of the significance F is paramount, it is also known as the P-value. To interpret the P-value it involves two scenarios the Null Hypothesis- There is no linear relationship between rainfall and groundnut yield and the alternative hypothesis there is a linear relationship between rainfall and groundnut yield.

The law of the p-value states that if the p-value is greater than 0.05 the hypothesis is Null and if the p-value is less than and equal to 0.05 the hypothesis is alternative. So, the p-value is 0.58 which is greater than and equal to 0.05 meaning the hypothesis is null. It shows that there is no linear relationship between rainfall and groundnut yield as shown in Table 4.2.

To interpret the p-value of the intercept of rainfall, the p-value is 1.711E-06. The law states that in the null hypothesis, the intercept or slope is equal to zero and in the alternative hypothesis the intercept or slope is not equal to zero. So, the result shows that the hypothesis is null this means that rainfall is not a significant variable that impacts groundnut yield.

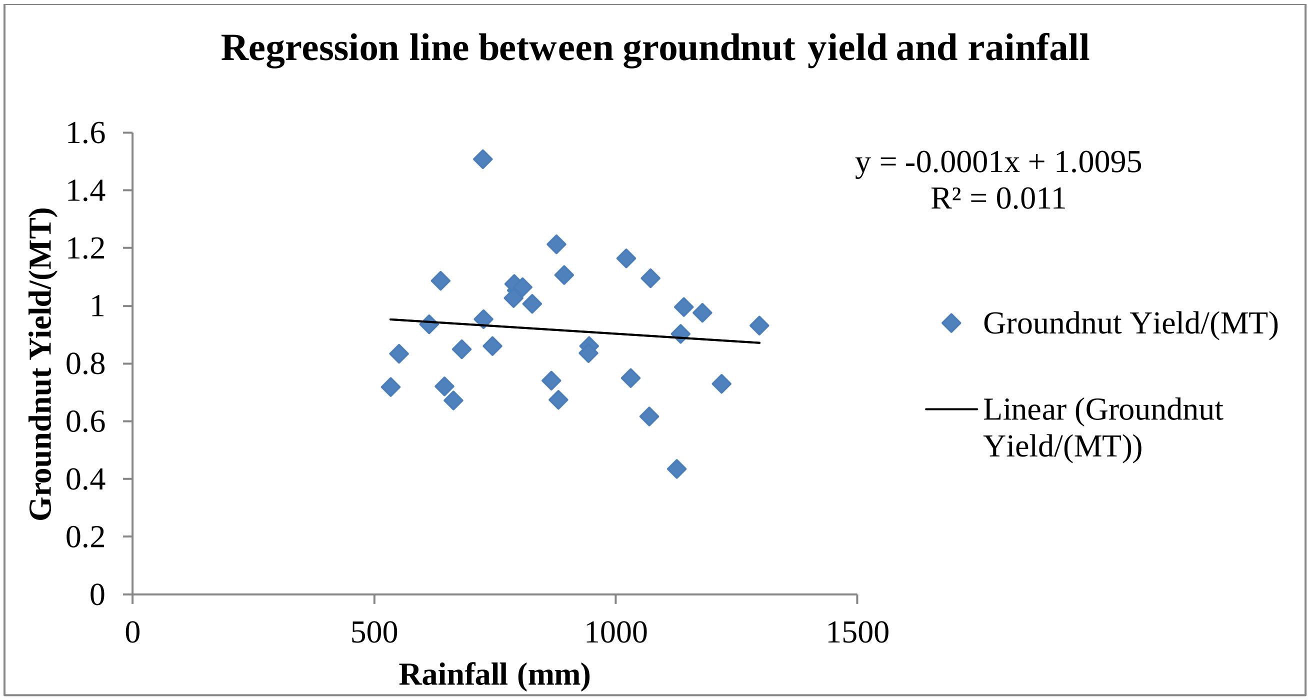


Figure 4.2: Regression analysis between rainfall and groundnut yield

A negative coefficient was obtained from the regression analysis indicating a negative relationship which means that as the independent variable (rainfall) increases, the dependent variable (groundnut yield) decreases during the years 1990 to 2020. Hence, it is inversely proportional.

In conclusion, the findings from the linear regression analysis between temperature and rainfall against groundnut yield show that the decline in groundnut yield is not rainfall, and temperature rise is causing a minimal increase in yield. So, the cause of the reduction in groundnut yield from the period 1990-2020 is due to other factors.

4.4 Potential climate impacts on groundnut irrigation water requirement in the North Bank region (kerewan station).

4.4.1 Baseline Analysis- The baseline analysis shows the analysis of the crop water requirements for groundnuts estimated for Kerewan, The Gambia, using the ClimWat software from (1971-2000).

Table 4.3: Description of the parameters used in the CROPWAT model

Parameter	Value	Justification
Crop Name	Groundnuts	Specified crop
Planting Date	June (Start of rainy season in The Gambia)	Typical onset of the rainy season in The Gambia
Kc Values (Initial)	0.4	Low water requirement during establishment (Ramachandran et al. 2022; Roja et al. 2020).
Kc Values (Development)	0.55-0.8	Increasing water requirement as the plant grows (Allen et al. 1998; Ramachandran et al. 2022)
Kc Values (Mid-season)	1.04-1.5	Peak water requirement for fully developed canopy (Ramachandran et al. 2022; Roja et al. 2020).
Kc Values (Late season)	0.6-0.83	Decreased water requirement as the crop matures (Roja et al. 2020)
Stage (Initial)	25 days	Typical for groundnuts in West Africa (Allen et al. 1998)
Stage (Development)	35 days	Typical for groundnuts in West Africa (Allen et al. 1998)
Stage (Mid-season)	45 days	Typical for groundnuts in West Africa (Allen et al. 1998)
Stage (Late season)	25 days	Typical for groundnuts in West Africa (Allen et al. 1998)

Parameter	Value	Justification
Rooting Depth (m)	0.5-0.7 m	Average rooting depth for mature groundnuts (Allen et al. 1998)
Critical Depletion	0.5 (50%)	Typical fraction for groundnuts before stress occurs (Allen et al. 1998)
Yield Response Factor	0.2-0.3	Standard yield response to water stress for groundnuts (Allen et al. 1998)
Crop Height (m)	0.3-0.6 m	Typical height of mature groundnuts (Allen et al. 1998)

4.4.2 Climatic Data- The climatic data and the potential evapotranspiration of the baseline analysis are presented in Table 4.4. The ET_0 on average was 4.82mm while the wind speed was 131km/day. The average sunshine hours were 7.6 hours meaning the sky was overcast most times of the day. The maximum and minimum temperatures were 34.7^0C and 21.1^0C which was ideal for the optimal growth and development of the groundnut (Peralta & Spooner, 2007). The length and intensity of rainfall, the connection between yearly precipitation and potential evapotranspiration, and the fluctuation in rainfall from year to year are the three main climatic elements that impact crops. The amount of rainfall, evaporation, temperature, soil conditions, and crop characteristics all affect how long the growing season is (Macharia, 2004).

Table 4.4: Climatic Data, Potential Evapotranspiration (ETO), Rain and Effective Rainfall

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Rad	ETo	Rain	Eff. Rain
	°C	C	%	Km/day	Hours	MJ/m^2/day	mm/day		
Jan.	17	33.7	44	104	7.8	18	4.24	1	1
Feb.	17.8	35.9	48	138	8.3	20.2	5.2	0	0
March	19.8	38	50	173	8.4	21.8	6.2	0	0
April	20.7	38.2	54	173	8.3	22.3	6.31	0	0
May	22.2	36.9	61	190	7.9	21.5	6.03	5	5
June	24	34.5	72	190	7.2	20.2	5.2	53	48.5
July	23.8	32.2	83	147	7	19.9	4.44	218	142
Aug.	23.7	31.6	90	104	6.5	19.4	4.05	256	150.6
Sept.	23.3	32.5	91	95	6.6	19.2	4	197	134.9
Oct.	23.2	33.9	87	95	7.7	19.6	4.2	49	45.2
Nov.	20.5	35.5	71	69	8	18.6	4.06	0	0
Dec.	17.3	33.7	52	95	7.2	16.7	3.92	1	1
Total								**780**	**528.1**
Average	**21.1**	**34.7**	**67**	**131**	**7.6**	**19.8**	**4.82**		

Temp.= Temperature; Max= Maximum; Min= Minimum; Rad= Radiation; ET_0= Evapotranspiration.

The effective rainfall of the USDA. S.C. Methods was used for the stimulation and the result was 528.1mm throughout the baseline (1971-2000) Table 4.4. The effective rainfall was high in August 150.6mm after two months of the growing season, which usually starts in June. So, in September the effective rainfall started decreasing in the late season, and at the maturity stage, it drastically reduced to 45.2mm in October, which is in line with (Rosenzweig et al., 2002) study which states if a crop reaches its maturity excessive damages can occur due to excess rainfall. The effective rainfall was highest from July to September and from November to May is the dry season, which is also the off-season of the groundnut production. Since the majority of the crop water requirement is met, minimal irrigation requirement is only needed towards the end of the crop growth.

4.4.3 Crop Water Requirement

The Crop water requirements (CWR) for groundnut under rain-fed agriculture during the growing season are shown in table 4.5. During June to July (Initial and Development Stages) the crop coefficient (Kc) is low (0.40-0.42), reflecting minimal water requirements as the crop is just beginning to develop. This is because the higher the rate of evaporation the faster the soil dries and the smaller the Kc value (Van Ranst & Verdoot, 2005).

Table 4.5: Crop Water Requirement for Groundnut Under Rainfed Agriculture at Kerewan Station

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req mm/dec
Jun	1	Init	0.40	2.19	21.9	9.8	12.1
Jun	2	Init	0.40	2.08	20.8	13.8	7
Jun	3	Deve	0.42	2.10	21.0	25.0	0.0
Jul	1	Deve	0.57	2.70	27.0	39.6	0.0
Jul	2	Deve	0.74	3.29	32.9	51.3	0.0
Jul	3	Mid	0.91	3.94	43.3	50.9	0.0
Aug	1	Mid	0.98	4.10	41.0	50.0	0.0
Aug	2	Mid	0.98	3.98	39.8	51.3	0.0
Aug	3	Mid	0.98	3.96	43.6	49.2	0.0
Sep	1	Mid	0.98	3.95	39.5	49.0	0.0
Sep	2	Late	0.94	3.78	37.8	48.5	0.0
Sep	3	Late	0.82	3.32	33.2	37.3	0.0
Oct	1	Late	0.70	2.88	23.1	18.9	0.0
					424.9	**494.6**	**19.1**

Init= Initiation; Deve= Development; Mid= Mid-Season; Late= Late-Season; K_c= Crop- Coefficient; ET_c= Crop Evaporation, Eff Rain= Effective Rain; Irr. Req= Irrigation Requirement

The evapotranspiration (ETc) values increase from 2.19 to 3.29 mm/day, which indicates rising water demands as the plants grow. There is no irrigation requirement (Irr. Req.) since the effective rain (Eff rain) meets or exceeds the ETc, suggesting that rainfall satisfies the crop's water needs during this stage.

