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Vulnerability of Rice and Maize Yields to Climate Variability in the Sudano-Sahelian Zone of The Gambia: Drivers and Adaptation Options

By

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CERTIFICATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Kwame Nkrumah University of Science and Technology, Kumasi or any other educational institution, except where due acknowledgement is made in the thesis.

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ABSTRACT

Staple food crops are considered as the driving force for household food security and source of livelihood activities for many developing nations. Farming practices face many challenges due to the adverse impacts of climate change and variability in the 21st century. This study assessed the extent to which maize (*Zea mays L.*) and rice (*Oryza sativa L.*) yields are vulnerable to climate variability in the Lower River Region of The Gambia. The influence of climate variability was assessed using the ordinary least square regression and heteroscedasticity methods. The potential soil physical and chemical properties were estimated using diagnostic soil survey of simple random sampling approach. Data were collected from 30 upland maize fields and 30 swamp rice fields. Crop yields were projected using two Global Circulation Model (GCM) models that performed best in the study area: CSIRO-RCP4.5 and NOAA-RCP4.5. Climate change adaptation options were assessed through semi-structured questionnaires with 180 selected households in eighteen communities using multistage sampling techniques. The results of climate influence on crop yields showed that CO_2 and rainfall unfavourably affect rice yield and were statistically significant. Maximum and minimum temperature negatively affect yield but not statistically significant at ($P < 0.05$). The results further revealed that CO_2, maximum temperature and sunshine duration adversely affect maize yield and statistically significant whilst rainfall and minimum temperature negatively affect maize yield but not significant at ($P < 0.05$). Soil survey results indicated that swamp rice ecologies had high percentage of NPK (N 0.07 %, P 0.0184 % and K 0.04 %) than percentage NPK contents in the maize fields (N 0.06 %, P 0.018 % and K 0.01 %). Soil pH is generally low and ranges from (4.6 to 4.7). The electrical conductivity of the soils for rice and maize fields are generally high (4.8 dS/m) indicating salt-affected soils. It is projected that, crop yields showed the percentage mean yield gain for maize under NOAA-RCP4.5 by 12 % and 41 % but most importantly CSIRO-RCP4.5 by 17 %, 31 %, and 48 % respectively, as the period gets close to mid-century compared to mean rice yield losses of -19 % and -23 % under NOAA-RCP4.5 scenario. The results showed that the majority (72 %) of farmers' use drought-tolerant crop varieties with 67 % adapting to changing planting date. Majority (64 %) of farmers were forced to fallow their lands with 40 % of farmers practising petty trading and 47 % depending on temporal migration as a coping mechanism. It is concluded that rice and maize yield were vulnerable to climate variability coupled with fragile soil conditions. The future projection of yields will be inadequate to feed the growing population in the Lower River Region of The Gambia. There is a need for more adaptation strategies that are compatible with the local condition that can strengthen the resilience of households to cope with climate variability. Therefore, climate change adaptation policy should include local knowledge as a bottom-up approach to enhance their sustainability at the local level.

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DEDICATION

This thesis is dedicated to my parents, my wife Mrs. Mariama Bajinka Sonko and my sons Lamin E. Sonko, Biba Sonko and Tumani Sonko for their patience and understanding during the course of this study.

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LIST OF ABBREVIATIONS

AR4:	Assessment Report Four
AR5:	Assessment Report Five
CO_2:	Carbon dioxide
CDDP:	Community Driven Development Project
CVI:	Climate Vulnerability Index
EC:	Electrical Conductivity
FGD:	Focus Group Discussion
FAO:	Food and Agriculture Organization of the United Nation
GBOS:	Gambia Bureau of Statistics
GCM:	Global Circulation Model
GDP:	Gross Domestic Product
GHG:	Green House Gas
Ha:	Hectares
IPCC:	Intergovernmental Panel on Climate Change
IPM:	Integrated Pest Management
JWS:	Jenoi Weather Station
Kg:	Kilogram
KT:	Kilo Tonnes
KKWS:	Kiang Karantaba Weather Station
KWS:	Kwenella Weather Station
LRR:	Lower River Region
LVI:	Livelihood Vulnerability Index
MT:	Metric Tonnes
mm:	Millimetres

NAPA: National Adaptation Plan of Action

NOAA: National Ocean and Atmospheric Administration

NPK: Nitrogen Phosphorus Potassium

OLS: Ordinary Least Square

OM: Organic Matter

PE: Potential Evapotranspiration

RAD: Regional Agricultural Directorate

RCP: Regional Climate Projection

SAT: Semi-arid Tropics

SSA: sub-Saharan Africa

SPSS: Statistical Package for Social Sciences

UNDP: United Nation Development Program

UNFCCC: United Nation Framework Convention on Climate Change

YD: Yield Deviation

WFP: World Food Program

CHAPTER ONE

INTRODUCTION

1.1 Background

The emerging trends in global atmospheric condition (variation in temperature and precipitation patterns) present evidence of uncertainties, and calls for an adjustment in societal endeavours. Most importantly, agriculture needs special attention, which is the sector most vulnerable to the consequences of climate change and variability and has a direct link to global food security (Roudier *et al*., 2011). If concerted efforts are not taken to, address this global threat, food security challenges and hunger will be a continuous issue in the future. Therefore, this may pose a great challenge towards the attainment of the Sustainable Developmental Goal 2, which strive to end hunger and achieve food security whilst preserving the ecosystem (Blanc, 2015). Globally, food insecurity affects approximately 800 million people, which account for 11 % of the world population (Acevedo *et al*., 2018). It is expected that farm productivity must be doubled by 2050 in order to meet the growing population in sub-Saharan Africa, which is projected to accelerate from 1.0 billion in 2017 to between 1.9 and 2.3 billion in 2050 (Godfray *et al*., 2010). It is projected that Africa's population will increase between 1.5 % to 3 % per year given the recent growth rate (Lutz and KC, 2011).

The IPCC fifth assessment report (AR5) highlighted that the global climate is changing and variation in temperature and precipitation patterns were erratic in different parts of the world (Stocker *et al*., 2013). Schmidhuber and Tubiello (2007) reported that anthropogenic greenhouse gases as the drivers of climate change and variability, and that CO_2 is the most important driver (IPCC, 2007). The historical environmental temperature has increased between 0.55 °C and 0.67 °C which was evident from 1951 to 2010

(Fitzgerald, 2016). If institutional policy framework is not put in place, temperatures will skyrocket beyond the maximum 2° C limit advocated by 2100, an indication for hazardous warming of the earth (Peters *et al.*, 2013). Rainfall patterns observed during the past decades over the globe is ambiguous, and evidence has shown that dryland countries will be prone to dryness in some regions (Dai, 2013; Niranjan *et al*., 2013).

Nearly 50 % of the global population in tropical countries are vulnerable to food insecurity due to climate extremes (Misselhorn, 2005). While this reference of food shortage in the world is considered the peak of food poverty estimates, the proportion of vulnerability between countries is evidence (Alam, 2017). Global Circulation Model analyses projected a decrease in productivity of all major crops due to increased temperature, rainfall variability, increase in potential evapotranspiration (PE), runoff and drainage by the year 2075 (Msowoya and Madani, 2016). The global projection of climate will significantly affect The Gambia, which is located at the southern fringe of the Sahara desert, which is vulnerable to weather events.

The Gambia is identified as one of the countries vulnerable to climate variability because of its geographical location, more importantly, prone to inconsistent rainfall patterns and droughts, which is associated with natural phenomena (Warner and Geest, 2013). The onset of the rainy season in The Gambia starts lately in different parts of the country with prolonged drought stretching across different regions (Yaffa, 2013; Loum and Fogarassy, 2015). The climate scenario in the country will exacerbate the farming system vulnerability to challenges of food security, which may cause economic challenges. Atmospheric dynamics may induce the intensity of climate variability and alter weather events, which may twist essential climate variables needed for crop production in the country. “Rainfall has traditionally been the major driver of crop production in subSaharan Africa, including The Gambia, and the temperature has not been considered a limiting factor” (Benjaminsen *et al.,* 2012). The recent projection of temperature and rainfall in The Gambia for 15 models under three emission scenarios shows an increase in mean temperature between 1.8 to 5 ^{o}C and a decrease in rainfall resulting to low crop productivity from -23 and 18 % by the 2090s (Atherton *et al*., 2013).

To offset the negative influence of climate change and variability on the social system and the environment, adaptation and mitigation were identified as the two most important complementary approaches to sustain the ecosystem (IPCC, 2007). Mitigation is a prerequisite to offset emissions of emitted gases in the atmosphere prior to exceeding the threshold, which causes irremediable effects to maintain environmental stability for human beings (Rurinda, 2014). Despite the relevant policies on mitigation, long-term strategies to climate change are perceived to be compulsory due to historic and current consequences of climate extremes (Joos *et al*., 2001). Sub-Saharan Africa is one of the sub-regions of the world that is prone to environmental stress, which makes adaptation critical not only at the low level of adaptive capacity but also due to uncertainties of climate and scanty data (Guan *et al*., 2017). Being a small dryland country, Gambian rural population constitutes 75 % of the farming population who depends on short season rain-fed agriculture for household food security (Dibba *et al*., 2012). The agricultural sector is the most vulnerable sector to climate change and that adaptation study is a prerequisite to explore adaptation needs of rural farming household to the weather extremes (Alemayehu and Bewket, 2017). The concept of adaptation in the natural sciences is disputed; it broadly refers to the development of genetic or behavioral characteristics, which enable organisms or systems to cope with environmental changes in order to survive and reproduce. In the climate context, adaptations can be defined as the ‘‘adjustments in individual groups and institutional behavior in order to reduce society’s vulnerability to climate effects.’’ Based on timing, adaptations can be anticipatory or reactive and depending on the degree of spontaneity, it can be autonomous or planned (Smit and Wandel, 2006). In the Gambia, farmers have always built resilience to adjust to shifts in the weather pattern in order to avoid the risk in agriculture associated with moisture deficiency and severe dry spell (Kutir, 2015).

Many alternative strategies have been identified to increase the resilience of smallholder farmers to climate change. ‘‘Farmers can adapt tactically to the changing climate by staggering planting dates’’(Rurinda, 2014). Technically, farmers use indigenous knowledge to maintain soil fertility, which is the key biophysical variable hindering upland crop cultivation in The Gambia (Sanyang *et al*., 2013). However, they use different crop cultivars with the integration of cereal-legume rotation as strategies to avoid total crop failure in case of drought occurrence. To attain food and nutrition security in the household, farmers adapt to crop diversification as response strategies to increase production within the agro-ecologies (Noriega *et al*., 2017). Most of the adaptation strategies identified have not been experimented by indigenous farmers in The Gambia. Exploring the applicability of adaptation options to farmers in the field will help to integrate the options into their cropping system. The farmer field school is a new direction that provides avenues for action linking to knowledge. Additionally, training with a demonstration by farmers and stakeholders, draw attention to policy direction, which enhances the bottom-up approach adaptation process. This will raise farmers’ capacity to continuous adaptation options to climate change and variability (Smit and

Wandel, 2006). This will make them make the distinction between changing climate and other environmental challenges. Therefore, it is of relevance to address adaptation in a general perspective to anticipate the current and evolving biophysical and climate risk (Morton, 2007). This study examined the extent of vulnerability of Rice (*Oryza sativa L.*) and Maize (*Zea mays L.*) yields to drivers of climate variability in the Gambia. It also seeks to come up with possible adaptation options with a view to addressing and improving the policy on adaptation options to climate variability in the country.

1.2 Problem statement

Agro-ecological regions are classification based on climate, vegetation, soils, and potential land use. In The Gambia, climate records indicate unequivocal negative changes since 1976 (Government of Gambia, 2012). Challenges associated with climate change in the Gambia are more severe in the Sahel and Sudano-Sahelian zones of the country. The annual temperature has risen by approximately 1.0 ^{o}C since 1960 and expected to increase from 1.1 to 3.1 ^{o}C by 2060. According to the second National Communication (July 2012) to the UNFCCC, climate episodes observed show statistically significant trends in historical low receipt of rainfall during the main rainy season, from June to October.