From July to August (Development to Mid-season Stages) the Kc values increase significantly to 0.57-0.98, showing the crop is entering its most water-demanding growth phase. ETc values rise accordingly, peaking at 4.10 mm/day in early August, which is indicative of the crop's peak water use during full development. Effective rain is still higher than or close to ETc, hence the irrigation requirement remains zero, implying that rainfall continues to be sufficient for the crop's needs.

Furthermore, from August to September (Mid-season to Late-season Stages) the Kc values remain high (0.98) in August but start to decrease in September (0.94 to 0.82), suggesting the crop is transitioning from peak water use towards preparation for harvest. ETc values start to decrease from 3.96 mm/day to 3.32 mm/day, aligning with the reduction in Kc values. Despite the decrease in ETc, the effective rain diminishes more rapidly, leading to a slight irrigation requirement of 19.1 mm by the end of the analyzed period in October.

Additionally, from September to October (Late Season Stage) the Kc value further decreases to 0.70, indicating significantly lower water requirements as the crop matures. ETc also lowers to 2.88 mm/day, which is almost half the peak ETc, reflecting the end of the active growth period. The effective rain is insufficient to meet the ETc, hence the emergence of an irrigation requirement (19.1 mm), which is the additional water needed to optimize groundnut yield.

The data indicates that the groundnuts are largely rainfed, with irrigation likely necessary only towards the end of the growing season to supplement decreasing rainfall. The progressive decline in Kc and ETc values from September to October aligns with the groundnut crop's natural progression toward harvest. This analysis suggests that under the current climatic conditions modeled, the groundnut crop's water requirements are mostly met by rainfall, with minimal need for supplemental irrigation.

4.4.4 Crop Parameters

For the critical depletion fraction for groundnuts, the FAO provides guidelines (irrigation and drainage manual 56) that suggest values are influenced by soil texture and other management factors. However, specific values for groundnuts are not directly provided in the materials accessed. As such, a common approach is to use a fraction that represents the amount of available water that a crop can use between irrigations without suffering from water stress. In the absence of specific data for groundnuts, similar crops were checked for guidance. For example, for tomatoes, a crop with somewhat similar water requirements, the fraction of Total Available Water (TAW) used before inducing stress is about 40% on silty soils. Values for this fraction can be adjusted by +/- 5-10% depending on whether the soil is more clayey or sandy. The critical depletion fraction for groundnuts, or the fraction of total available water (TAW) that can be depleted from the root zone before the crop experiences water stress, typically varies through the growth stages Table 4.6.

Table 4.6: The growth stages, rooting depth, and yield response factor

	Initial	Development	Mid-Season	Late-Season
Stages (days)	25	35	45	25
Yield Response f.	0.2	0.3	0.5	0.7

	Initial	Mid-season	Late-season
Kc Values	0.04	1.04	0.7
Rooting depth	0.3	0.6	
Critical depletion	0.05	0.4	0.4

At the initial stage, the plants are establishing their root systems and are more tolerant of water stress. The critical depletion fraction can be larger. Suggested value: 0.4 - 0.5 of TAW. During the development to mid-season Stage: As the crop develops especially during the flowering and pod development stages, groundnuts become more sensitive to water stress. Maintaining higher soil moisture levels is critical. Suggested value: 0.3 - 0.4 of TAW.

Furthermore, in the late season to maturity stage towards the end of the growing season, the crop's sensitivity to water stress may decrease slightly. However, to ensure proper pod filling, a moderate approach to water depletion may still be necessary. Suggested value: 0.4 - 0.5 of TAW.

For the rooting depth, typically, the initial rooting depth for groundnuts is shallower and increases as the plant matures. Initial rooting depth might be around 0.3 to 0.5 meters, expanding to 0.5-0.7 meters as the groundnut plants reach maturity. Hence, the Kc value is 130, and the rooting depth of 0.60 after stimulation.

Regarding the yield response factor, the FAO guidelines (Irrigation and Drainage Manual 56) suggest that this factor (Ky) varies across different stages of crop growth and reflects how sensitive the crop yield is to water stress. Again, while specific values for groundnuts are not detailed in the sources, one can infer those groundnuts, like other similar crops, would have different Ky values throughout the growing season, usually increasing as the crop moves from initial to late stages, reflecting the increased sensitivity to water stress as the crop approaches maturity. Groundnuts (peanuts) are known to be moderately sensitive to water stress, and the yield response factor varies according to the growth stage of the crop:

Initial Stage (planting to emergence) of the Ky values are typically lower because the plants are less sensitive to water stress. A value of about 0.2 to 0.3 could be suggested. The vegetative Stage (emergence to flowering) is when the plants develop, they become more sensitive to water stress, especially as they approach flowering. A Ky value in the range of 0.4 to 0.5 might be appropriate.

Furthermore, from flowering to Pegging Stage this is a critical period for groundnuts as water stress can significantly affect yield. The Ky value might be higher, such as 0.5 to 0.6. Pegging to the Maturity Stage as the water stress during this stage can reduce pod filling and size, which is directly related to yield. A Ky value of 0.7 to 0.8 might be appropriate, and as the groundnut reaches the maturity stage it may become slightly less sensitive to water stress again, so a Ky value could decrease slightly to around 0.6 to 0.7.

4.4.5 Soil Parameters

Total Available Soil Moisture (FC - WP) is the water content available to plants, ranging between field capacity (FC) and wilting point (WP), Table 4.7. For most tropical soils where groundnuts are cultivated, this value can range between 100 to 200 mm/meter. 150 mm/meter was used for the stimulation since it is the intermediate value.

Table 4.7: Soil parameters

Total available soil moisture (FC-WP)	150.0 mm/meter
Maximum rain infiltration rate	20 mm/day
Maximum rooting depth	70 centimeters
Initial soil moisture depletion (as %TAM)	40%

Initial available soil moisture	90.0mm/meter

The maximum Rain Infiltration Rate is the rate that is highly dependent on the soil texture. Sandy soils have higher infiltration rates, while clay soils have lower rates. So, the soil texture of the study area is: clay-loam, loam, sandy-loam, sandy-clay-loam, and water, a conservative estimate might be in the range of 15-25 mm/day. In the CropWat model, an estimation of 20mm/day was made, and a maximum rooting depth of groundnut during maturity is estimated at 0.7 meters.

Initial Soil Moisture Depletion (as % TAM): The initial depletion can be set to a value reflecting the soil's ability to retain moisture without stressing the crop. A starting value of 40-50% of TAW for the initial stage, 30-40% for the mid-season, and 40-50% for the late stage could be considered.

Initial Available Soil Moisture: This value should be based on soil moisture readings taken at the time of planting. In the absence of actual measurements, a general assumption could be that the soil moisture is at field capacity, especially if planting occurs at the onset of the rainy season.

4.4.6 Implications for Irrigation (Groundnut Irrigation Schedule)

The irrigation schedule output from the CROPWAT model for groundnut cultivation in Kerewan indicates that the total actual water use by the crop throughout the growing season was 422.0 mm. Below is a breakdown of the data that was provided as shown in Table 4.8 and Table 4.9.

Table 4.8: Irrigation schedule of groundnut during the study of the baseline as per the CropWat Model

Date	Day	Stage	Rain mm	Ks fract	Eta mm/day	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm
1 Jun	1	Init	0.0	1.00	2.2	45	0.0	20.5	0.0	0.0
2 Jun	2	Init	0.0	1.00	2.2	49	0.0	23.0	0.0	0.0
3 Jun	3	Init	4.3	1.00	2.2	45	0.0	21.2	0.0	0.0
4 Jun	4	Init	0.0	1.00	2.2	49	0.0	23.7	0.0	0.0
5 Jun	5	Init	0.0	1.00	2.2	54	26.2	0.0	0.0	37.4
6 Jun	6	Init	0.0	1.00	2.2	5	0.0	2.5	0.0	0.0
7 Jun	7	Init	4.3	1.00	2.2	5	0.0	2.5	0.0	0.0
8 Jun	8	Init	0.0	1.00	2.2	10	0.0	4.9	0.0	0.0
9 Jun	9	Init	0.0	1.00	2.2	14	0.0	7.4	0.0	0.0
10 Jun	10	Init	0.0	1.00	2.2	19	0.0	9.8	0.0	0.0

11 Jun	11	Init	0.0	1.00	2.1	23	0.0	12.2	0.0	0.0
12 Jun	12	Init	0.0	1.00	2.1	27	0.0	14.6	0.0	0.0
13 Jun	13	Init	6.1	1.00	2.1	20	0.0	10.8	0.0	0.0
14 Jun	14	Init	0.0	1.00	2.1	24	0.0	13.2	0.0	0.0
15 Jun	15	Init	0.0	1.00	2.1	28	0.0	15.5	0.0	0.0

Ks fract= Water stress coefficient; Eta= Actual Evapotranspiration; Depl= Depletion; Net Irr= Net Irrigation; Gr. Irr=Gross Irrigation

Table 4.9: Total irrigation, total net irrigation, and effective rainfall

Total gross irrigation	37.4 mm	Total rainfall	753.5 mm
Total net irrigation	26.2 mm	Effective rainfall	660.0 mm
Total irrigation losses	0.0 mm	Total rain loss	93.4 mm
Actual water uses by crop	422.0 mm	Moist deficit at harvest	5.1 mm
Potential water used by crop	422.0 mm	Actual irrigation requirement	-238.0 mm
Efficiency irrigation schedule	100 %	Efficiency rain	87.6 %
Deficiency irrigation schedule	0.0 %		

Rainfall and Irrigation: In Table 4.9 the total rainfall during the growing season was substantial, at 753.5 mm, with an effective rainfall of 660.0 mm after accounting for total rain loss (93.4 mm). Despite the high rainfall, the model still recommends a total gross irrigation of 37.4 mm. The net irrigation required is slightly less at 26.2 mm, indicating that some water efficiency is built into the model's recommendations.

Soil Moisture and Irrigation Timing: The irrigation was timed to occur at critical depletion, which is when the soil moisture falls to a threshold level where the crop might begin to experience water stress. On the 5th of June, the initial soil moisture depletion was calculated at 54%, and the recommended net irrigation was 26.2 mm to refill the soil to field capacity, which is the highest volume of water the soil is capable of storing.

Efficiency and Yield: The model assumes an irrigation efficiency of 70%, which is quite high and indicates that the irrigation method effectively delivers water to the crop with minimal losses. The yield reduction due to water stress is reported as 0.0%, suggesting that the groundnut crop did not experience significant water stress that would impact yield, corroborated by the actual irrigation requirement being a negative value (-238.0 mm). This negative value indicates that the effective rainfall exceeded the crop's water requirements, negating the need for additional irrigation.

End-of-Season Moisture: At harvest, there is a minor moisture deficit of 5.1 mm, indicating that the crop is slightly under the optimal moisture level. Still, given the zero-yield reduction, this deficit does not seem to have impacted the crop yield.

Rain Efficiency: Rain efficiency is quite high at 87.6%, indicating that most of the rainfall received contributed effectively to meet the crop's water needs.

The analysis suggests that the groundnut crop in Kerewan can be successfully cultivated with minimal to no irrigation due to the high amount of effective rainfall during the growing season. The CROPWAT model outputs show that the natural rainfall meets the crop's water requirements, leading to no expected yield loss from water stress. This analysis also reinforces the importance of accurate weather data and soil moisture monitoring in planning irrigation schedules to prevent the unnecessary use of water resources.

The "Total gross irrigation" required over the period is 37.4 mm, and the "Total net irrigation" is 26.2 mm, indicating that some of the gross irrigation accounts for system losses or inefficiencies. "Total irrigation losses" are at 0.0 mm, which suggests that the irrigation system is highly efficient or the model assumes no losses.

"Actual water use by crop" matches the "Potential water use by crop" at 422.0 mm, implying that the groundnut plants had all their water needs met, either through rainfall or irrigation. The "Moist deficit at harvest" is very low, only 5.1 mm, meaning the crop is almost at the optimal moisture level at the end of the growing season. Despite the "Actual irrigation requirement" showing a negative value (-238.0 mm), this likely indicates that the model's calculation of water requirements versus actual effective rainfall results in no additional irrigation being necessary beyond what nature provides.

4.4.7 Yield Reductions

No yield reductions are reported, as evidenced in Table 4.10 showing the 0.0% in the "Cumulative yield reduction" field. This suggests that any potential water stress did not significantly affect the groundnuts' yield. The yield response factors listed (0.20, 0.30, 0.50, 0.70, 0.60) across different growth stages show the crop's varying sensitivity to water stress, but since there is no yield reduction, it indicates that stress levels did not reach thresholds that would impact yields.

Table 4.10: Yield reduction at 100% of critical depletion

Stage Label	A	B	C	D	Season	
Reduction in ET_c	0	0	0		0	%
Yield Response Factor	0.2	0.3	0.05	0.7	0.6	
Yield Reduction	0	0	0	0		%
Cumulative Yield Reduction	0	0	0	0	0	%

In conclusion, the soil moisture balance analysis indicates that the rainfall is sufficient to meet the groundnut crop's water needs with minimal additional irrigation required. The effective rainfall efficiency of 87.6% demonstrates that most of the rain contributed to satisfying the crop water demands. The lack of yield reduction suggests that the crop was not subject to significant water stress that would impact its productivity. These findings underscore the importance of considering local rainfall patterns and soil moisture holding capacity when planning for irrigation in similar agroecological zones.

4.5 RCP 4.5 Analysis

4.5.1 Climatic Data- The climatic data and the potential evapotranspiration of the RCP 4.5 analysis are presented in Table 4.11. The ET_0 on average will be 4.90 mm while the wind speed will be 131 km/day. The average sunshine hours will be 7.6 hours meaning the sky was overcast most of the day. The maximum and minimum temperatures will be 32.1^{0}C and 22.1^{0}C, which will be ideal for the optimal growth and development of the groundnut (Peralta & Spooner, 2007). The length and intensity of rainfall, the connection between yearly precipitation and potential evapotranspiration, and the fluctuation in rainfall from year to year are the three main climatic elements that impact crops. The amount of rainfall, evaporation, temperature, soil conditions, and crop characteristics all affect how long the growing season is. (Macharia, 2004).

Table 4.11 Climatic data, Potential evapotranspiration (ET_0), and Effective Rainfall Out-put

Month	Min Temp °C	Max Temp °C	Humidity %	Wind Km/day	Sun-shine Hours	Rad $MJ/m^2/day$	ETo mm/day	Rain	Eff rain
January	19.8	31.5	44	104	7.8	18.6	4.21	0.5	0.5
February	20.6	32.3	48	138	8.3	20.6	5.14	0.6	0.6
March	21.4	33.3	50	173	8.4	22.4	6.32	0.9	0.9
April	21.5	32.9	54	173	8.3	22.0	5.94	1.5	1.5
May	21.8	32.3	61	190	7.9	21.4	5.57	5.7	5.6
June	22.5	31.6	72	190	7.2	19.9	4.89	18.2	17.7
July	23.1	31.1	83	147	7.0	20.1	5.62	44.8	41.6
August	23.5	30.9	90	104	6.5	19.8	4.46	112.6	92.3
September	23.6	31.6	91	95	6.6	19.3	4.06	103.0	86.0
October	23.7	32.7	87	95	7.7	19.9	4.65	38.5	36.1
November	22.6	33.2	71	69	8.0	18.8	3.98	4.4	4.4
December	20.6	31.8	52	95	7.2	17.1	4.00	0.6	0.5
Total								**331.3**	**287.8**
Average	**22.1**	**32.1**	**67**	**131**	**7.6**	**20.0**	**4.90**		

Temp= Temperature; Min= Minimum; Max=Maximum; Rad= Radiation; ET_0= Evapotranspiration; Eff Rain= Effective Rain

The effective rainfall of the USDA. S.C. Methods was used for the stimulation and the result was 287.8mm throughout RCP 4.5 (2020-2039) Table 4.11. The effective rainfall will be high in August with 92.3mm after two months of the growing season, which usually starts in June. So, in September the effective rainfall started decreasing in the late season, and at the maturity stage, it drastically reduced to 36.1mm in October, which is in line with (Rosenzweig et al., 2002) study which states if a crop reaches its maturity excessive damages can occur due to excess rainfall. The effective rainfall was highest from August to September and from November to May is the dry season, which is also the off-season of the groundnut production.

4.5.2 Crop water requirement

The Crop water requirements for groundnut under rain-fed agriculture during the growing season are shown in Table 4.12. From June to July (Initial and Development Stages) during the initial stages, the crop coefficient (Kc) is low (0.40-0.44), reflecting minimal water requirements as the crop is just beginning to develop. The evapotranspiration (ETc) values increase from 2.02 to 5.18 mm/day, which indicates rising water demands as the plants grow. There is an irrigation requirement (Irr. Req.) since the effective rain (Eff rain) is lower than the ETc, suggesting that rainfall would not satisfy the crop's water needs during this period.

Table 4.12: Crop Water Requirement for Groundnut

Month	**Decade**	**Stage**	**Kc Coeff**	**ETc mm/day**	**ETc mm/dec**	**Eff rain mm/dec**	**Irr. Req mm/dec**
Jun	1	Init	0.40	2.02	20.2	4.2	16.0
Jun	2	Init	0.40	1.92	19.2	5.3	13.8
Jun	3	Deve	0.44	2.21	22.1	8.2	13.9
Jul	1	Deve	0.65	3.59	35.9	10.4	25.5
Jul	2	Deve	0.89	5.18	51.8	12.6	39.2
Jul	3	Mid	1.14	6.11	67.2	18.7	48.5
Aug	1	Mid	1.24	5.99	59.9	26.9	33.0
Aug	2	Mid	1.24	5.51	55.1	33.5	21.6
Aug	3	Mid	1.24	5.35	58.8	31.9	26.9
Sep	1	Mid	1.24	5.10	51.0	30.7	20.3
Sep	2	Late	1.18	4.65	46.5	30.7	15.8
Sep	3	Late	0.96	4.04	40.4	24.5	15.9
Oct	1	Late	0.77	3.47	27.7	13.6	10.7
					555.9	**251.2**	**301.2**

Kc Coeff = Crop coefficient; ET_c = Crop evapotranspiration; Eff rain = Effective rain; Irr.Req = Irrigation Requirement

From July to August (Development to Mid-season Stages) the Kc values increase significantly from 0.65-1.24, showing the crop is entering its most water-demanding growth phase. ETc values rise accordingly, peaking at 5.99 mm/day in early August, indicative of the crop's peak water uses during full development. Effective rain is still lower than the ETc, hence the irrigation requirement increases, implying that rainfall is not sufficient for the crop's needs.

Furthermore, from August to September (Mid-season to Late-season Stages) the Kc values remain high (1.24) in August but start to decrease in September (1.18 to 0.96), suggesting the crop is transitioning from peak water use towards preparation for harvest. ETc values start to decrease from 5.35 mm/day to 4.04 mm/day, aligning with the reduction in Kc values. Despite the decrease in effective rainfall, the ETc increases more rapidly, leading to more irrigation requirements of 301.2 mm by the end of the analyzed period in October, and from September to October (Late Season Stage) the Kc value further decreases to 0.77, indicating significantly lower water requirements as the crop matures. ETc also lowers to 3.47 mm/day, which is almost half the peak ETc, reflecting the end of the active growth period. The effective rain is insufficient to meet the ETc, hence the emergence of an irrigation requirement (301.2 mm), which is the additional water needed to optimize groundnut yield.

The data indicates that groundnuts are likely going to be irrigated under RCP 4.5 2020-2039 in the near future due to a reduction in rainfall, with irrigation necessary throughout the growing season to supplement a decrease in rainfall. The progressive decline in Kc, and ETc values from September to October aligns with the groundnut crop's natural progression toward harvest. This analysis suggests that under the future climatic conditions modeled, the groundnut crop's water requirements will not be met by rainfall, and there is a need for more supplemental irrigation.

4.5.3 Irrigation Scheduling

The irrigation schedule output from the COPWAT model for groundnut cultivation in Kerewan indicates that the total actual water that would be used by the crop throughout the growing season will be 552.3mm. Here's an analysis of the data presented as shown in Table 4.13, and 4.14.