Crop production is significantly influenced by rainfall intensity and duration, and the relationship between evapotranspiration and annual rainfall variation. The prevailing elevated temperatures influence evapotranspiration. Changes in the above climaterelated hazards will negatively affect agriculture, which is the backbone of The Gambia in terms of economy and rural livelihoods. Increase in temperature and intra-annual rainfall distribution reduces the ability to grow crops. The study of Yaffa (2013) reported that there would be a 40 % drop in perennial and shallow-rooted crops due to high temperatures. Tidal movements and seasonal flooding from the Atlantic Ocean, with subsequent seawater intrusion into the river Gambia, which results in the high salt content of the lowland soils, destroying the rich fertile soils that would otherwise be very suitable for rice cultivation, characterise the lowlands.

Changing cropping patterns and unsuitable agricultural practices have been the primary agents contributing to the loss of livelihoods. It is perceived that the depletion of vegetation cover is caused by the growing demand for more food crops and urbanization due to rapid population growth. The forest cover area has reduced to 423,000 ha indicating a loss of 97,000 ha mainly from the forest reserve category being converted due to transition to either agricultural use and infrastructural development or settlements. Despite the challenges, there are few studies or inadequate empirical evidence on how these two crops (rice and maize) yields are vulnerable to climate change and variability in The Gambia.

1.3 Research objective

1.3.1 Main objective

The aim is to evaluate the extent to which food crops (rice and maize) yields are vulnerable to climate variability and assess the adaptation options used by local farmers to sustain and improve the yields.

1.3.2 Specific objectives

The specific objectives were to assess:

1. The extent to which food crops (rice and maize) yields are vulnerable to climate variability.
2. The effect of soil fertility and properties on the yields of rice and maize in the study area.
3. Yield response of rice and maize to the future effect of climate variability.
4. Adaptation practises used by local farmers to address the adverse impacts of climate variability.

1.4 Research Questions

1. To what extent are food crops (rice and maize) yields vulnerable to climate variability?
2. How do soil fertility and properties changes influence rice and maize yields over time?
3. How will the yield of food crops (rice and maize) respond to the future effect of climate variability?
4. What adaptation practises can be useful for local farmers to cope with climate variability?

1.5 Justification of the study

The economy of the Gambia depends immensely on agriculture, which is currently facing challenges because of the increase in population, household food insecurity, environmental degradation, climate change, and variability. Agriculture and rural livelihood activities in The Gambia depend on rainfall and constitute about 75 % of the national GDP (Dibba *HWDO*, 2012). The potentials of agricultural productivity of a region depend on climate, good soils, vegetation, and land use pattern. It was observed that climate change and variability is altering the suitability of growing ecologies, skewing their food security potential. Since 2009, cereal yield shows a decreasing trend that could be attributable to climate change and variability (Yaffa, 2013). However, it was not clear whether climate-related, non-climate related hazards or a combination of both contributes to yield decline. An agricultural vulnerability was used in identifying cereals and food crop production strength of the Sudano-Sahelian Zone, areas susceptible to an adverse event that required high agricultural intensification. This study will be useful to identify areas susceptible to climate change and variability for policy intervention to attain food security in the study area.

1.6 Limitation of the study

Vulnerability assessment of rice and maize yields required biophysical and socioeconomic data for good model results. Time series data for soil nutrient, yield parameters, and socio-economic (management) data were not available for the period considered. Historical soil data was not available to make a comparison for the rate of change. Finally, the influence of pest, diseases, and technological development, which could also affect crop yield, were not considered. The data obtained from the adaptation practices identified during this study were strategies farmers adopt based on their convenience to use the strategies but were unable to tell the cost involved in some adaptation strategies.

Thesis structure

This thesis consists of seven chapters. **Chapter 1** presents the general introduction, giving an overview of the importance of food security and some of the negative impact of climate change on crop yield. **Chapter 2** covered the review of available literature that forms the theoretical and conceptual framework of this study. **Chapter 3** addressed specific objective 1 which assessed the influence of climate variability on the yield of maize and rice. **Chapter 4** addressed specific objective 2 on soil physical and chemical properties of upland and lowland field soils. **Chapter 5** deals with future climate variability on maize and rice yield over a 30-year period based on two climate models. **Chapter 6** addressed specific objective 4 to identify adaptations practised by local farmers to cope with climate variability. **Chapter 7** presented a summary of the results, conclusions, and recommendations for the study.

1.7 A brief description of the study sites

The study was conducted in the Lower River Region of The Gambia which is located between latitudes 13^{o} and 14^{o} N and longitude 16^{o} and 13^{o} W (Figure 1.1). The region has an agrarian economy and more than half of its inhabitants are directly or indirectly involved in crop production. It has a Sudano-Sahelian climate characterised by a short rainy season from June to October. Mean annual rainfall varies from 900 mm in the South West to about 600 mm in the North East. Mean temperatures ranging from 25° C to 28° C are generally higher in the eastern part of the country. It has a total land surface area of 1,618 km^2 (GBoS, 2013).

Figure 1. 1: Map of The Gambia showing different districts in the Lower River Region

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This Chapter presents a review of the available literature that forms the theoretical and conceptual framework of this study. The review covers existing knowledge and theory on climate variability and its drivers as well as adaptation options and management approaches to cope with the situation. The theoretical framework focuses on a range of issues relating to climate and climate variability, the impact of climate change and variability in The Gambia. Other aspects examined include vulnerability to climate variability, the vulnerability of rice to climate variability, and vulnerability of maize to climate variability. The latter part of the theoretical framework dwelt on drivers of vulnerability and adaptation options to climate variability. The last section of the review centered on the conceptual framework for this study, which was derived, based on the existing knowledge and theories relating to the various aspects of this study.

Scientific evidence on the climate change impact on smallholder farming communities on their tolerant or susceptibility to historical long-term weather problems is inadequate at household and village levels. Responding to these shortfalls will enhance the perception of farming communities to manage with the consequences of climate extremes, conveying relevant information obtained from this study into the arrangement of factors and drivers of vulnerability (Shah and Dulal, 2015).

2.2 Theoretical framework

2.2.1 Climate and climate variability

The global atmosphere is comprised of different climate variables (such as elevated temperature, humidity, rainfall/precipitation, and air pressure) which have been altered as a result of greenhouse gas emission from anthropogenic activities (IPCC, 2007; Chiarelli *HWDO*., 2016). As reported by many climate scientists (Klopper *HWDO* 2006; Dawson *HWDO*., 2014; IPCC, 2007), "climate is usually defined as the "average weather", or more thoroughly, as the statistical description of the weather in terms of the mean and variability of relevant quantities over periods of several decades".

Climate variability is considered as the difference in the average state of the weather and conventional statistics of the climate on a short duration space beyond anthropogenic atmospheric events (Bronkhorst, 2011). According to Cohn *HW DO* (2016), "climate variability is not a man-made alteration of the climatic system and occurs as a short-term fluctuation". Climate change is viewed as a shift in a pattern of normal average weather variable over a long-term period, usually three decades or more (Connolly-Boutin and Smit, 2016). The consequences attributed to accelerated climate variability portray economic and technological shortfalls to the societies, which are self-evident in agriculture for livelihood. Toggweiler and Key (2001) pointed out during their study that, the concept of climate variability is attributed to a shift in climate variables especially rainfall and temperature which go beyond the normal condition. This is the concept adopted in the study.

2.2.2 Impact of climate change and variability

Climate change over the globe has significant impacts on natural and human systems as well as on economic sectors. It is obvious that inter-annual variability is large over most of the continents of the world and, for some regions, multi-decadal variability is also extensive (Toggweiler and Key, 2001). Hence, in recent decades many regions have suffered from different climate change such as floods and droughts with greater frequency and intensity (Molua, 2002). Consequently, climate reports suggest that accelerated alteration in climate are projected to lead to possible great impacts across different continents in the future (Peters *et al.*, 2013).

IPCC (2007) reported that "by 2020 between 75 and 250 million people are projected to be exposed to an increase in water stress due to climate change. Coupled with increased demand, this will adversely affect livelihoods and exacerbate water-related problems". Some studies have noted that climate change and variability is caused because of anthropogenic activities contributing to the emission of greenhouse gas (Berry *HWDO*, 2006; Wheeler, *HWDO* 2013; Iizumi and Ramankutty, 2016). Furthermore, Sanneh *HWDO* (2014) pointed out that, sub-Saharan Africa is projected to face serious climate extremes due to its sensitivity and low adaptive capacity to the consequences of climate change and variability.

2.2.3 Climate change and variability in The Gambia

The Gambia has been facing many climate-related hazards, which include erratic rainfall, drought, flood and temperature fluctuations for the past decades. During the Second National Communication to UNFCCC, the historical rainfall variability in The Gambia showed a significant decreasing trend over the entire country (Camara, 2013). Many regions in The Gambia have shown different climate risks such as droughts and floods with greater frequency and intensity for the periods 1998–2018 (Kutir, 2015). Furthermore, climate projections in the literature suggested that slight changes in climate are expected to cause negative consequences across the African continent (Lobell and Burke, 2010; Rochdane *et al*., 2014). Braman *et al.* (2013) noted that the number of climate disasters over the African continent is on the rise. In 2007, total rice production in The Gambia dropped by about 68 %, from 35,900 tonnes in 2002 to 11,395 tonnes in 2007. Similarly, the drop in the production of coarse grains (e.g. Maize Sorghum, Millet) was about 27 % (from 248,400 tonnes in 2003 to 181,400 tonnes in 2007), both attributed to drought (Figure 2.1b). Recently, it was reported that torrential rains (Figure 2.1a) have displaced more than half the rural population, submerging crops in the rural areas and destructions of properties in The Gambia (Warner and Geest, 2013).

(a) (b)

Figure 2. 1: Examples of extreme climate-related events: (a) Flood hazard in The Gambia in 2012 (b) NERICA rice field affected by drought in The Gambia. (Source: https://reliefweb.int/disaster/fl-2012-000175-gmb)

Climate variability has caused a tremendous effect on the agricultural sector, which drives the economy of The Gambia. Loum and Fagassy (2015) noted that cereals yield will be affected by any accelerated change in climate variables especially rainfall in the future given the effects of climate variables on cereals production. Rainfall variability can also lead to a disparity in terms of agricultural output within the same agro-ecology resulting in low yield.

However, the temperature, on the other hand, has a negative influence on the growth stage of crops. Asseng *HWDO* (2011) found out that variations in average growing season temperatures of +/-2 ºC in the main rice growing regions of the tropics could cause reductions in grain production of up to 50 %. Similarly, Campus (2015) studied the influences of temperature and rainfall on the yields of maize in Nigeria. The results revealed that extreme temperatures of >34 °C can cause leaf senescence and low grain filling. Based on the severity and occurrence of climate change and variability, it is still unknown to poor farmers on how to distinguish between temperature and other biophysical effects on the yield of crops.

2.2.4 Vulnerability to climate variability

Vulnerability evaluation among humans and their socio-ecological habitat have been used to study the pairs of various interactions (Rochdane *HWDO* 2014). Moreover, climate change and variability perception are quite challenging to calculate. Much indicatorbased vulnerability evaluation has been explored at both local, country and regional level (Antwi-Agyei *HWDO*, 2012; Maiti *HWDO*., 2017). The empirical evidence from vulnerability studies will give an opportunity to identify the impact among vulnerable groups to the consequences of climate events. Vulnerability has been conceptualized into three interrelated components namely; Exposure, Sensitivity and Adaptive capacity (IPCC, 2007). In an effort to comprehensively explore the ecosystem challenges since three decades (1988 to 2018) ago, empirical evidence on the vulnerability of agro-ecology and agricultural productivity to adverse weather was the priority for global scientists. Initially, vulnerability was conceptualized in disaster study to explore the level of damage, but with the consequences of climate change episodes, IPCC in their 1996 second assessment report defined vulnerability as a function of exposure, sensitivity and adaptive capacity (Tao *HWDO*, 2011).