Table 4.13: Irrigation schedule of groundnut as per the CropWat Model

Date	Day	Stage	Rain mm	Ks fract	Eta mm/day	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm
1 Jun	1	Init	0.0	0.95	95	46	29.7	0.0	0.0	42.4
19 Jun	19	Init	0.0	1.00	100	40	30.0	0.0	0.0	42.8
6 Jul	36	Dev	0.0	1.00	100	43	35.5	0.0	0.0	50.8
15 Jul	45	Dev	0.0	1.00	100	38	33.7	0.0	0.0	48.2
24 Jul	54	Dev	0.0	1.00	100	37	34.6	0.0	0.0	49.4
1 Aug	62	Mid	0.0	1.00	100	40	38.2	0.0	0.0	54.5
11 Aug	72	Mid	0.0	1.00	100	39	37.2	0.0	0.0	53.2
22 Aug	83	Mid	0.0	1.00	100	36	34.2	0.0	0.0	48.8
1 Sep	93	Mid	0.0	1.00	100	35	33.8	0.0	0.0	48.2
16 Sep	108	End	0.0	1.00	100	33	31.7	0.0	0.0	45.3
22 Sep	114	End	0.0	1.00	100	28	26.7	0.0	0.0	38.1
30 Sep	122	End	0.0	0.99	100	19	17.8	0.0	0.0	25.5
5 Oct	127	End	0.0	1.00	100	11	10.4	0.0	0.0	14.9

Ks Fract = Water stress coefficient; Eta = Actual Evapotranspiration; Depl. = depletion; Net Irr = Net Irrigation; Gr Irr = Gross Irrigation

Table 4.14: Total irrigation, total net irrigation, and effective rainfall

Total gross irrigation	562.1mm	Total rainfall	297.7 mm
Total net irrigation	393.5 mm	Effective rainfall	196.6 mm
Total irrigation losses	0.0 mm	Total rain loss	101.1 mm
Actual water used by crop	552.3 mm	Moist deficit at harvest	3.5mm
Potential water uses by crop	552.4 mm	Actual irrigation requirement	355.8 mm
Efficiency irrigation schedule	100 %	Efficiency rain	66.0%
Deficiency irrigation schedule	0.0 %		

In Table 4.14, the total rainfall and irrigation during the growing season will be substantial, at 297.7 mm, with an effective rainfall of 196.6 mm after accounting for total rain loss (101.1 mm). Due to the low rainfall, the model recommends a total gross irrigation of 562.1mm. The net irrigation required is high at 393.5 mm. For Soil Moisture and Irrigation Timing, the irrigation was timed to occur at critical depletion, which is when the soil moisture falls to a threshold level where the crop might begin to experience water stress. On the 1st of June, the initial soil moisture depletion was calculated at 46%, and the recommended net irrigation was 29.7 mm to refill the soil to field capacity, this is the most volume of water that the soil is capable of retaining.

Meanwhile, for efficiency and yield the model assumes an irrigation efficiency of 70%, which is quite high and indicates that the irrigation method effectively delivers water to the crop with minimal losses. The yield reduction due to water stress is reported as 0.1%, suggesting that the groundnut crop will experience significant water stress that would impact yield, corroborated by the actual irrigation requirement being a positive value (355.8 mm). This positive value indicates that effective rainfall did not exceed the crop's water requirements, negating the need for additional irrigation, the end-of-season moisture during harvest, there will be a minor moisture deficit of 3.5 mm, indicating that the crop is slightly under the optimal moisture level. Still, given the 0.1 yield reduction, this deficit has impacted the crop yield. Rain efficiency is somehow high at 66.0%.

The analysis suggests that the groundnut crop can be successfully cultivated with the addition of irrigation due to the moderate amount of effective rainfall during the growing season. The CROPWAT model outputs show that the natural rainfall is not sufficient enough to meet the crop's water requirements under RCP4.5, leading to an expected yield loss of 0.1% due to water stress. This analysis also reinforces the importance of accurate weather data and soil moisture monitoring in planning irrigation schedules to prevent the unnecessary use of water resources.

Furthermore, as shown in Table 4.14, the "Total gross irrigation" required over the period is 562.1 mm, and the "Total net irrigation" is 393.5 mm, indicating that some of the gross irrigation accounts for system losses or inefficiencies. "Total irrigation losses" are at 0.0 mm, which suggests that the irrigation system is highly efficient or the model assumes no losses. "Actual water use by crop" is 552.3 and "Potential water use by crop" at 552.4 mm, implying that 0.1 mm of groundnut plants may not have utilized the available water resources due to soil water retention or some water stress experienced by the plant. In this case, the difference between the actual and potential water use is minimal and the "Moist deficit at harvest" is very low, only 3.5 mm, meaning the crop is almost at the optimal moisture level at the end of the growing season. Despite the "Actual irrigation requirement" showing a positive value (355.8 mm), this likely indicates that the model's calculation of water requirements versus actual effective rainfall results in additional irrigation being necessary beyond what nature provides.

4.5.4 Yield Reduction

Yield reductions as reported in Table 4.15, shows a 0.1% in the "Cumulative yield reduction" field. This suggests that any potential water stress has significantly affected the groundnuts' yield. The yield response factors listed (0.35, 0.45, 0.65, 0.75, 0.60) across different growth stages show the crop's varying sensitivity to water stress, but since there is a yield reduction, it indicates that stress levels did reach thresholds that would impact yields.

Table 4.15: Yield reduction at 100% of critical depletion

Stage Label	A	B	C	D	Season	
Reduction in ET_c	0.2	0.0	0.0	0.0	0.0	%
Yield Response Factor	0.35	0.45	0.65	0.75	0.60	
Yield Reduction	0.1	0.0	0.0	0.0	-	%
Cumulative Yield Reduction	0.1	0.1	0.1	0.1	0.0	%

The soil moisture balance analysis indicates that the rainfall will not be sufficient enough to meet the groundnut crop's water needs under RCP 4.5. Since the additional irrigation requirement is somehow high. The effective rainfall efficiency of 66.0% demonstrates that the majority of the rain cannot satisfy the crop water demands shortly. A yield reduction of 0.1% at all the stages of the groundnut growth suggests that the reduction in rainfall would affect all the stages of growth of the crops. All stages must be given adequate water to achieve optimal yield (Obreza et al., 2010; Patane & Cosentino, 2010).

4.6 RCP 8.5 Analysis

4.6.1 Climatic Data- The climatic data and the potential evapotranspiration of the RCP 8.5 (2060-2079) mid-term future analysis are presented in Table 4.16. The ET_0 on average will be 5.03mm while the wind speed will be 131km/day. The average sunshine hours will be 7.6 hours meaning the sky was overcast most of the day. The maximum and minimum temperatures will be 33.90C and 23.90C. The length and intensity of rainfall, the connection between yearly precipitation and potential evapotranspiration, and the fluctuation in rainfall from year to year are the three main climatic elements that impact crops. The amount of rainfall, evaporation, temperature, soil conditions, and crop characteristics all affect how long the growing season is. (Macharia, 2004).

Table 4.16: Climatic data, Potential Evapotranspiration (ET_0), Rain, and Effective Rainfall

Month	**Min Temp °C**	**Max Temp °C**	**Humidity %**	**Wind Km/day**	**Sun-shine Hours**	**Rad $MJ/m^2/day$**	**ETo mm/day**	**Rain**	**Eff rain**
January	21.6	33.4	44	104	7.8	18.9	4.40	0.4	0.4
February	22.5	34.4	48	138	8.3	20.8	5.25	0.3	0.3
March	23.4	35.2	50	173	8.4	22.6	6.07	0.7	0.7
April	23.3	34.5	54	173	8.3	22.2	6.55	1.5	1.5
May	23.6	33.9	61	190	7.9	21.5	5.69	3.8	3.8
June	24.1	33.2	72	190	7.2	20.6	5.14	9.9	9.7
July	24.9	33.1	83	147	7	20.4	4.83	26.6	25.5
August	25.3	32.7	90	104	6.5	19.8	4.91	62.3	56.1
September	25.3	33.5	91	95	6.6	19.8	4.22	91.4	78.0
October	25.6	34.3	87	95	7.7	20.1	4.76	32.0	30.4
November	24.8	35.0	71	69	8	19.8	4.37	4.6	4.6
December	22.8	33.6	52	95	7.2	17.2	4.21	0.4	0.4
Total								**233.9**	**211.3**
Average	**23.9**	**33.9**	**67**	**131**	**7.6**	**20.3**	**5.03**		

Temp. = Temperature; Min = Minimum; Max = Maximum; Rad = Radiation; Eff rain =Effective rain; ET_0 = Evapotranspiration

The effective rainfall of the USDA. S.C. Methods was used for the stimulation and the result was 211.3mm throughout RCP 8.5 (2060-2079) Table 4.16. The effective rainfall will be high in September with 78.0mm after three months of the growing season, which usually starts in June. So, in October the effective rainfall started decreasing in the late season, and at the maturity stage, it drastically reduced to 4.6mm in November, which is in line with (Rosenzweig et al., 2002) study which states if a crop reaches its maturity excessive damages can occur due to excess rainfall. The effective rainfall will reach the highest from August to September and from November to May is the dry season, which is also the off-season of the groundnut production.

4.6.2 Crop Water Requirement

Table 4.17 shows the result of the IWR of groundnut under RCP 8.5 starting from June to July (initial and development Stages). During the initial stages, the crop coefficient (Kc) is low (0.40-0.44), reflecting minimal water requirements as the crop is just beginning to develop. The evapotranspiration (ETc) values increase from 2.13 to 4.58 mm/day, which indicates rising water demands as the plants grow. There is an irrigation requirement (Irr. Req.) since the effective rain (Eff rain) is lower than the ETc, suggesting that rainfall would not satisfy the crop's water needs during this period.

Table 4.17: Crop water requirement for groundnut

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req mm/dec
Jun	1	Init	0.40	2.13	21.3	2.3	19.0
Jun	2	Init	0.40	2.05	20.5	2.8	17.7
Jun	3	Deve	0.44	2.22	22.2	4.7	17.5
Jul	1	Deve	0.68	3.36	33.6	6.3	27.3
Jul	2	Deve	0.95	4.58	45.8	7.8	38.0
Jul	3	Mid	1.23	5.96	65.5	11.5	54.1
Aug	1	Mid	1.34	6.52	65.2	15.5	49.7
Aug	2	Mid	1.34	6.56	65.6	19.0	46.5
Aug	3	Mid	1.34	6.25	68.7	21.4	47.4
Sep	1	Mid	1.34	5.85	58.5	25.8	32.8
Sep	2	Late	1.26	5.18	51.8	29.3	22.5

Sep	3	Late	0.99	4.28	42.8	22.9	19.9
Oct	1	Late	0.74	3.43	27.5	11.8	12.7
					589.1	**181.1**	**405.0**

Kc = Crop coefficient; Etc = Crop evapotranspiration; Eff rain = Effective rain; Irr.Req = Irrigation Requirement

Meanwhile, from July to August (Development to Mid-season Stages) the Kc values increase significantly from 0.68-1.34, showing the crop is entering its most water-demanding growth phase. ETc values rise accordingly, peaking at 6.52 mm/day in early August, indicative of the crop's peak water uses during full development. Effective rain is still lower than the ETc, hence the irrigation requirement increases, implying that rainfall is not sufficient for the crop's needs.

Furthermore, from August to September (Mid-season to Late-season Stages) the Kc values remain high (1.34) in August but start to decrease in September (1.26 to 0.99), suggesting the crop is transitioning from peak water use towards preparation for harvest. ETc values start to decrease from 5.18 mm/day to 4.28 mm/day, aligning with the reduction in Kc values. Despite the decrease in effective rainfall, the ETc increases more rapidly, leading to more irrigation requirements of 405.0 mm by the end of the analyzed period in October and September to October (Late Season Stage): The Kc value further decreases to 0.74, indicating significantly lower water requirements as the crop matures. ETc also lowers to 3.43 mm/day, which is almost half the peak ETc, reflecting the end of the active growth period. The effective rain is insufficient to meet the ETc, hence the emergence of an irrigation requirement (405.0 mm), which is the additional water needed to optimize groundnut yield.

The data indicates that groundnuts will be irrigated under RCP 8.5 2060-2079 in the Mid-term future due to a reduction in rainfall, with irrigation necessary throughout the growing season to supplement a decrease in rainfall. The progressive decline in Kc, and ETc values from September to October aligns with the groundnut crop's natural progression toward harvest. This analysis suggests that under the future climatic conditions modeled, the groundnut crop's water requirements will not be met by rainfall, and there is a need for more supplemental irrigation.

4.6.3 Irrigation Scheduling

The irrigation schedule output from the COPWAT model for groundnut cultivation in Kerewan indicates that the total actual water that would be used by the crop throughout the growing season will be 585.4 mm as shown in Table 4.18, and 4.19.

Table 4.18: Irrigation Schedule of Groundnut as per the CropWat Model

Date	Day	Stage	Rain mm	Ks Fract.	Eta mm/day	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm
1 Jun	1	Init	0.0	0.93	93	39	20.3	0.0	0.0	29.0
10 Jun	10	Init	0.0	1.00	100	32	18.2	0.0	0.0	26.0
20 Jun	20	Init	0.0	1.00	100	32	19.2	0.0	0.0	27.5
1 Jul	31	Dev	0.0	1.00	100	34	22.4	0.0	0.0	31.9
10 Jul	40	Dev	0.0	1.00	100	36	25.2	0.0	0.0	36.0
18 Jul	48	Dev	0.0	1.00	100	41	29.9	0.0	0.0	42.7
25 Jul	55	Dev	0.0	1.00	100	45	33.9	0.0	0.0	48.4
1 Aug	62	Mid	0.0	1.00	100	47	36.7	0.0	0.0	52.5
9 Aug	70	Mid	0.0	1.00	100	48	37.2	0.0	0.0	53.1
16 Aug	77	Mid	0.0	1.00	100	45	35.3	0.0	0.0	50.5
21 Aug	82	Mid	0.0	1.00	100	42	32.5	0.0	0.0	46.4
29 Aug	90	Mid	0.0	1.00	100	41	31.7	0.0	0.0	45.2
6 Sep	98	Mid	0.0	1.00	100	42	32.6	0.0	0.0	46.6

Ks = Crop water stress; Eta = Actual evapotranspiration; Depl. = depletion; Net Irr. = Net Irrigation; Gr. Irr = Gross Irrigation

Table 4.19: Total irrigation, total net irrigation, and effective rainfall

Total gross irrigation	695.3 mm	Total rainfall	206.5 mm
Total net irrigation	486.7 mm	Effective rainfall	125.0 mm
Total irrigation losses	0.0 mm	Total rain loss	81.6 mm
Actual water used by crop	585.4 mm	Moist deficit at harvest	3.4 mm
Potential water uses by crop	585.6 mm	Actual irrigation requirement	460.7 mm
Efficiency irrigation schedule	100 %	Efficiency rain	60.5 %

Deficiency irrigation schedule 0.0 %

Rainfall and Irrigation signify the total rainfall during the growing season will be substantial, at 206.5 mm, with an effective rainfall of 125.0 mm after accounting for total rain loss (81.6 mm). Due to the low rainfall, the model recommends a total gross irrigation of 695.3 mm. The net irrigation required is high at 486.7 mm. The irrigation was timed to occur at critical depletion, which is when the soil moisture falls to a threshold level where the crop might begin to experience water stress. On the 1st of June, the initial soil moisture depletion was calculated at 39%, and the recommended net irrigation was 20.3 mm to refill the soil to field capacity.

Therefore, for the efficiency and yield the model assumes an irrigation efficiency of 70%, which is quite high and indicates that the irrigation method effectively delivers water to the crop with minimal losses. The yield reduction due to water stress is reported as 0.1% and 0.2 % at the harvesting stage, suggesting that the groundnut crop will experience significant water stress that would impact yield, corroborated by the actual irrigation requirement being a positive value (460.7mm). This positive value indicates that effective rainfall did not exceed the crop's water requirements, negating the need for additional irrigation, and for the end-of-season moisture during harvest, there is a minor moisture deficit of 3.4 mm, indicating that the crop is slightly under the optimal moisture level. Still, given the 0.1 yield reduction at the first three stages of growth, and 0.2 yield reduction at the harvesting stage this deficit has impacted the crop yield.
Rain Efficiency: Rain efficiency is not that high at 60.5%, indicating that a slight majority of the rainfall received meets the crop's water needs.

The analysis suggests that groundnut crops can be successfully cultivated with the addition of irrigation due to the moderate amount of effective rainfall during the growing season. The CROPWAT model outputs show that the natural rainfall is not sufficient enough to meet the crop's water requirements under RCP8.5, leading to an expected yield loss of 0.1% in the first three stages and 0.2% yield reduction at the harvesting stage due to water stress. So, in this case, to avoid yield reduction in groundnut production much water should be applied at the development stage. This is because large quantities of water are needed during seed formation (Kheira & Atta, 2009). Since irrigation water is a limiting factor in crop production in the study area, deficit irrigation can be practiced especially at the initials and maturity stage of the groundnut because they are least sensitive to water. In deficit irrigation, water is given to crops during their least vulnerable growth stages (Fereres & Garcia-Vila, 2019). The main goal of deficit irrigation is to minimize irrigation water use and to find a coping mechanism in the areas that have water issues despite the supply being constrained satisfactory yield can still be achieved (Ferere & Garcia-Vila, 2019).

As shown in Table 4.19 the "Total gross irrigation" required over the period is 695.3 mm, and the "Total net irrigation" is 486.7 mm, indicating that some of the gross irrigation accounts for system losses or inefficiencies. "Total irrigation losses" are at 0.0 mm, which suggests that the irrigation system is highly efficient or the model assumes no losses. "Actual water use by crop" is 585.4 mm and "Potential water use by crop" at 585.6 mm, implying that 0.2 mm of groundnut plants may not have utilized the available water resources due to soil water retention or some water stress experienced by the plant. In this case, the difference between the actual and potential water use is minimal. The "Moist deficit at harvest" is very low, only 3.4 mm, meaning the crop is almost at the optimal moisture level at the end of the growing season. Despite the "Actual irrigation requirement" showing a positive value (460.7 mm), this likely indicates that the model's calculation of water requirements versus actual effective rainfall results in additional irrigation being necessary beyond what nature provides.

4.6.4 Yield Reductions

Yield reductions are reported in Table 4.20, as evidenced by the 0.1% in the "Cumulative yield reduction" at the three stages and 0.2% at the harvesting stage. This suggests that any potential water stress has significantly affected the groundnuts' yield. The yield response factors listed (0.40, 0.50, 0.70, 0.80, 0.60) across different growth stages show the crop's varying sensitivity to water stress, but since there is a yield reduction, it indicates that stress levels did reach thresholds that would impact yields.

Table 4.20: Yield reduction at 100% of critical depletion

Stage Label	A	B	C	D	Season	
Reduction in ET_c	0.3	0.0	0.0	0.0	0.0	%
Yield Response Factor	0.40	0.50	0.70	0.80	0.60	
Yield Reduction	0.1	0.0	0.0	0.0	-	%

Cumulative Yield Reduction	0.1	0.1	0.1	0.2	0.0	%

The soil moisture balance analysis indicates that rainfall will not be sufficient enough to meet the groundnut crop's water needs under RCP 8.5. Since the additional irrigation requirement is somehow high. The effective rainfall efficiency of 60.0% demonstrates that the majority of the rain cannot satisfy the crop water demands in the mid-term future. A yield reduction of 0.1% at the three stages of growth and 0.2% yield reduction at the harvest stage suggests that the crops can be subjected to significant water stress that would impact their productivity.

4.7 Changes in the historical climate data (rainfall and temperature) compared to RCP 4.5 and RCP 8.5 as used in the CropWat Model

The data in Fig 4.3 shows the average minimum temperature under historical (1971-2000), and future (2020-2039 and 2060-2079) conditions for the North Bank Region. The lowest 21.1^{0}C average minimum temperature was found during the historical period. The highest average minimum temperature 23.9^{0}C will be found in RCP 8.5(2060-2079) and 22.1^{0}C in RCP 4.5 (2020-2039) respectively.

In Fig 4.4 the average maximum temperature of 34.7^{0}C was higher during the historical period (1971-2000), for RCP 8.5(2060-2079) it will be high with 33.9^{0}C and RCP 4.5 (2020-2039) it will be 32.1 ^{0}C.

In Fig 4.5 the total rainfall was higher during the historical period (1971-2000) with 780mm, at RCP 4.5 (2020-2039) it will reduce to 331.3mm, and for RCP 8.5 it will drastically reduce to 233.9 as compared to the historical.

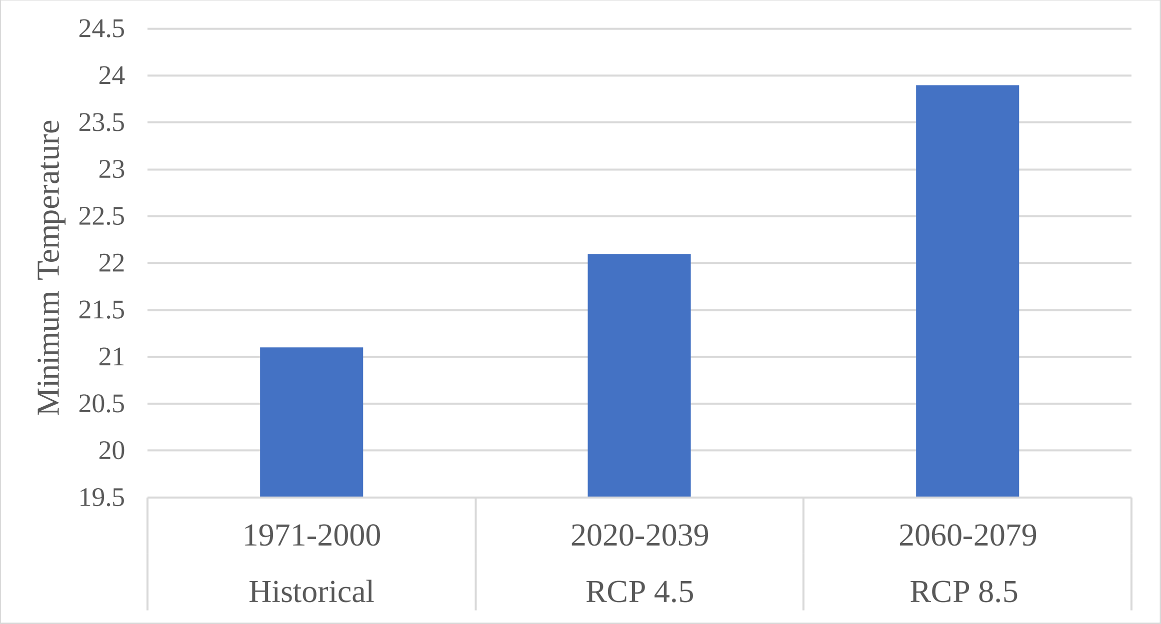


Fig 4.3 Average minimum temperature in North Bank Region, under historical and future conditions for RCP 4.5 and RCP 8.5 scenarios