Maiti *HWDO* (2017) conducted a study on climate change induced social vulnerability of the districts of Arunachal Pradesh in India. Their study showed that vulnerability was associated with low adaptive capacity with average among newly established communities lacking good infrastructure within their districts. According to the same research, about 60 % of the household does not have access to drinking water facility within their environment demonstrating that vulnerability is more pronounced in the rural areas. As demonstrated in the study of Rurinda (2014), South Sumatra experiences a high level of vulnerability to climate change due to the fact that the changing pattern of climate variables shows a negative approach. It was also observed that sensitivity was seen to be the dominant indicator in terms of the level of severity to food security. In order to remedy and mitigate the future impact of climate, specific adaptation strategies were not well defined which was identified as a research gap for climate scientists.

Alam (2017) conducted a study on vulnerability to climate change with an emphasis on policy implication, livelihood and social development on the Bangladeshian natural resource using IPCC framework on vulnerability assessment approaches (the Livelihood Vulnerability Index (LVI) and Climate Vulnerability Index (CVI)). The study observed that livelihood strategies and access to daily needs were the drivers of vulnerability. Targeted priorities of policies and development for adaptation options were identified as research gaps to accelerate adaptive capacity in a given vulnerable country. Using the livelihood vulnerability index, Antwi-Agyei *HWDO*. (2013) studied and characterized the nature of household vulnerability to climate variability in two regions of Ghana. The results highlighted that variation occurred within the household in the same agroecological zone in terms of climate vulnerability. Communities, which tend to be outlier communities shows an array of adaptation options than household within the vulnerable communities. Emphasis was given to building social capital and institutional capacity as a research gap to give detailed empirical evidence.

2.2.5 Vulnerability of rice to climate variability

The current issue confronting agricultural activities in the world is the consequences of changing weather pattern, which generates high occurrence of drought, frequent flooding, higher temperatures and salinization into coastal agricultural fields. Studies by Buan *et al.* (1996), Xiong *et al.* (2009) and Rowhani *et al.* (2011) reported that vulnerability of cereal production to climate variability is driven by erratic rainfall and high salinization in coastal swamp ecologies. Similarly, Clark *et al*. (2016) reported that an increase in temperature and erratic rainfall events are projected to exacerbate cereal production during the 21st century. The past "IPCC projections have indicated a likely increase in drought and cyclone activity, both of which could have major detrimental effects on global crop productivity" (IPCC, 2007).

In sub-Saharan Africa, rice is considered as a major staple food crop consumed by about 60 % of the population (Tanaka *et al.*, 2017). Studies by Carney (2008) and Jaiteh (2003) concluded that The Gambia has the highest per capita rice consumption (107 kg) among the Sahelian countries, and the third highest per capita consumption in West Africa. The possible effects of climate change on rice production in Africa was studied by Oort and Zwart (2018) using the most recent IPCC emission scenarios the representative concentration pathway (RCP). The results revealed that reduced photosynthesis at extremely high temperatures is the main cause of yield reduction of rice. Contrary, Page *et al*. (2010) reported that rice yields decreased as a result of rainfall variability coupled with high salinization into swamp ecologies suitable for rice production. Many climate projections highlighted that crop yields especially cereals will be compromised due to the growing populations demand in future (Clements *et al.*, 2011; Dawson *et al.*, 2014; Guan *et al.*, 2017). However, how climate variability affects productivity at different spatial scale is still unknown. It is assumed that yield reduction in rice production under current climate change scenarios could be improved by intensive irrigation.

2.2.6 Vulnerability of maize to climate variability

With the advent of climate change and variability impacts, many studies have been conducted at agro-ecological levels to provide empirical evidence (Tubiello *HWDO* 2015; Alemayehu and Bewket, 2017). Shi and Tao (2014) studied the vulnerability of African maize yield to climate change and variability during 1961–2010. Their study employed the "detrended yield deviation (ΔYd) and climate variables (Temperature, Precipitation, and standardized precipitation evapotranspiration index) to analyse the vulnerability of maize yields to climate change for each country in Africa". The results indicate that any 1°C of Tmean increase will result in a yield loss of over 10 % and increased by more than 5 % in cool countries. Therefore, maize yield is vulnerable to variation in temperature and precipitation in Africa. Further research to be explored needs to quantify the impacts of climate extreme including droughts, floods and high temperature episodes as research gaps, which were not included in this study and may become more frequent in parts of Africa.

Similarly, Antwi-Agyei *HWDO* (2012) evaluated new multi-scale, multi-indicator methods for assessing the vulnerability of crop production to drought at a national and regional scale in Ghana. The study showed that vulnerability of crop production to drought in Ghana has visible geographical and socioeconomic patterns indicating a variation of vulnerability at different regions. The study concluded that Guinea Savannah and Sudan Savannah agro-ecological zones are the most vulnerable to increasing drought events in Ghana, which is characterized by uni-modal rainfall pattern, and predominantly drier conditions and fragile agro-ecosystems. The study suggested the need for region and district specific climate adaptation policies, as different regions and districts within a country display different levels of vulnerability.

Loum and Fogarassy (2015) "explored the effects of climate change on crop production specifically (Maize and Millet) and food security in the Gambia". They used a time series data from (1960 – 2013), using Just and Pope modified Ricardian production functions for climate change impact assessments. The result indicated a strong relationship between climate and Maize and Millet yield. The authors suggested that 77 % and 44 %

of the variability in the yield of Maize and Millet respectively was explained by the climate and non-climate variables included in the model. It is recommended that other climate variables such as solar radiation, sunshine duration, humidity, socio-economic and adaptation that affect cereal production apart from temperature, rainfall and CO_2 need to be explored.

Berry *HWDO* (2006) established that agriculture and species vulnerability is associated with climate and socio-economic scenario. It was observed from their findings that agricultural vulnerability was pronounced on socio-economic condition whereas species are affected by climate scenario. The vulnerability can be alleviated through crosssectoral assessment in order to enhance development and policy implementation. Similarly, Magehema *HWDO* (2014) pointed out that rainfall variability is the most critical climate variable contributing to yield reduction in sub-Saharan Africa. Yet there is a gap in terms of assessment of rainfall distribution across different regions where maize production is suitable. There is a need to study the pattern of rainfall distribution in order to inform policy formulation towards adaptation programs.

2.2.7 Drivers of vulnerability

The driving force of the growing population of the world’s continents is the food supply system which supports the livelihood and economic activities of human wellbeing. Despite the potential ecological settings to enhance the production of the food supply system, the African continent still experiences food insecurity. About 23 % of the population is undernourished due to high intra and inter-annual climatic variability (Sonwa *HW DO* 2016). “Although vulnerability to climate change is very unevenly distributed across Africa, the potentially damaging climatic effects and risks pose serious threats to sustainable development in many parts of Africa”(Alam, 2017). Studies in the

African continent by Sonwa *HWDO*(2016), Fitzgerald (2016) and Mubaya *HWDO* (2010) also highlighted factors that drive the vulnerability of agriculture to climate variability. The results obtained showed that climate change and variability coupled with low soil nutrients are the key main drivers of vulnerability. However, the frequency and variation in the distribution of climate change have fundamentally reduced the complexity and time required for developing countries to adapt. Therefore, it will be much easier to build on existing adaptation strategies in order to domesticate their implementation.

Misselhorn (2005) made similar conclusions using meta-analysis to synthesize 49 household economy. The results show that household food insecurity is driven by climate change and biophysical variables. However, not all indicators measured the same degree of vulnerability, even though they are considered the key drivers of vulnerability. Ingram (2011) stated climate change indicators as the main drivers of production in his study. The results pointed out that rainfall variability is the most limiting factor exacerbating low crop yield and the approaches used by other researchers lack specific adaptation options to a direction of use for a specific location.

2.2.8 Adaptation options to climate variability

Adaptation in the environment of human context to global climate change usually refers to a practise, demonstration or results in a system that fosters it to adjust to the consequences. Many concepts of adaptation are established in climate change literature. Smit and Skinner (2002) describe adaptation as ‘‘adjustments in a system’s behavior and characteristics that enhance its ability to cope with external stress. Smit *HWDO* (2001) in the climate change context, referred to adaptations as ‘‘adjustments in ecological socioeconomic systems in response to actual or expected climatic stimuli, their effects or impacts.'' Previous studies by Antwi-Agyei *HWDO* (2014) identified the main adaptation strategies used by farming households in the Sudan savannah and forest-savannah transitional agro-ecological zones of Ghana. The findings revealed that many households use adaptation strategies linked to livelihood diversification to adapt to the increased climate variability seen in recent decades (1998 to 2018).

In a similar study, Alemayehu and Bewket (2017) identified different coping and adaptation strategies used by smallholder farmers to mitigate the adverse impacts of climate change and variability in the central highlands of Ethiopia. It was reported from the finding that most household sells livestock and adopt the changing consumption pattern as coping strategies while changing cropping date was used as an adaptation option to climate variability. Douxchamps *HWDO* (2016) categorized different adaptation options in Burkina Faso, Ghana, and Senegal into crop diversity, soil and water conservation, trees on the farm, rearing of small ruminants and use of improved crop varieties and fertilizers. The results showed that different adaptation strategies may be climate smart. It was recommended that farmers need to be empowered to access, test and modify these adaptation options if they were to achieve higher levels of food security.

Several approaches based on country specifics in the 21st century were studied by Downing *HWDO* (1997), Akon-yamga *HWDO* (2011) and Webber*HWDO* (2014) to investigate adaptation strategies implemented by farmers and identify the challenges they face in adopting the strategies. This period marked the initiation of climate change conventions to address the implementation of climate change adaptation and mitigation program for countries vulnerable to current climate consequences. In a general consensus of studies in sub-Saharan Africa's vulnerability to climate change and variability, Molua

(2002), Rurinda (2014), Allakonon (2015) and Richardson*HWDO* (2018) agreed on the same conclusion that some challenges "(low adaptive capacity, high dependence on rainfed agriculture, low capacity of farmers, high cost of input, low soil nutrients and unpredicted climate) are the key hazards in attaining sustainable adaptation strategies to climate change". However, these main constraints deviating adaptation strategies can be addressed through a national adaptation plan of action (NAPA).

Moreover, NAPA through countries development agendas and policies can offer enormous opportunities to enhance food self-sufficiency. According to FAO (2003), subSaharan African food security will be affected by climate events and continuous soil nutrient mining. Based on the adaptation plan of action which foster resilience of farmers to achieve food security and income generation, farmers are advised to manage the natural resources potential for farming. The current work takes a further step to assess possible adaptations and attempts to provide guidance for prioritizing adaptation investments.

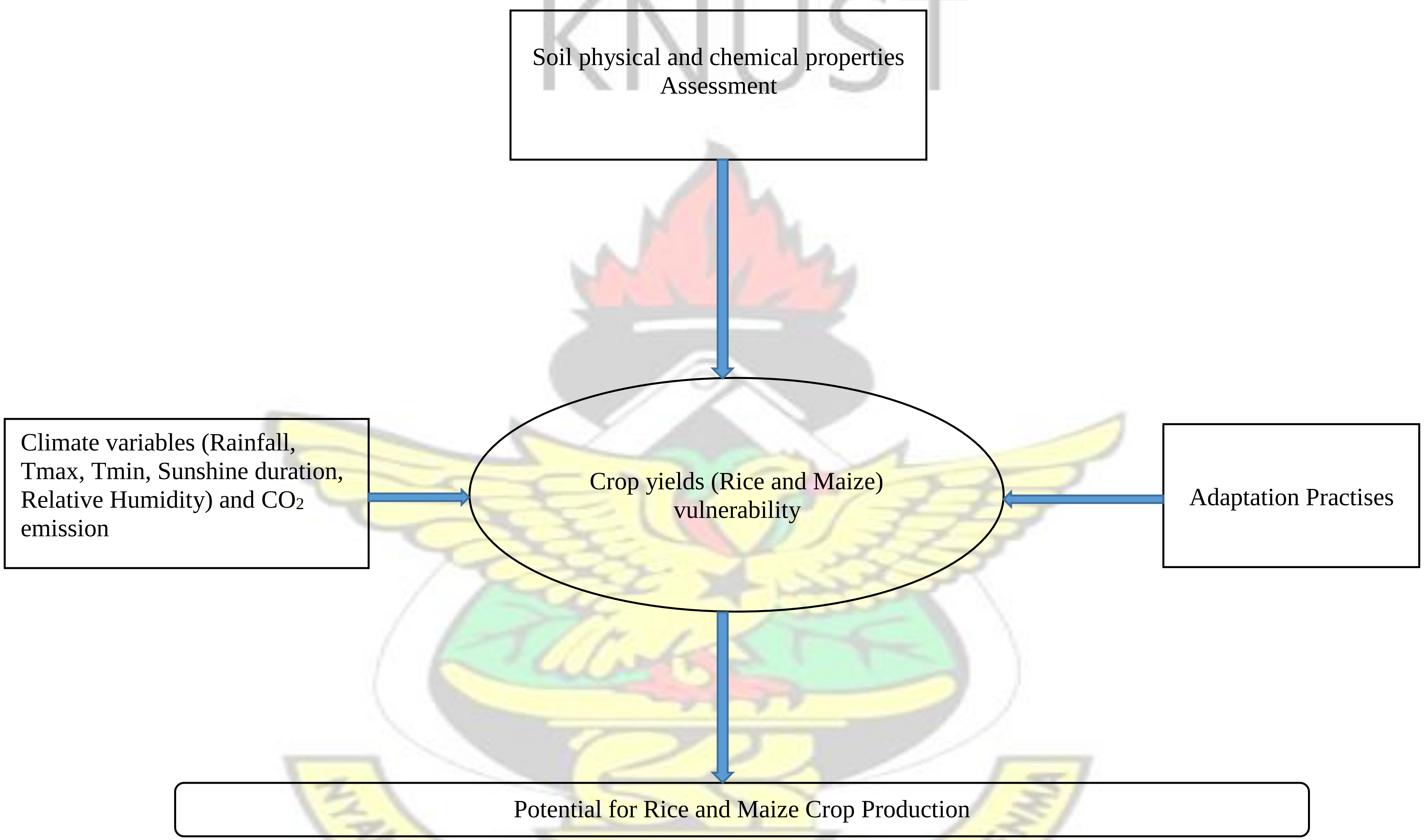


Figure 2. 2: The schematic illustration of the conceptual framework

CHAPTER THREE

INFLUENCE OF CLIMATE VARIABILITY ON THE YIELD OF RICE (*Oryza sativa L.*) AND MAIZE (*Zea mays L.*) IN THE SUDANO SAHELIAN ZONE OF THE GAMBIA

Abstract

Climate change and variability will have an impact on all eco-systems but more importantly in the developing countries of the world. The Gambia is vulnerable to climate change and variability due to its negative effect threatening rainfed agriculture. Many scientists are concerned about the future effect of climate on crop yields. This study assessed the effects of climate variability (e.g., rainfall, maximum and minimum temperature, sunshine duration, relative humidity, and CO_2 emission) on the yield of rice and maize. The Ordinary Least Square and heteroscedasticity techniques were applied using time series data for the period 1981-2016. The results showed that CO_2 and rainfall unfavourably affect rice yield and were statistically significant. Maximum and minimum temperature negatively affect yield and but not statistically significant. In addition, the results further showed that CO_2, maximum temperature and sunshine duration adversely affect maize yield significantly. Rainfall and minimum temperature negatively affect maize yield but were not statistically significant. It is concluded that rainfed agriculture may no longer be viable in the face of climate change and variability in the future and may affect household food security. To offset the negative effects of climate change and variability, new crop varieties need to be introduced into the farming system to augment the local varieties to enhance food security in the country.

3.1. Introduction

Climate change and variability will have an impact on all eco-systems but more importantly in the developing countries of the world (IPCC, 2007). Many scientists believed that high-elevation eco-systems of the mountainous regions are the most vulnerable regions of the world to climate change (Cavaliere, 2009; Maiti *et al.*, 2017). Evidence from IPCC (2007) and Stocker et *al*. (2013) point out that, developing countries are the most vulnerable to climate change and variability, though it contributes only 4 % of GHG emissions globally. Majority of African countries economy rely on agriculture and their staple food crops depend on rainfed agriculture to feed the fast-growing population (Sasson *et al.*, 2012).

Scientists have attributed yield reductions of the major staple food crops of the African continent to the consequences of climate change and variability. Shi and Tao (2014) assessed the vulnerability of African maize yield to climate change and variability using time series and detrended yield deviation approach. The results indicated that any 1°C of increase in mean minimum temperature will lead to yield losses of cereal of over 10 %. Similarly, Antwi-Agyei *HW DO* (2012) concluded that the vulnerability of Ghanaian agriculture affected by climate change due to frequent drought observed in different agroecologies especially Guinea Savannah and Sudan Savannah agro-ecological zones. Studies in The Gambia reaffirmed that climate change and variability poses a serious challenge to growing ecologies of major staple crops (Munasinghe, 2012; Atherton*HWDO*.,
2013; Braman *HWDO* 2013). Agriculture is the backbone of The Gambian economy and contributes to the staple food supply for the country (33% GDP of the country) and produces 41 % of rice, 12 % of maize and 16 % groundnut respectively (Moseley *et al.*, 2010).

Vulnerability by definition is typically described to be a function of three interrelated components: exposure, sensitivity, and adaptive capacity. But, as in the agricultural point of view, vulnerability to climate change is termed not only the inability to adapt to elevated temperature but the sensitivity of crop yield to environmental temperature and the resilience of farmers to tolerate the effect of that sensitivity (Oter *et al*., 2005). Vulnerability assessment is based on the biophysical and the socio-ecological systems that replicate the concept that anthropogenic activities and social organizations are integral to flora and fauna and hence any disturbance between them is arbitrary (Adger, 2006).

Jute and Ricardian production functions were used by Loum and Fogarassy (2015) to assess climate change and variability of millet and maize in The Gambia. The results showed a decrease in yield by 77 % and 44 % for maize and millet respectively due to negative erratic rainfall pattern. However, Tanaka *et al.* (2017) surveyed different rice growing ecologies (Irrigated lowland, Rainfed lowland, and Rainfed Upland) using cluster analysis approach. Their study reported that rainfed upland rice is vulnerable to low quality soil and rainfall variability. In view of the potentials for rice and maize production, climate and soil variables are considered the two most limiting factors affecting yield. Many studies used models to project yields in the future but failed to distinguish the trends of rainfall and temperature from other variables as the limiting factors. This study aims to assess the extent to which rice and maize yield are vulnerable to climate variability using a regression approach.

3.2. Materials and methods

This study was carried out in the Lower River Region (LRR) located in South bank of river Gambia (Figure 1.1). It has a land mass of 1618 km^2 with a population of about 82,361 people (GBOS, 2013). Geographically, it is located between latitude 13^0 34' N and longitude 14^0 47' W and bordered west by West Coast Region and on the eastern by Central River Region South covered approximately 122 km from the Atlantic Ocean. LRR shares a similar climate to the rest of The Gambia, which is characterized by a long dry season (November to May) and a unimodal rainy season from June through to October. The Average rainfall of the region ranged from 600 to 900 mm per annum with a mean temperature of 32^0 C.

3.2.1. Source of data

The data for this study was obtained from different institutions mandated to deal with climate information and crop productivity. The study relied on secondary data for the period from 1981 to 2016. The annual regional data on yield of the two staple crops were obtained from the Department of Planning Service of Agriculture of The Gambia, which is responsible for agricultural survey. The yearly climate data was collected from the Department of Water Resource of The Gambia including the CO_2 data.

3.2.2. Model specification

In a normal environmental condition, each crop requires certain conditions for productivity, such as high CO_2 concentration, good rainfall, optimum air temperature, average sunshine duration, and relative humidity. CO_2 is one of the main pillars for the survival of the plant and has a beneficial effect on crop production. High CO_2 concentration in the atmosphere with an increase in temperature can boost cereal production especially rice as reported by (Fitzgerald, 2016). In contrary, high CO_2

concentration may lead to negative effect, hence increase in temperature leading to global warming, high evapotranspiration which may deplete the ozone layer (Godfray *et al.*, 2010). Rainfall is the most limiting climate variable affecting plant growth either surplus or deficit. According to Rosegrant and Cline (2014), torrential rains can lead to soil erosion and submergence of crops in the lowland ecologies which destroy crop plant. Severe drought may lead to total crop failure, which may frustrate farmers in getting food to eat and hence trigger food insecurity (Yaffa, 2013). Rowhani *et al.* (2011) concluded that minimum and maximum temperatures provide the energy source for photosynthesis and when adequate can increase crop yield.

Based on the above variable descriptions, (an appropriate multiple regression model was applied) to the study. The ordinary least square (OLS) regression and heteroscedasticity methods were used, looking into the nature of the dependent and independent variables (Molua, 2002). The regression equation for computing rice yield is given in equation 3.1.

…equation (3.1)

Where, RY = rice yield, CO_2 = Carbon dioxide, R*f*= rainfall, Tmin = Minimum temperature, Tmax = Maximum temperature, RH = Relative humidity, Shd = Sunshine duration are the variables, $\boldsymbol{e_t}$ is the joint effect of those variables not included in the model, (i.e. random factors which cannot be accounted for in the model), a_0 is the intercept, a_1, a_2, a_3, a_4, a_5, a_6 are the coefficient of the independent variables.

The regression equation for computing rice yield is given in equation 3.2.

…equation (3.2)

Where, M*Y* = maize yield, CO_2 = Carbon dioxide, R*f*= rainfall, Tmin = Minimum temperature, Tmax = Maximum temperature, RH = Relative humidity, Shd = Sunshine duration are the variables, e_t is the joint effect of those variables not included in the model, (i.e. random factors which cannot be accounted for in the model), β_0 is the intercept, β_1, β_2, β_3, β_4, β_5, β_6 are the coefficient of the independent variables (explanatory

Table 3.1: The units of measurement and expectation of the variables used in the ordinary least square regression model

Variables	Rice	Maize	Units of Measurement
CO_2	+ve	+ve	Kt
Rainfall	+ve	+ve	Mm
Minimum Temperature	-ve	-ve	^oC
Maximum Temperature	+ve	+ve	^oC
Relative humidity	+ve	+ve	%
Sunshine Duration	+ve	-ve	hrs

3.3. Results

The results of the descriptive statistics are shown in Table 3.2, which presents the essential properties of the model variables in the study. The observed mean yield between the two staple crops showed that rice (1288.78 Kg/ha) has the highest mean yield. Considering the average production, rice yield was higher than that of maize for the period studied. In addition, more area was cropped under rice than maize. The observed mean climate variables of the descriptive statistics showed that the mean CO_2 concentration is 287.71 Kt. Rainfall, which is the determinant for production showed a mean value of 810 mm per annum. Maximum and minimum temperatures were 35^0 C and 20^0 C respectively. Relative humidity averaged at 55 % and the average sunshine duration was 7.6 h. The effect of climate variability on rice and maize yields are discussed subsequently.

Table 3. 2: Descriptive statistics of model data (OLS) from (1981-2016)

Variables	Staple Crops	Mean	S.t.d Dev.	Min.	Max.	Skewness	Kurtosis
Area Cultivated (ha)	Rice	2672	1939	670	11310	0.000	0.000
Yield (kg/ha)	Rice	1289	362	646	2093	0.765	0.128
Production (MT)	Rice	3187	1792	535	9036	0.003	0.020
Area Cultivated (ha)	Maize	1297	1155	346	4448	0.002	0.205
Yield (kg/ha)	Maize	1142	262	692	1761	0.143	0.546
Production (MT)	Maize	1301	920591	364	3537	0.092	0.942
CO_2	Rice Maize	288	115	158	491	0.147	0.004
Rainfall (mm/y)	Rice Maize	811	215	383	1338	0.444	0.974
Minimum Temperature (^oC)	Rice Maize	20	0.5	19	21	0.009	0.008
Maximum Temperature (^oC)	Rice Maize	36	1	35	38	0.109	0.249
Relative Humidity (%)	Rice Maize	55	3	46	60	0.012	0.059
Sunshine (h/d)	Rice Maize	7.6	0.4	6.6	8.4	0.155	0.976

3.3.1. C limate and rice yield

The OLS regression results showed the influence of climate variability on the yield of rice. It was observed that CO_2 and rainfall were significant at ($P \leq 0.05$) but the effect differs in terms of magnitude (Table 3.3). CO_2 negatively affected rice yield whilst rainfall had a positive effect. Maximum and minimum temperatures contributed negatively to the yield of rice but not significant. Similarly, sunshine duration showed a negative effect on the rice yield except for relative humidity, which influenced rice yield positively. The effect was however not statistically significant. Furthermore, the coefficient of determination R^2 showed that 68 % variation in rice yield was subject to climatic factors and CO_2 emission.