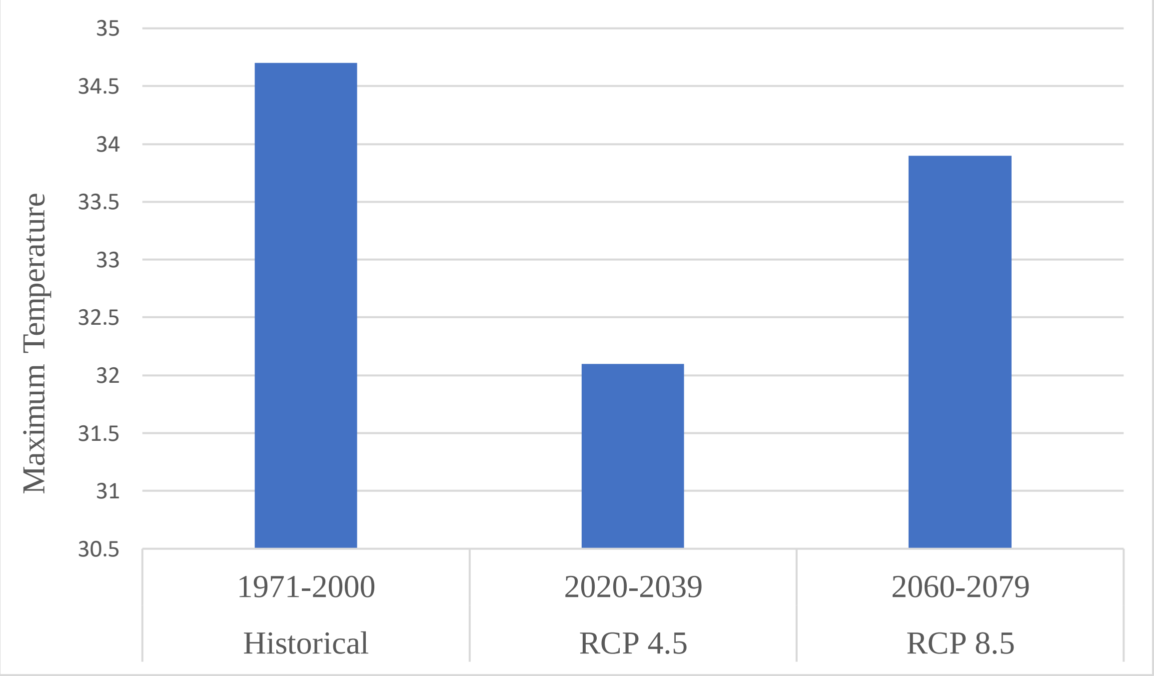


Fig 4.4 Average maximum temperature in North Bank Region, under historical and future conditions for RCP 4.5 and RCP 8.5 scenarios

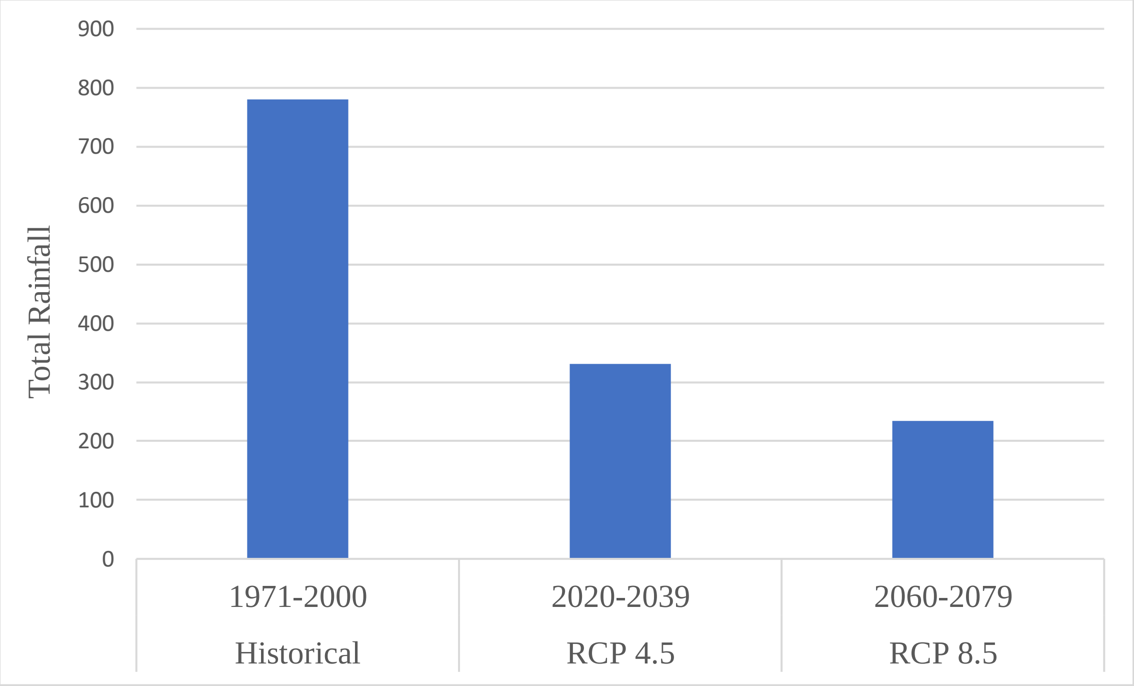


Fig 4.5 Total Rainfall in North Bank Region, under historical and future conditions for RCP 4.5 and RCP 8.5 scenarios

4.8 Examining farmers' perceptions of some of the challenges they face in groundnut production due to climatic, and non-climatic factors

4.8.1 Demographic characteristics of the groundnut farmers

Results from the demographic characteristics of the groundnut farmers (Table 4.21), indicated that the youngest and the oldest ages of the farmers were 20 and 85 years respectively with a mean age of 45 years. The majority representing 24.07% of the farmers were within the age bracket of 31-40 years old. This implied that farmers in the study area were predominantly in their middle ages hence, are economically active and thus, can undergo stress and have the manpower to carry out labor-intensive response strategies. This has a positive corollary for the productivity of the farmers (Girei A. et al., 2013). Groundnut production in the study area is male-dominated with a percentage of 94% and females of 6%. This is because more men are likely to be engaged in groundnut production than women due to its economic and commercial values. Women are more into other food crops for home consumption and household activities. This is consistent with research that was done by (Kaaria et al., 2007; World Bank, 2009) which indicates that in Africa, when a crop is considered, commercial men dominate more than women. The survey results further show that

92% of the farmers own land and 8% do not own land. The result also revealed that 58.33% of the respondents had a farm size of between 1-3 hectares, 37.96% had a land size of between 4-7 hectares, and 3.7% had a farm size of more than 6 hectares. This demonstrated how vulnerable the farmers in the study area were to climate change because they were primarily subsistence farmers. This outcome is consistent with the MoFA's (2017) results, which showed that 90% of Ghana's farm holdings are smaller than two hectares.

Table 4.21: Demographic statistics of groundnut farmers

Age	Frequency	Percent
20-30	17	15.74
31-40	26	24.07
41-50	25	23.15
51-60	24	22.22
61-70	8	7.41
>70	8	7.41
Total	108	100
Gender	**Frequency**	**Percent**
Male	102	94.00
Female	6	6.00
Total	108	100
Do you own a land?	**Frequency**	**Percent**
Yes	99	92.00
No	9	8.00
Total	108	100

Size of Farmland (hectares)	Frequency	Percent
1-3	63	58.33
4-6	41	37.96
>6	4	3.70
Total	108	100

4.8.2 Constraints facing groundnut farmers in the study area

The production constraints of the respondents analyzed include the following: Storage problems, pest infestations, soil fertility decline, labor scarcity, inadequate fertilizer, post-harvest challenges, disease problems, and land scarcity which are all ranked according to the magnitude of the problem they faced in the region. The result of Table 4.22 showed that storage problems ranked as the first major problem faced by groundnut farmers in the region. This is firstly represented by a 19.24% storage problem, pest infestations ranked second with 15.45%, soil fertility decline ranked third with 14.91%, disease problems ranked fourth with 11.92%, inadequate fertilizer ranked fifth with 11.11%, while labour scarcity, post-harvest challenges, and land scarcity occupied the sixth, seventh, and eighth with 10.03%, 9.21%, and 8.13%. The major non-climatic factors that they faced were storage problems, pest infestations, and soil fertility decline according to the survey conducted.

Table 4.22: Distribution of respondents based on constraints associated with groundnut production

Problems	Frequency	Percent (%)	Rank
Storage Problem	71	19.24	1
Pests Infestation	57	15.45	2
Soil Fertility Decline	55	14.91	3
Disease Problem	44	11.92	4
Inadequate Fertilizer	41	11.11	5
Labor Scarcity	37	10.03	6