Table 3. 3: The regression results of rice crop of Lower River Region, The Gambia evaluated by ordinary least square (OLS)

Rice Yield (kg/ha)	Coefficient	Standard Error	P-values
CO_2	-2.72	0.43	0.000**
Rainfall	0.52	0.21	0.017**
Minimum Temperature	-3.58	79.96	0.965
Maximum Temperature	-59.51	76.95	0.446
Relative Humidity	6.47	13.53	0.636
Sunshine	-61.09	96.91	

No. of Observation = 36
R-squared = 0.6789
Adj. R-squared = 0.6125
Prob > F = 0.000

* *represents a level of statistical significance at (P ″ 0.05) *represents a level of statistical significance at (P ″ 0.10

3.3.2. Climate and maize yield

The findings presented in Table 3.4 showed that CO_2 and maximum temperature were found to be significant at 5 % level of significance whilst sunshine duration is significant at 10 % level of significance and has a negative effect on the yield of maize accept maximum temperature. Contrary, rainfall and minimum temperature were not statistically significant and that both of them negatively influenced maize yield except relative humidity, which has a positive effect on maize yield. The coefficient of determination R^2 value indicated that almost 39 % of yield variation on maize yield is an indication of climatic effect. Other variables affect maize yield other than this selected climate variables and CO_2 emission.

Table 3. 4: The regression results of maize crop of Lower River Region, The Gambia evaluated by ordinary least square (OLS)

Maize yield (kg/ha)	Coefficient	Standard Error	P-values
CO_2	-1.35	0.43	0.003**
Rainfall	-.06	0.21	0.785
Minimum Temperature	-99.97	79.54	0.219
Maximum Temperature	203.81	76.55	0.013**
Relative Humidity	6.22	13.46	0.647
Sunshine	-169.79	96.39	0.089*
No. of Observation = 36			
R-squared = 0.3920			
Adj. R-squared = 0.2662			
Prob > F = 0.0176			

* *represents a level of statistical significance at (3 ″) *represents a level of statistical significance at (3 ″)

3.4. Discussion

3.4.1. Climate and rice yield

Rice is the staple food for The Gambia but it undergoes numerous production challenges including the effect of climate change (Salvo *et al.*, 2013). CO_2 is one of the components for the plant to manufacture food through photosynthesis. Increase in atmospheric CO_2 can enhance crop production. These findings agreed with the study of Fitzgerald (2016) who concluded that CO_2 stimulate carbon assimilation in C_3 plant species like rice, and reduces stomatal conductance in both C_3 and C_4 species, which can lead to crop productivity. The historical CO_2 recorded in the study region had a negative effect on rice yield, which implies that if CO_2 concentration is low, rice production will be affected by nutrient availability negatively. On the contrary, an increase in CO_2 concentration may also induce an indirect effect on climate by increasing temperatures hence causing global warming (Dono *et al.*, 2016).

Rainfall drives the potentials of crops to reproduce through mineralization of nutrients in the soil (Rowhani *et al.*, 2011). Other studies reported that low rainfall has a negative effect on rice yield, hence below normal rainfall may induce crop failure (Lobell and Gourdji, 2012; Choudhury *et al*., 2015; Tanaka *et al.*, 2017). This study confirmed that rainfall negatively affected rice yield in the study area using ordinary least square approach. However, the results showed that minimum temperature had a negative effect on rice yield than maximum temperature, which is positive. When night temperature increases by 1^0 C it induces a decrease in rice yield by 15 % (Lobell and Field, 2007). Relative humidity has a positive influence on rice yield that implies that once relative humidity increases, it minimizes evapotranspiration hence prevents crops from desiccation (Chiarelli *et al*., 2016). Sunshine duration has a negative effect on rice yield as shown by the regression results but it is significant at 10 % level of significance.
Campus (2015) “reported that sunshine hour during the tillering stage had a significant positive correlation with the grain yield”.

3.4.2. Climate and maize yield

The maize ranked as the second most important food crop and feed ingredient for livestock in The Gambia. Generally, the production of maize shows a remarkable reduction in the yield in the face of climate change during the 21st century (Shi and Tao, 2014). The influence of CO_2 on the yield of maize showed a significant effect and had a negative impact on the yield. When there is a low concentration of CO_2 in the atmosphere, it affects photosynthesis and plant may not be able to produce and obtain good yield (Cairns *et al*., 2013). Rainfall negatively influenced maize yield during tasselling because it is the critical stage of maize for reproduction during which maize plant bear fruits (Campus, 2015).

Sub-Saharan Africa is characterized as the most vulnerable region to extreme climate events such as drought, which is persistent in the past 30 years over the continent (Guan *et al*., 2017). It is reported in the study of Krishnamurthy *et al.* (2014) that rainfed agriculture will be impotent to future climate variability and may not be able to provide enough food for the growing population if strategies are not put in place. It was evident from the findings that rainfall has negatively impacted maize yield and it supported the findings of earlier studies of (Krishnamurthy *et al*., 2014). The results showed that the minimum temperature was negative and not significant whilst the maximum temperature is statistically significant and positive.

These results contradict the findings of Zhang *et al*. (2016) who reported that an increase in maximum temperature may lead to a negative effect on maize yields. This could depend on the maize variety grown during the growing season. Relative humidity positively affects maize yield as seen from the results but not significant at ($P \leq 0.05$). Sunshine duration furnishes the required energy for certain chemical activities within growing plants, as well as promotes evapotranspiration from the foliage. The results showed that reduced length of solar radiation may induce negative effect (such as less solar radiation reaching the leaf area) on maize yield and has shown a statistically significant at ($P \leq 0.10$) in the findings. Therefore, combined climate effects were not statistically significant with R^2 of 39 % indicating that there are some other factors affecting maize yield in the study area.

3.5. Conclusion and Recommendations

The ultimate aim of this study was to assess the extent to which climate variability (e.g., rainfall, maximum and minimum temperature, sunshine duration, and relative humidity and CO_2 concentration) affect major staple food crops such as rice and maize. There is a difference in terms of variable outputs were some variables affect the yield significantly whilst others are not significant. The most influential variables affecting rice yield are CO_2 and rainfall. The findings confirmed that CO_2 is significant and negatively affect rice yield whilst maximum and minimum temperatures, sunshine duration are both not significant but negatively affect rice yield. CO_2 and sunshine duration were statistically significant and negatively influenced maize yield. Rainfall and minimum temperature both had a negative influence on maize yield but were not statistically significant. In contrast, maximum temperature showed a positive effect on the yield of maize and was statistically significant.

Generally, climate variability has a detrimental effect on staple food crops. Nearly, 70 % of the people living in rural Gambia are small-scale subsistence farmers who rely on rainfed agriculture for their livelihood. Rainfed agriculture may not be feasible in the face of climate change and variability in the future. Therefore, the government needs to strengthen agricultural research to introduce improved rice and maize varieties that are tolerant to climate variability. Future research needs to be conducted to assess the influence of other biophysical factors affecting rice and maize yield in order to guide the implementation of adaptation.

CHAPTER FOUR

ASSESSMENT OF THE EFFECT OF SOIL FERTILITY AND PROPERTIES ON THE YIELDS OF RICE AND MAIZE IN THE LOWER RIVER REGION OF THE GAMBIA

Abstract

Soil fertility status presents a daunting challenge to farming ecologies of The Gambia. Extreme climate events influence nutrient movement through erosion, which exacerbates crop production. This study assessed the fertility levels of soils in selected communities in the Lower River Region of The Gambia. A Conventional soil survey approach was used by taking composite samples to characterize soils in the rice and maize growing ecologies. Sixty (60) topsoil (0-15 cm) composites soil samples were randomly collected from 10 sites of Lower River Region for laboratory analysis. Results showed that swamp

rice ecologies had high percentage of NPK (N 0.07 %, P 0.0184 % and K 0.04 %) than in the maize upland fields (N 0.06 %, P 0.018 % and K 0.01 %). Soil pH is generally low and range from (4.6 to 4.7), whilst electrical conductivity of the soils in the rice and maize fields are generally high 4.8 dS/m indicating salt-affected soils. In contrast, the organic matter deposit is low in all fields (<1 %) and 75 % of the texture of the soils were sandy loam in the maize fields and 58 % of rice fields were silty loam. The fragile nature of soils in the study area coupled with poor distribution of rainfall is due to a site-specific gradient in the nutrient flow towards inland from the coast. In conclusion, soil chemical and physical properties are generally low together with the poor distribution of rainfall patterns may no longer support rainfed agriculture. It was observed that salt intrusion is encroaching to the upland ecologies resulting in marginal lands of productive swamp fields. It is recommended to adopt soil conservation practices and intensification of irrigation schemes to remedy soil and rainfall deficit to enhanced food crop productivity.

4.1. Introduction

Food insecurity is one of the major livelihood and economic threat to increasing global population growth. Despite the suitability of agricultural lands to support the production of food crops, the African continent still faces food insecurity. This is attributed to low soil fertility and erratic rainfall patterns affecting about 23 % of the population living in sub-Saharan Africa (Sonwa *et al*., 2016). “Although vulnerability to climate change and variability is very unevenly distributed across Africa, the potentially damaging climate effects and risks pose serious threats to sustainable development in many parts of Africa”(Alam, 2017).

The Gambia is projected to experience low cereal productivity due to the erratic nature of the rainfall and low soil nutrients (Olaniyan, 2017). Soils in The Gambia are very fragile and studies by Hartemink (2006), Royal and Society (2016) have shown that nutrient depletion is a factor that causes the reduction of crop yields leading to per capita food insecurity in sub-Saharan Africa (SSA) (Sadowski and Baer-Nawrocka, 2018). The erratic nature of the weather system affecting crop production is an additional problem in the current deficiency of soil nutrient. Organic matter enhances moisture build-up and releases available nutrients to the soil but Jatta (2013) reported that the system of indigenous farming exposes the soils which makes it vulnerable to the agent of erosion. According to Hartemink (2006), nutrient removal may result in a decline of the soil fertility if replenishment with inorganic or organic nutrient inputs is inadequate. Peters and Schulte (1994) pointed out that, Gambian productive soil layer of the dryland fields are generally deficient in primary nutrients (NPK). They further stated that soil pH, organic matter and nitrogen decrease with depth. The productive soil depth in The Gambia is declining as a result of erosion and continuous tilling of the land. Continuous exposure to these fields may lead to nutrient deficiency and affect productivity. Challenges to food security have gone beyond the three components of vulnerability (exposure, sensitivity and adaptative capacity). There are other independent variables which also limit production at farm level (Rurinda, 2014). However, as a prerequisite for more empirical evidence to enhance policy implementation, soil assessment provides baseline information for policy options on crop production (Maxwell *HWDO*, 2014).

In view of challenges faced by food security in developing countries, rainfall is one of the most important climate variables determining high production for the individual as well as national food security. This is particularly evident in the semi-arid tropics (SAT) of Africa, where a population of 80 million of the continent depends on rainfed agriculture for household food security (Shapiro and Sanders, 2002). However, Yaffa, (2013) concluded that the nature and extent of the impacts of climate change on rainfall distribution patterns remain uncertain. Rainfall is the bedrock of agriculture in The Gambia; the fluctuation of rain during the growing season means a huge economic and livelihood lost (Fatajo, 2010).