Post-Harvest Challenges	34	9.21	7
Land Scarcity	30	8.13	8
Total	369	100	

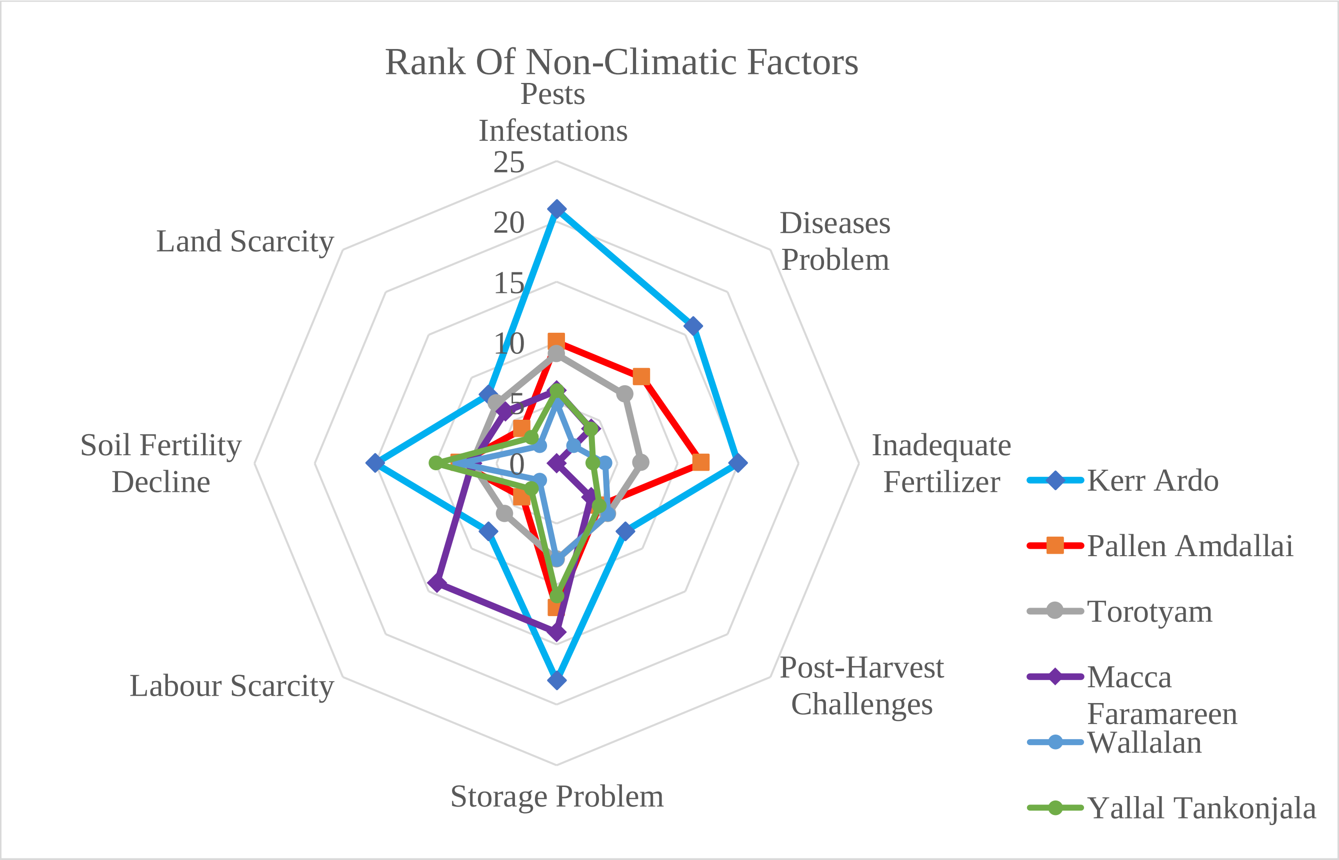


Figure 4.6: Rank of non-climatic factors based on constraints affecting groundnut farmer

Storage problems have the highest number in which 71 farmers out of the 108 mentioned that it is a huge problem in the study area. It might be explained by the inadequate goods store rooms to keep the groundnut yield until it is marketed across the country and beyond. Even if there is a store it has little or no ventilation causing a lot of post-harvest losses due to pest infestations, and heat accumulation which result in a fungal-causing disease called aflatoxins. This disease affects groundnut yield hence degrading its quality and quantity before it is marketed locally and internationally. A reduction in the quality of the groundnut would lead to a low pricing thereby reducing the income of the farmer. This argument is further justified by (Hoffmann & Moser, 2017) stating that products with higher prices tend to be less contaminated than products sold for a lower price.

Farmers rank pest infestations as an important constraint affecting groundnut production in the study area. According to the survey, 57 farmers out of the 108 farmers complained about three pests that affect their groundnuts mostly, two on the farm (groundnut aphid, and bruchid) and one (red flour beetle) in the store room. The groundnut farmers unanimously agreed that the red flour beetle pest affects their groundnuts in the store room by boring inside the kernel of the groundnut and reducing it to powder making them unfit for use as seed and human consumption resulting in a powdery appearance as seen in the figure 4.7 is the most stubborn, they lamented during the focus group discussion. The presence of creamy white grubs and active adults is indicative of this infestation, which is thought to be able to inflict both direct and indirect losses affecting both the viability and quality of the produce. A study conducted by Tadesse M. (2020) further supports the claim that the red flour beetle damaged stored groundnuts to the extent of leading to economic losses.

Figure 4.7: A pictorial of red flour beetle pest and damaged groundnut seeds

Farmers rank soil fertility decline as an important factor affecting groundnut production in the study area. Out of the 108 farmers interviewed 55 of them justified the fact that the decline in the soil fertility is hindering their groundnut production. Soil fertility is declining in many parts of Sub-Saharan Africa (Bationo et al., 2012; Kamaa et al., 2012). Nutrient imbalances are seen to be the main constraints of groundnut production among farmers (Tittonell & Giller 2012; Kamaa et al., 2012). Land scarcity due to population increase limits the use of traditional soil fertility restoration techniques (natural fallow) which was possible in the past due to smaller populations. The absence of fallowing, coupled with large nutrient deficits of major nutrients- Nitrogen (N), Phosphorus (P), and Potassium (K) leads to the decline of soil fertility (Yengoh & Brogaard, 2014).

Disease problem is a challenge faced by the groundnut farmers in the study area. Most of the farmers lamented that their groundnuts are normally affected by diseases such as tick diseases namely the leaf spots and aflatoxins which is mainly a post-harvest problem. This finding conforms with the work of (Crauford et al., 2006), who stated that early and late leaf spots commonly called tick diseases cause a huge yield loss in groundnuts due to defoliation.

Inadequate fertilizer has been a constraint that is affecting the farmers in the study area. 41 farmers out of the 108 said that fertilizer is very expensive. Despite, the Government of The Gambia has subsidized it yet still they cannot afford it. Some of them further buttressed that the fertility of the soil has drastically declined and fertilizer is the only way for them to have a bumper harvest.

Labor scarcity is a problem that they faced in the study area as it is mentioned by 37 farmers out of the 108 who were interviewed. During the focus group discussion, some of the farmers mentioned that the major reason why they are facing labour shortage is due to illegal migration through the Mediterranean Sea to Europe in search of greener pastures.

Post-harvest challenges are a problem that they faced in the study area, 34 farmers out of the 108 mentioned that some of the post-harvest problems they faced were numerous. Post-harvest can be defined as all the activities that are involved immediately after harvest and before they reach the final consumer. Such activities include cleaning, grading, separations, drying, storage, milling, processing, packaging, transportation, and marketing before it reaches the final consumers. Improper post-harvest handlings can lead to post-harvest losses. For example, improper handling of groundnuts can introduce aflatoxins, making the product unfit for human consumption.

Finally, land scarcity is another constraint that they faced in the study area. 30 farmers out of the 108 mentioned that land scarcity is due to the land tenure system which is why their farm size is small, and agricultural land is now been used for residential purposes due to an increase in population in the study area.

4. 8. 3 Perception of Changes in Rainfall

Groundnut farmers were enquired about the changes they had noticed in rainfall over the past ten years. Firstly, the survey inquired whether the farmers had noticed any change in rainfall, of which 96.2% responded affirmatively. 83.33% responded that rainfall had decreased over the past ten years as indicated in Table 4.23, 15.74% of the farmers stated that rainfall had increased over the ten years, and 0.9% of the farmers said they had not observed any changes.

Furthermore, about 61% of all these farmers from the six communities unanimously indicated that there is a change in the onset of the rainy season (which used to be the 10th of June ± 3 days) is no longer as reliable as it used to be. They believed that there is an increasing tendency for the rainy season to start later than the expected start period. The start of the rainy season is an important event for farmers because a lot of their communities' activities revolve around this event. This involves scheduling the preparation of the land and seeds, enlisting labor to assist with the crucial planting process, and making plans for weeding and fertilizer purchases, among many other tasks that are essential to the farmers' lives. In farming communities, the yearly schedule of these events is typically meticulously coordinated with other social and economic activities. A lack of uncertainty about the start of the rains has the potential to put many other activities in disarray. Farmers may incur financial costs in certain situations due to the delayed onset of rains, such as having to replant due to damaged seeds from the protracted dry season. The problems associated with the late start of the rainy season are the same as those associated with lengths of dry spells and the cessation of rainfall had been observed together with an increase or decrease in the amount of rain. The detailed results of this part of the survey are indicated in Table 4.23.

Table 4.23: Observed changes in rainfall

Rainfall Changes Observed	Name of the community						Total	Percent
	Kerr Ardo	Pallen Amdallai	Torotyam	Macca Farafenni	Wallalan	Yallal Tankongali		
Decreased	21	15	8	20	20	6	90	83.33
Increased	2	0	2	0	0	13	17	15.74
No Changes	0	0	0	0	0	1	1	0.9
Total	23	15	10	20	20	20	108	100

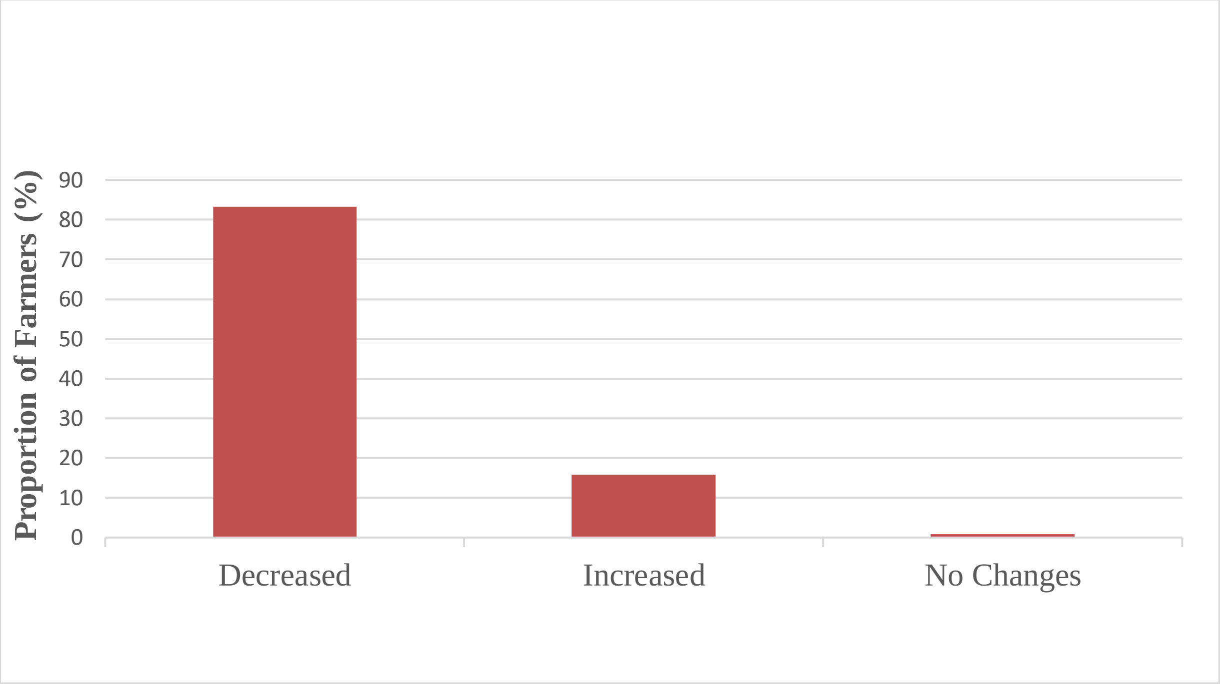


Figure 4.8: Perceived changes in rainfall for the past ten years

4.8.4 Perception of Changes in Temperature

Groundnut farmers were enquired about their observations in temperature for the past ten years, being given the option of temperatures increasing, decreasing, or remaining the same. (78.71%) of the farmers observed an increased trend in temperature whereas (14.81%) of the farmers observed a decreased trend in temperature. Meanwhile, (6.48%) stated that temperatures have not changed over the past years as shown in figure 4.7.