"Regular rainfall is an ideal condition for a successful farming season. Over the past five decades (1962 to 2012), crop yield has been fluctuating just like rainfall. This is due to the inability to give a good prediction about the climate pattern in the country. Most cereals are usually pre-sown, hence a small amount of rain could trigger the seeds to germinate and in most cases. However, the gap between the first and the real raining season is huge. Therefore both the cereals and grasses that germinate might eventually die due to water stress" (Loum and Fogarassy, 2015). The negative impact of droughts as well as excessive rainfall on agriculture can be found in both wet and dry regions. The positive and negative rainfall shocks compromise agricultural outcomes in a wide range of agro-ecological settings, considering that smallholders build their farming systems around an expected quantity of rainfall (Borgomeo *et al.,* 2018). Similarly, the physical environment was also conditioned by an expected level of rainfall. While lots of rain may seem beneficial to dry savannah, its soils may be incapable of absorbing the precipitation, resulting in run-off, floods and waterlogging (Crookes *et al.,* 2017). Agricultural production systems play a particularly crucial part in determining societies' abilities to cope with external shocks. However, the ways in which agriculture may enhance the resilience of African communities, in a context of erratic and changing weather conditions, has been a particularly burning issue among scholars and policymakers. To contribute to the body of scientific knowledge, this paper uses a soil survey and literature search to:

1. Assess the soil fertility levels across swamp and maize fields within Lower River Region of The Gambia
2. Identify which soil parameter affect rice and maize production at the productive soil depth of swamp and maize fields.
3. Provide recommendation to guide implementation towards sustainable soil fertility management in order to enhance food security in the study region.

4.2. Materials and Methods

4.2.1. Site description

The study was carried out in five (5) communities (Kemoto, Jasobo, Toniataba, Badumeh Koto, and Pakaliba) of Lower River Region in the south bank of river Gambia (Figure 4. 1). Lower River Region is the transition of Sudano-Sahelian agro-ecological zone at the south bank of river Gambia bisected by a river that divides the country into two, South and North bank. Due to the proximity of the region to the sea, the low-lying topography along the river makes them vulnerable to saltwater intrusion into the banks of swamp fields. The Gambia is characterized by unimodal rainfall season from May through October and about more than 90 % of its rainfall is associated with convective cloud and thunderstorm activity producing of high intensity and short duration (Amuzu, 2018).

Rainfall ranges from 600 to 900 mm annually and mean temperatures vary from 25° C to 28° C and generally higher in the eastern part of the country.

Figure 4. 1: Map of distance of soil sampling points to river Gambia

4.2.2. Data sources

4.2.2.1. Field measurement data

This study uses a two-stage methodology. Firstly, a diagnostic soil survey was conducted after 2017 farming season to assess farmers' fields planted with maize and rice in the different agro-ecological zone. Secondly, a literature search of previous soil surveys conducted in The Gambia was done to enable comparative analysis about the fertility status of growing rice and maize ecologies. The survey was assisted by district agricultural extension agents and village heads enlisted to sample rice and maize field. Farmer's consent was requested to sample their fields prior to the identification of their fields for the survey. The fields were purposively selected to assess the soil chemical and physical properties of the field after harvest prior to the subsequent season. Consequently, thirty fields were randomly sampled in the swamp rice ecology and thirty fields in maize fields. Six cores to a depth of 15 cm were taken from crop fields for a composite and 12 composites from each district. The Staff of the National Agricultural Research Institute assisted in the collection of soil samples from 30 maize fields and 30 rice fields.

4.2.3 Laboratory analysis for soil chemical and physical parameters

4.2.3.1. Soil preparation

Soil samples were removed from the sample bags and emptied into hard carton boxes, in order to allow them to dry at room temperature. These usually took one week for upland soils and swamp soils took up to 3 weeks. The samples were then taken for grinding before it was sieved with 2 mm mesh.

4.2.3.2. Soil pH

Soil pH was analysed using the glass electrode method by calibrating the pH meter using two-buffer solutions with neutral pH (7.0), acidic (4.0) and the pH determinant in the soil. The buffer solutions were put into a beaker and an electrode was inserted alternately in the beakers containing the two buffer solutions whilst the instrument was adjusted to take the reading. 10 g of soil sample was put into a 50-ml beaker, containing 20 ml of distilled water. The samples were allowed to absorb the water without stirring and then later stirred thoroughly until it was well mixed using a glass rod. The suspension was stirred for 30 minutes whilst the calibrated pH meter was used to take readings. As the pH, affects the microbial activity in the soil, most nutrient elements available to crop range between 5.5-6.5 (Scherer *et al.*, 2018).

4.2.3.3. Organic matter

Organic matter was determined using Loss of weight on ignition method, which is a direct method of the OM contained in the soil. Five grams of sieved soil was put into a tare weigh ashing vessel of 50-ml beaker placed in a drying oven set at 105 ^{o}C to be dried for 2 hours. The vessel was removed and weighed before it was put back to the oven to be heated at 360 ^{o}C for 2 hours. Then the hot soil sample was re-weighed from the muffle furnace and was cooled down to room temperature before it was weighed to the nearest 0.01 g. The percentage of OM was determined using this formula:

$$\% OM = \frac{(W_1 - W_2)}{W_1} \times 100$$

Where:

- W_1 is the weight of soil at 105 ^{o}C
- W_2 is the weight of soil at 360 ^{o}C

4.2.3.4. Electrical conductivity (EC)

Electrical conductivity is a measure of dissolved salts in a solution. Therefore, the salinity of soil is conventionally based on the assessment of the EC in soil solution extract from a saturated soil paste and is about 2-3 times higher than the field capacity. EC was determined using 10 g of soil in a 50-ml Erlenmeyer flask. Distilled water was added, thoroughly shaken and let to stand for 1 hour. It was filtered through a filter paper, and then the conductivity electrode was rinsed with standard KCl solutions after washing with distilled water. The electrode was dipped into a 25-ml beaker, containing KCl solution before adjusting the conductivity meter to read the conductivity standard of 1.412 mS/cm corrected to 25 ^{o}C. The electrode was then washed before dipping into soil extract to record EC values corrected to 25 ^{o}C which was a measure of the soluble salt content of the soil extract and an indication of salinity status of soil sample.

4.2.3.5 Soil texture, total nitrogen, and available phosphorus

Soil textural classification was determined using Hydrometer method, total nitrogen (micro-Kjeldahl), available phosphorus (modified Olsen) as described by Teagasc (2017) and plant-available K in the soils was determined by a flame photometer (Teagasc, 2017).

4.3 Statistical analysis

The data were analysed using the XLSTAT 2014 version. Separation of means was tested using Tukey's honestly significant difference with a significance level of $P \leq 0.05$. The historical soil data in Tables 4.1 and 4.2 were compared with the data obtained from the field study.

Table 4. 1: Mean, Median, and Range of Soil Analyses from Maize Field

Crop	No. of samples	pH	Elect. Cond.	Bray P	Exchangeable K	Na	Ca	Mg	Organic matter
			dS/m	……..……………..Mg/kg………………….…..					g/kg
					Mean				
Ma	279	6.9	0.08 a	29 a	89 a	52 a	465 a	104 a	9.2 a
					Median				
Ma		6.9	0.07	15	70	52	365	104	7.7
					Range				
Ma		4.1-8.8	0.01-0.36	1-260	4-383	5-113	124-2937	8-423	2.0-56

(Peter and Schulte, 1996)   Ma: Maize

Table 4. 2: Mean of soil test values from upland fields by region

Division	Year	No. of Samples	pH	P	K	Ca	Mg	Organic Matter
				……….…… mg/kg			…………………	%
LRR	1992	51	7.2	15	58	399	149	0.72
	1998	1	6.8	65	53	860	100	0.9
CRR	1992	55	7.3	10	115	343	72	0.69
	1998	12	6.9	13	127	580	155	1.00
NBR	1992	47	6.7	16	43	398	152	0.73
	1998	13	6.1	7	43	380	110	0.60
URR	1992	70	6.5	10	68	297	68	0.75
	1998	5	5.5	9	65	300	90	0.60
WCR	1992	56	6.9	25	64	388	77	0.92
	1998	9	6.3	14	47	510	160	1.00
Overall	1992	279	6.9	15	70	365	104	0.77
	1998	40	6.5	10	63	460	125	0.85

(Southorn and Cattle, 2000)

(LRR) Lower River Region, (CRR) Central River Region, (NBR) North Bank Region, (URR) Upper River Region, (WCR) West Coast Region

4.4. Results

4.4.1 Soil test values by crop fields

The test for soil properties in both rice and maize monoculture fields indicated that mean values for both crops show a different result. The primary nutrients (NPK) tend to be higher in rice fields than maize fields (Table 4.3). The mean soil total nitrogen was less than 1 % in both fields; available mean soil total nitrogen for rice fields was 0.07 % whereas the mean total soil nitrogen for maize field was 0.06 %. The mean for available P showed no significant difference at ($P \leq 0.05$), whilst mean potassium (0.04 %) was higher in rice fields than maize fields, which shows a lower value of 0.01 %. The mean Soil pH and EC levels of rice monoculture and maize monoculture fields showed a similar acidic (<5) and salinity (4.8 dS/m) conditions. However, soil organic matter content observed in the study showed a variation between the two fields. Rice monoculture field tend to have more organic matter deposit (1.2 %) than maize monoculture field (0.5 %). The overall mean sand content observed in the maize monoculture field was 76 % whereas only 12 % sand content was discovered in the rice monoculture field. Consequently, the mean clay and silt content was higher in the rice monoculture field than the maize monoculture field.

Table 4. 3: Least significant mean of soil test values from crop fields in the study area of Lower River Region, The Gambia.

Crop fields	No. of Samples	N %	P %	K %	Soil pH	EC dS/m	OM %	Sand %	Clay %	Silt %
Rice	30	0.07	0.0184	0.04	4.7	4.8	1.2	12.9	28.1	58.9
Maize	30	0.06	0.0180	0.01	4.6	4.8	0.5	75.9	9.7	14.3

Table 4.4 presents the soil test results for maize monoculture field between different communities of the study area. The mean nitrogen content of soils in the study communities differs within the productive soil layer. Kemoto had the highest mean nitrogen content of 0.097 % whereas the lowest mean nitrogen content was recorded in

Jasobo and Pakaliba (0.03 %). There is a significant difference ($P \leq 0.05$) between communities in terms of N content in the study fields. One of the major nutrients required for crop production is P. The highest mean P value was found in Kemoto (0.041 %) and the lowest in Pakaliba (0.006 %). The situation about the available K shows no significant difference between survey communities. The mean pH value observed between survey communities showed no significant difference in terms of the acidic content of the soil except for Kemoto, which showed a slightly acidic condition of the fields (5.8). For the mean EC content, Kemoto recorded high salinity content of 6.7 dS/m whereas Pakaliba recorded only 2.86 dS/m being the lowest. Soil organic matter was low in general and ranged from 0.3 to 0.8 % of all the communities surveyed. Kemoto had the highest mean OM content (0.8 %) but differences between communities were small. For the soil physical properties (sand, silt, and clay), there was no significant difference between communities in the study area.

Table 4. 4: Least significant mean comparison test of values of soil analyses from maize fields by communities in The Gambia

Cmt	NS	N %	P %	K %	Soil pH	EC dS/m	OM %	Sand %	Clay %	Silt %
Ke	6	0.1^{a}	0.04^{a}	0.02	5.77^{a}	6.67^{a}	0.78^{a}	77.00	10.00	16.00
To	6	0.07^{ab}	0.03^{ab}	0.02	4.87^{ab}	5.50^{ab}	0.53^{b}	76.67	10.00	14.33
Bk	6	0.05^{bc}	0.01^{b}	0.01	4.18^{b}	4.67^{ab}	0.36^{b}	76.33	10.00	14.33
Ja	6	0.03^{c}	0.01^{b}	0.01	4.17^{b}	4.35^{ab}	0.36^{b}	75.67	9.33	13.67
Pa	6	0.03^{c}	0.01^{b}	0.01	4.07^{b}	2.87^{b}	0.34^{b}	74.00	9.33	13.33

Means followed by different letters are significantly different by each other according to Fisher's (LSD) multiple range test at $P \leq 0.05$. Cmt = Communities, Ke = Kemoto, To = Toniataba, Bk = Badumeh koto, Ja = Jasobo, Pa = Pakaliba NS = number of Samples.

Table 4.5 shows the soil test results for rice monoculture fields between communities in different districts of the study area. In contrast, the nitrogen content of soils in the study communities differed within the productive soil layer. Pakaliba had the highest mean nitrogen content of 0.117 % whereas the lowest mean nitrogen content was recorded in Jasobo. There was no significant difference between communities in terms of N content in Kemoto, Toniataba, Badumeh Koto, and Jasobo. One of the major nutrients required for crop production is P. The highest mean P value was found in Toniataba (0.025 %) and the lowest in Kemoto and Jasobo (0.014 %). The available K showed a significant difference between survey communities with Jasobo recording the highest (0.095 %) and the lowest in mean K content in Kemoto and Badumeh Koto. The mean pH value observed between survey communities showed a significant difference in terms of the acidic content of the soil. Kemoto rice monoculture fields recorded the highest value (4.9) and the lowest value in Badumeh koto (4.78). Generally, all the rice monoculture fields appeared to be acidic. The mean EC content shows no significant difference and it ranged from 3.9 to 6.4 dS/m. Soil organic matter was low in general and ranged from 0.8 to 1.5 % for all the communities surveyed. Pakaliba had the highest mean OM content (1.5 %) but differences between communities were small. For the soil texture (Sand, Silt, and Clay), there is no significant difference between communities in the study area.

Table 4. 5: Least significant mean comparison test of values of soil analyses from rice fields by communities in The Gambia

Cmt	NS	N	P	K	Soil	EC	OM	Sand	Clay	Silt
		%	%	%	pH	dS/m	%	%	%	%
Ke	6	0.06^{b}	0.01^{b}	0.01^{d}	4.93^{a}	6.50	0.92^{c}	13.33	29.33	57.33
To	6	0.05^{b}	0.03^{a}	0.07^{b}	4.87^{ab}	3.88	1.27^{ac}	10.00	27.33	62.67
Bk	6	0.08^{ab}	0.02^{ab}	0.01^{d}	4.78^{b}	4.83	1.73^{a}	13.33	29.33	57.33
Ja	6	0.04^{b}	0.01^{b}	0.10^{a}	4.87^{ab}	4.28	0.84^{c}	15.33	27.67	57.00
Pa	6	0.12^{a}	0.02^{ab}	0.04^{c}	4.93^{ab}	4.70	1.45^{ab}	12.66	27.00	60.33

Means followed by different letters are significantly different by each other according to Fisher's (LSD) multiple range test at $P \leq 0.05$. Cmt = Communities, Ke = Kemoto, To = Toniataba, Bk = Badumeh koto, Ja = Jasobo, Pa = Pakaliba. NS = number of Samples

Table 4.6 presents the historical and measured soil nutrient contents of different regions in The Gambia. The results recorded in this study were compared with the historical soil fertility content of the productive soil depth of upland fields. The primary soil nutrient contents (NPK) between regions showed a substantial reduction of <1 % in 1992 and 1998 as compared to 1996 which indicated a slight increase in P and K content. However, the present 2017 primary soil nutrients (NPK) content also showed a similar value of <1 % between communities of the Lower River Region. The historical (1992, 1996 and 1998) soil pH content ranged from 5.5 to 7.3 indicating slightly acidic to alkaline condition whilst the present (2017) soil pH content range from 4.1 to 5.8 indicating acidic to slightly acidic condition. The mean EC content in 1996 showed no statistically significant difference at ($P \leq 0.05$) indicating that the salinity level is low

(< 1 dS/m). Contrary, in 2017, the EC content of Lower River Region showed a sharp increase depicting the presence of salt in the productive soil depth, ranging from 2.9 to 6.7 dS/m. In general, OM contents in The Gambian soils decreased temporally since 1992 and increased in 1996 whilst decreasing again in 1998 respectively. The current OM content was very low (< 1 %) from the study area and was ranging from 0.34 to 0.78 % in all the sample fields. Considering the soil physical properties, the historical content of the physical properties was not available and comparison was not possible to draw a conclusion. The current (2017) soil survey on soil physical properties indicated that upland soils are generally deficient in organic inputs, indicating a sand deposit, which ranges from 74 to 77 %, which is an indication of sandy loam. The changes observed in soil fertility status of The Gambia and most importantly in Lower River Region may no longer support future crop production. Therefore, the overall soil condition of the study area is inadequate, may lead to low yield, and may affect food security.

Table 4.6: The historical and recent least significant mean comparison test of soil analyses from upland fields in The Gambia

Location	Year	NS	N %	P %	K %	pH %	EC dS/m	Na %	Ca %	Mg %	OM %	Sand %	Silt %	Clay %
CRR	1992	55	0	0.00	0.01	7.3	0	0	0.03	0.01	0.69	0	0	0
	1998	12	0	0.00	0.01	6.9	0	0	0.06	0.02	1.00	0	0	0
NBR	1992	47	0	0.00	0.00	6.7	0	0	0.04	0.02	0.73	0	0	0
	1998	13	0	0.00	0.00	6.1	0	0	0.04	0.01	0.60	0	0	0
URR	1992	70	0	0.00	0.01	6.5	0	0	0.03	0.01	0.75	0	0	0
	1998	5	0	0.00	0.01	5.5	0	0	0.03	0.01	0.60	0	0	0
WCR	1992	56	0	0.00	0.01	6.9	0	0	0.04	0.01	0.92	0	0	0
	1998	9	0	0.00	0.00	6.3	0	0	0.05	0.02	1.00	0	0	0
LRR	1992	51	0	0.00	0.01	7.2	0	0	0.04	0.01	0.72	0	0	0
	1998	1	0	0.01	0.01	6.8	0	0	0.09	0.01	0.9	0	0	0
							Mean							
Ma	1996	279	0	29[a]	89[a]	6.9	0.08[a]	52[a]	465[a]	104[a]	9.2[a]	0	0	0
Gn	1996	472	0	7[b]	33[c]	6.0	0.07[a]	39[b]	252[b]	85[a]	6.8[b]	0	0	0
Mi	1996	399	0	10[b]	28[b]	6.2	0.07[a]	39[b]	279[b]	92[a]	7.4[b]	0	0	0
							Median							
Ma	1996	279	0	15	70	6.9	0.07	52	365	104	7.7	0	0	0
Gn	1996	472	0	4	26	6.0	0.05	39	238	64	6.4	0	0	0
Mi	1996	399	0	5	32	6.1	0.05	41	256	77	6.6	0	0	0
							Range							
Ma	1996	279	0	1-260	4-383	4.1-8.8	0.01-0.36	5-113	124-2937	8-423	2.0-56	0	0	0
Gn	1996	472	0	1-350	2-242	3.8-8.4	0.07-0.71	1-162	8-1919	8-450	0.5-43	0	0	0
Mi	1996	399	0	1-140	9-404	4.3-8.5	0.01-1.0	7-126	8-970	8-340	0.4-71	0	0	0
		6	0.1[a]	0.04[a]	0.02	5.77a	6.67[a]	0	0	0	0.78[a]	77.00	10.00	16.00
LRR	2017	6	0.07[ab]	0.03[ab]	0.02	4.87[ab]	5.50[ab]	0	0	0	0.53[b]	76.67	10.00	14.33
		6	0.05[bc]	0.01[b]	0.01	4.18[b]	4.67[ab]	0	0	0	0.36[b]	76.33	10.00	14.33

6	0.03[c]	0.01[b]	0.01	4.17[b]	4.35[ab]	0	0	0	0.36[b]	75.67	9.33	13.67
6	0.03[c]	0.01[b]	0.01	4.07[b]	2.87[b]	0	0	0	0.34[b]	74.00	9.33	13.33

Source: (Peter and Schulte, 1996; Southorn and Cattle, 2000; Authors soil survey, 2017)

Means followed by different letters are significantly different by each other according to Fisher's (LSD) multiple range test at $P \leq 0.05$. NS = number of Samples

Ma = Maize, Gn = Groundnut, Mi = Millet CRR = Central River Region, NBR = North Bank Region, URR = Upper River Region, WCR = West Coast Region, LRR = Lower River Region

4.5. Discussion

4.5.1. Soil chemical and physical properties as the principal driver for crop production

The essential soil nutrients are the most limiting factor for crop production at the normal planting in each season. However, the survey output showed strong contrasting results in terms of soil amendments in the Lower River Region of The Gambia. The primary nutrients NPK were very low in the maize monoculture fields due to the limited application of organic inputs in the soil, which could have added the primary nutrients in the soil. Maize had relatively higher nutrient requirements as compared to other upland cereals. The stover could have been left in the field to be incorporated into the soil. Similarly, Hartemink (2006) found out that primary soil nutrients were the most limiting factor than rainfall for production of cereals under drier conditions in West Africa.

It was observed that the overall mean NPK decreased from the coast towards inland as you move inland from (Kemoto, which is close to the coast toward Pakaliba) in the maize monoculture fields. In addition to increasing soil fertility for plant uptake, organic matter may increase crop available water due to infiltration and conservation of soil moisture (Peters, 2000). The organic matter content of the soil was very low, less than 1% in the maize monoculture fields of the study area but the distribution is erratic and decreases from the coastal area in Kemoto towards Pakaliba in the inland. This could be due to the fact that most farmers' have removed the entire crop biomass and free-range livestock would have grazed the leftover after harvest. Similarly, Ingram (2011) reported that the removal of entire crop biomass could lead to erosion and leaching of nutrients beyond the root zone of crops. The practise of harvesting the entire crop biomass after harvest for fencing materials and animal feed is a common practice in the northern part of

Senegal, Burkina Faso and Mali (Butt *et al.*, 2004; Bostick *et al.*, 2007; Connolly-Boutin and Smit, 2016).

It was observed from the findings that the mean pH value for the districts of Lower River Region showed some slight variation ranging from 4.1 to 5.8 which is less than the overall country-wide mean value (Peters and Schulte, 1994). Therefore, the acidic condition of the upland monoculture maize fields is highly acidic except Kemoto which shows slightly acidic condition. The high acidic content of these districts could be as a result of probably low soil moisture available in the soil to mineralize soil nutrients for plant uptake. Highly acidic soil can cause aluminium toxicity on crops as plants have restricted access to stored subsoil water for grain filling (Kropff *et al.,* 2001). The salt content of the upland maize monoculture fields of the study districts was found to be high, which ranged from 4.4 to 6.7 dS/m except for Pakaliba, which appeared to be very low to an acceptable EC range (2.9 dS/m). The communities near the sea (Kemoto and Toniataba) had slightly higher average EC values than the other communities. Those furthest from the ocean (Pakaliba) had the lowest EC, with a mean of 2.9 dS/m. It appeared that there was a gradient in the average salt content of the upland soils inland from the sea. The influence of salt in upland soils could have been the low lying of the topography of these communities near the sea or encroachment of salt into the uplands.

Soil is considered as the medium that supports the sustenance for plant growth. The composition of soil in the upland fields in the study area shows contrasting results. As with the maize monoculture fields, sand deposit gradually ranged from 74 % to 77 % which is higher in Kemoto and decreases toward Pakaliba. Generally, upland soils are sandy loam as a result of poor farming practices exposing the soil to wind and water erosion. Studies have concluded that soils exposed are vulnerable to erosion, hence causing acceleration of the fine soil particles to become sandy (Hartemink, 2006; Antwi et *al*., 2018). Continuous exposure of soils may lead to more sand deposit, hence soil is the most limiting factor as a medium for plant growth.