Temperature is very important for groundnut growth and development. According to Kumar et al., (2012), after the seed is sown, germination and emergence are primarily determined by the temperature and soil moisture in the seeding zone. There is a minimal threshold value, an optimal range, and a maximum threshold value for the emergence and germination processes related to soil moisture content and temperature. The germination processes do not begin at minimum threshold values of soil moisture content and temperature (base temperature). Both emergence and germination occur at their fastest rates at the ideal range of soil moisture and temperature. Temperature and soil moisture increase enhance the rates of emergence and germination between their lower optimum levels and minimal threshold. These processes gradually slow down over their optimal range until they reach their maximum threshold values (damaging thresholds), at this point, they stop entirely. For example, Prasad et al., (2006) reported that the base temperature for germination of groundnut is approximately 10^0C and the optimum temperature (OT) for emergence is between 25^0C and 30^0C.

Table 4.24: Observed changes in temperature

Temperature Changes Observed	Name of the community						Total	Percent
	Kerr Ardo	Pallen Amdallai	Torotyam	Macca Farafenni	Wallalan	Yallal Tankongali		
Increased	21	11	9	18	19	7	85	78.71
Decreased	0	2	1	1	0	12	16	14.81
No Changes	2	2	0	1	1	1	7	6.48
Total	23	15	10	20	20	20	108	100

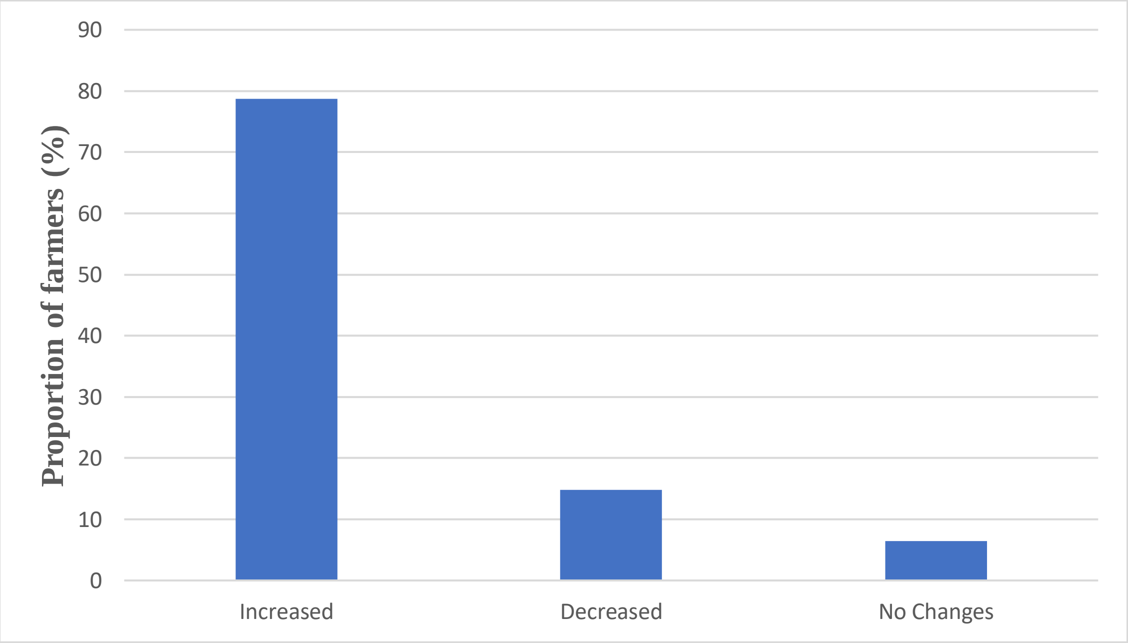


Figure 4.9: Perceived changes in temperature for the past ten years

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the research findings and includes some recommendations for sustained groundnut production in The Gambia.

5.1 Conclusions

The exportation of groundnut from the Gambia has decreased drastically, prompting this research to be conducted to investigate some of the problems that cause this decline. A linear regression analysis was used to examine the relationships between the key climatic variables such as temperature and rainfall against groundnut yields for the period of 1990-2020 (30 years). The potential impacts of climate change were assessed by using the cropwat model, and a farmer's perception survey was conducted to determine some of the climatic and non-climatic challenges that they faced.

The result from the linear regression analysis between temperature and groundnut yield is positive while rainfall and groundnut yield are negative indicating that the decline in groundnut yield is not rainfall, whilst temperature rise has a minimal influence on groundnut yield. Hence, the cause of groundnut yield reduction from 1990-2020 could be due to non-climatic factors such as pests and diseases, poor soil fertility, storage problems, poor quality seeds, post-harvest challenges, etc.

In addition, the simulated result for the baseline (1971-2000) in the Cropwat model shows that the CWR of the groundnut was met because the efficiency of the rain was 87.6%, the IWR was minimal (19.1mm) which was only required at the end of the maturity period, and there was a 0% cumulative yield reduction at all the stages of the groundnut growth. Under RCP 4.5 (2020-2039) near future, the CWR of the groundnut will not be met due to a decrease in the rain efficiency of 66.0% an additional irrigation supplement of 301.2mm is required throughout the growth stages, for optimal groundnut growth. Under RCP 8.5 (2060-2079), in the mid-term future the CWR of the groundnut will not be met either due to a reduction in rainfall, with irrigation necessary throughout the growing season. The rain efficiency will be 60.5% and the additional IWR is 405.0mm for optimal groundnut growth.

Furthermore, the demographic statistic shows that more males are into groundnut production than females and most of them are in their prime producing years. Many of the farmers own land and the land size is less than three hectares which indicates that they are mainly subsistence farmers. The problems that are found to be associated with groundnut production in the study area include storage problems, pest infestations, soil fertility decline, labor scarcity, inadequate fertilizer, post-harvest challenges, disease problems, and land scarcity. But, the three major problems that they face are storage problems, pest infestations, and soil fertility decline. In addition, 83.33% of the respondents indicated that they observed a decrease in rainfall, 15.74% observed an increase in rainfall, and 0.9% observed no changes in rainfall. While 78.71% observed an increase in temperature, 14.81% observed a decrease in temperature, and 6.48% observed no changes. The study area is the hub of groundnut production in the Gambia. Based on the constraints identified, it will help policymakers and government stakeholders to adopt suitable adaptation measures to revitalize groundnut production in the Gambia.

5.2 Recommendations

Climate change will continue to fluctuate; it will have negative impacts on smallholder agriculture and water supplies as long as the climate keeps changing. Future climate projections have shown even harsher weather conditions. Hence, there is a need to come -up with good adaptations and mitigation measures to curb the situation. The following recommendations are made based on the reviewed literature, modelling output, and farmers-focused group discussions.

1. Agricultural research should be strengthened through the National Agricultural Research Institute in the Gambia to carry- out research on the breeding of new groundnut varieties that can withstand extreme temperatures, pests and disease problems affecting groundnuts, and soil analysis for proper irrigation design.
2. Government interventions are needed to build quality storage facilities around the country to help groundnut farmers address the issue of post-harvest losses.
3. Farmers need to be sensitized on climate change-related issues to enhance their knowledge and build their capacity on some of the adaptation measures.
4. To promote year-round groundnut production adopting rainwater harvesting techniques will help to increase its yield.
5. A shift in the planting date of the groundnut is recommended to have optimal production due to a delay in the onset of rainfall.
6. The agriculture extension officers may advise the farmers to irrigate their groundnuts early in the morning or late hours in the evening because by then the rate of evapotranspiration is minimal and the plant can make maximum utilization of the water.
7. Since groundnut production in the North Bank Region is projected to need irrigation under a change in climate both in the near (2020-2039) and far future (2060-2079), drip irrigation practices are recommended.
8. Further research should be done on the potential impact of climate change on groundnut production in the entire country by using the coupled model intercomparison project (CMIP 6) considering the shared socioeconomic pathways (SSPs) scenarios.

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Annexes 1

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Research Questionnaires

Appendix 1:

This survey aims to gather data on "Climatic and non-climate factors that affect groundnut production in the North Bank Region" for academic purposes. Respondents are free to respond to the questions.

Introduction

This research is being conducted by an MSc. Student of the Pan African University Institute of Water and Energy Science, studying Climate Change (Technical Focus). As part of the thesis, this field survey is being conducted based on information on some of the challenges the groundnut farmers face and their perception of rainfall and temperature changes due to climate change.

Your assistance is humbly requested in this survey as your contributions are key to making this study significant. The outcomes of this survey would help to inform decisions, policies, and actions in the agriculture sectors of communities and the country at large, as far as climate change is concerned thus building resilience and promoting sustainable development. You are not required to reveal your identity and your responses will be handled discretely.

Target groups: Groundnut Farmers

Section A: Demographic

1. Age (a) 20-30 [ ] (b) 31-40 [ ] (c) 41-50 [ ] (d) 51-60 [ ] (e.) 61-70 [ ] (f.) above 70[ ]

2. Gender [] (a) Male [] (b) Female []

3. Do you own the land that you are cultivating?

(a) Yes [ ] (b) No [ ]

4. How big is the farm you are working on:

(a.) 1-3 hectares [ ]

(b.) 4-7 hectares [ ]

(c.) 8-12 hectare [ ]

Section B: Constraints facing groundnut farmers (non-climatic factors)

5. What are the major challenges you face in groundnut production in the North Bank Region?

(i.) Land scarcity [ ]

(ii.) Labor scarcity [ ]

(iii.) Soil Fertility Decline [ ]

(iv.) Inadequate Fertilizer [ ]

(v.) Disease problem [ ]

(vi.) Post-harvest challenges [ ]

(vii.) Storage problem [ ]

(vii.) Others [ ]

Section C: Perception of groundnut farmers on rainfall and temperature issues (climatic-factors)

6. Have you noticed changes in rainfall over the past 10 or more years?

(A) In agreement [ ] (b.) No [ ]

7. If yes, what are the changes in rainfall you have noticed?

(a) Rainfalls have increased

(b) Rainfalls have decreased

(c) Rainfalls have not changed.

(d) The onsets and cessation of rainfalls have changed

8. Did you observe any temperature increase for the past ten years? (a.) Yes [ ] (b.) No [ ]

9. If yes, what have you observed about temperatures in the past 10 years?

(a) Temperatures have decreased

(b) Temperatures have increased

(c) Temperatures have not changed.

Section D: Recommendations for Improving Groundnut Production

10. In light of changing climatic conditions, what policies or suggestions do you think could help increase groundnut output in the North Bank Region?

Your involvement is much valued and will help this research to be successful. Your answers will be kept private and used exclusively for study.
I appreciate your time and insightful comments.

The researcher's signature is ____________________________.
Date: _______________________