Contrary, soils in the rice field differs as compared to upland fields. The average primary nutrients (NPK) content of swamp rice fields showed different levels within the productive soil depth (0-15 cm). The average N content was higher in Pakaliba than other communities in the study area. On the other hand, available P was higher in Toniataba than the other communities. For the K content, it was observed to be higher in Jasobo and lower in Pakaliba. Meanwhile, all the other communities show no significant difference in terms of K content. The variation of NPK distribution could be as a result of management practices of rice straw in the field. Lee *et al.* (2011) reported that about 40 % of the N, 30 % to 35 % of the P, 80 % to 85 % of the K, is said to remain in rice straw after plant uptake. Their study concluded that straw incorporation into the soil returns most of the nutrients and helps conserve soil nutrients. It is a common practice in The Gambia that rice straws are always burnt to ashes during land preparation.

Soil salinity is a hazardous environmental problem in arid and semiarid regions of the world. In the study area, the findings showed that swamp rice fields are saline based on an indication of the pH values observed during the findings and ranged from 4.8 to 4.9 and EC ranged from 3.8 to 6.5 dS/m. “According to the US Salinity Staff Laboratory, soils with conductivity of the saturation extract (EC) > 4 deciSiemens per meter (dS/m) at 25˚C, Exchangeable Sodium Percentage (ESP) < 15 and pH (soil reaction) < 8.5 are referred to as saline soils” (Allbed and Kumar, 2013). Areas closed to the river tend to be more saline than areas furthest from the river. The tidal movement of the river during high-tide flows into its bank and soils adjacent to the river get affected by the salt deposit

(Peters and Schulte, 1994). "The genesis and fast spread of the sodicity and salinity problems may be accelerated by the prevailing climatic condition and geographical setting of the area which is characterized by high evapotranspiration that exceeds precipitation" (Meliyo *et al.*, 2016).

The decrease in organic matter have been observed in the swamp soils and this could be attributed to the removal of the entire crop biomass from the field after harvest. The swamp fields of Badumeh Koto had the highest deposit of organic matter in the soils and lower in Jasobo swamp fields. Generally, the organic matter content of swamp soils are very low and could be attributed to either burning of residues by farmers or being grazed by free range animals. Studies revealed that overgrazing and burning of crop residues could lead to low organic matter deposit in the soil, where stony entisol soils dominate (Maracchi *et al.*, 2005; Bugri, 2008; Carney, 2008). Soil texture is an important soil characteristic, particularly for irrigation and rice production. It drives the potentials for soil's capacity to conserve moisture and nutrients available to crops *(*Meliyo *et al.*, 2016). The study showed that soil texture variability within the surveyed communities showed no significant difference, indicating a similarity in nature. Generally, Jasobo tends to be more sandy than all the other communities whereas Toniataba has the lowest sand deposit. Therefore, more silt is deposited in Toniataba, which is an indication of high runoff carrying sediments and deposited in the lower valley. Generally, textural characteristics of the swamp rice ecologies in the study area are silty loam indicating that they contained more siltation from erosion.

The geographic location of the region with respect to river Gambia makes the crop growing fields vulnerable to salt water inundation. These findings are in agreement with the study of Mcleod *HWDO*. (2010) who concluded that soil salinity tended to be higher in rice paddy areas which can be held at the productive soil depth for a longer period. It was observed that because of the proximity of rice fields to the river, most of the fields are conditionally been abandoned by farmers. Similarly, Warner and Geest (2013) reported that Gambian swamp rice fields were vulnerable to seawater inundation which has displaced most rice farmers from growing them. These have an implication to household food security, hence rice is the staple grain crop for The Gambia (Sillah, 2013).

4.6. Conclusions and Recommendations

Giving the overview of the soil test proportion of the rice and maize monoculture fields of Lower River Region, the following conclusions were drawn from the study. The rice fields sampled, being close to the river than maize fields had higher pH, organic matter content, and soil NPK content.

However, maize fields are sandier than rice fields due to the high rate of erosion in the uplands than rice fields. The organic matter deposit in the maize fields is low compared to rice fields. A similar soil condition was observed in the past where primary nutrient (NPK) was found to be inadequate and the pH content was high as compared to the current situation. It is observed that rice fields are becoming more saline whereas uplands are getting sandy. Soil conservation can sustainably improve the nutrients needed to support plant growth. There is a general deficiency of soil nutrients within the communities of the study area. Primary nutrients tend to decrease from the coast towards the inland with Kemoto recording higher mean value and reduces as one moves inland toward Pakaliba in the maize fields.

In contrast, salinity increases in Kemoto and decreased towards Pakaliba in the far inland in the rice fields. The fragile nature of soils in Lower River Region could be the geographical location of the region and its proximity to the river, which absorbed salinity effect into the agro-ecologies during the tidal flow of the river Gambia. Birhanu *et al.* (2011) projected that by 2020 yields from Africa's rainfed farm production could decrease by 50 % due to changes in inter and intraseasonal rainfall variability. The vulnerability of rice fields to environmental degradation is due to high EC content as an indication of salt-affected soil. The high EC content displaced some essential nutrients needed for rice production. Soil nutrient deficiency is a common problem in The Gambia since the 90s and that primary nutrient (NPK) has been decreasing over time since three decades ago (Table 4.6). Comparing the historical pH and EC content of the soil with the present (2017) condition, the acidic and salinity content of the present soil condition do not enhance to support crop production.

Generally, organic matter content is low in both the past and present. The overall soil nutrients are inadequate in the past and the present, which could have contributed to household food insecurity in the study area. These findings provide the basis for soil conservation practices through agroforestry and shift of rice production to upland ecologies to minimized loss of production through salt intrusion. To counteract this low soil nutrient depletion, soil conservation practices should be adopted into all agricultural projects to regain the marginal growing fields. Furthermore, there should be an agricultural land use policy for the proper management of agricultural fields. Soil salinity mapping is necessary to determine the spatial extent of salinity flow into rice ecologies. Upland rice and maize cultivation should be intensified coupled with modern irrigation facilities to minimize total dependence on rainfed agriculture. Research needs to explore the effect of seasonal rainfall pattern on the growth stages of cereals in different agro-ecological zones of The Gambia couple with routine soil assessment.

CHAPTER FIVE

EVALUATING THE YIELD RESPONSE OF MAIZE (*Zea mays L.*) AND RICE (*Oryza sativa L.*) TO FUTURE CLIMATE VARIABILITY

Abstract

The study assesses future climate variability on maize and rice yields over a 30-year period by comparing the outcomes under two GCM models, namely, CSIRO-RCP4.5 and NOAA-RCP4.5 of Australia's Commonwealth Scientific and National Oceanic and Atmospheric Administration respectively. Historical climate data and yield data were used to establish correlations and then subsequently used to project future yields between 2021 and 2050. The study employed the average yield data for the period 1987-2016 as baseline yield, future yield predictions for 2021-2030, 2031-2040 and 2041-2050 were then compared with the baseline data. The results showed that the future maize and rice yields would be vulnerable to climate variability with CSIRO-RCP4.5 showing increase in maize yield whilst CSIRO-RCP4.5 gives a better projection for rice yield.

Furthermore, the results estimated the percentage mean yield gain for maize under CSIRO-RCP4.5 and NOAA-RCP4.5 by about 17 %, 31 % and 48 % for the period 20212030, 2031-2040 and 2041-2050 respectively. Mean rice yield losses of -23 %, -19 % and -23 % were expected for the same period respectively. Based on the findings, the study recommended the use of extra early rice and maize cultivars to offset the negative effects of climate variability in the future.

5.1 Introduction

At the beginning of the 21st century, Scientists were worried about climate change which they believed was caused by anthropogenic activities leading to global warning (Sissoko *HWDO*, 2011). As reported by IPCC (2007), "climate change refers to a change in the state of the climate that can be identified by changes in the mean or variability of its properties and that persists for an extended period, typically decades or longer". Previous studies reported that nearly 90 % of crop production in sub-Saharan comes from rain-fed agriculture (Godfray *HWDO* 2010; Conceição *HWDO*2016). Agricultural production since 1988 has been faced with interrupted consequences of climate variables in The Gambia such as a decline in rainfall and an increase in temperature (Sanneh *HWDO* 2014). Since the 1960s, variation in climate in The Gambia was attributed to the fluctuation of rainfall distribution, extreme temperature, storms, drought, and flooding. This has exacerbated household food security.

Many researchers and development practitioners tried to model the future climate variability on crop production using different explanatory variables which enhanced production. Wei *HWDO* (2009) used the Ricardian method to model the economic influence of climate change on crop production in Ethiopia. The result established that a shift in normal temperature will have a negative influence on crop yield hence impacting on the net revenue after harvest. In contrary, Nakano *HWDO* (2014) used three models (crosssectional, crop simulation and response function) to compare agricultural output to the effects of climate variability in Japan. The results showed that climate change will increase agricultural production from 2 to 4 %. However, the models showed a disparity of yield in terms of geographical location.

The evaluation of Asian rice to the effects of climate change was conducted by Kropff *HW DO* (1997) using SIMRIW rice crop simulation model. The study reported that an increase in CO_2 concentration in the atmosphere at a higher temperature can boost rice yield. In contrast, below average temperature may show a negative effect on rice yield. Although, yield projections can help to determine the levels at which a system can be exposed to the effect of different biophysical and climate variables. Similarly, Zhijuan *HWDO* (2012) simulated maize phenology and yield using APSIM-Maize model to investigate the impact of climate change on maize yield. The result indicated that on-farm maize yield will drop by 30 % at a seasonal rainfall of <500 mm. In a similar study, Lobell and Burke (2010) projected maize yield with a "widely used process-based model CERES-Maize to simulate historical yields, and then fit statistical regressions to the simulated data. The results suggested that statistical models, as compared to CERES-Maize, represent a useful imperfect tool for projecting future yield responses". Using the simplified processbased model, Clark *HWDO*(2016) and Sheahan and Barrett (2017) describes potentials to examine the distribution of parameter values from data on yields of rice and maize. The results showed uncertainties of climate variables to predict future crop, reporting that climate variables exceeded those in the calibration period. On-farm production in The Gambia has been under pressure due to uncertainties of the growing ecologies to climate change and variability. The farming households food security is being threatened due to interrupted weather events leading to poverty in sub-Saharan Africa (Nigatu *HWDO* 2017).

Few studies in The Gambia focused on the productivity of major crops and how they are impacted by climate change (Hayes*HWDO* 1997; Akon-yamga *HWDO*, 2011). Bojang *HWDO* (2016) "formulated a Linear Programming model with the aim to maximize the farmers' net profit under a set of constraints (plant area and water)". Their findings revealed that about 50 % of the annual revenue of the farm can be achieved through optimum water use efficiency. In a different study, Al-Amin and Ahmed(2016) concluded that by 2100, agriculture in sub-Saharan Africa including The Gambia may likely face yield reduction and low GDP due to climate change. Climate change and variability can cause a total economic failure if a system depends immensely on this primary driver for optimum survival (Lobell and Field, 2007). This study aims to determine the future yield of staple food crops (rice and maize) under climate change and variability using simulated data. To achieve this aim, the following analyses were carried out :

(i) Evaluation of the effect of historical climate variables on historical rice and maize yields

(ii) Evaluation of the effects of future climate variables on the yield of rice and maize

(iii) Evaluation of the decadal percentage change on future crop yields using different climate scenarios

5.2. Materials and Methods

5.2.1. Study area and source of data

Lower River Region (LRR) of The Gambia is a rural agro-pastoralist region and the majority of its resident are directly or indirectly engaged in crop production. Further details are in Figure 1.1. The region produces major crops like maize, rice, millet, groundnut, and fonio. In this study, maize and rice were used as test crops for future projection in the context of climate variability. Rice and maize are the two most important household staple foods in the study area. The system of farming practices in

LRR is predominantly subsistence. At least every farmer manages to grow two or more staple crops including rice. The fragile nature of soils in LRR, coupled with the changing climate, is posing challenges to agricultural production.

5.2.2. Climate and crop yield data

The historical climate data used to generate the model in this study was obtained from the Department of Water Resources of The Gambia. The historical data used spanned from 1987 to 2016 at Jenoi weather station. Further, the time series crop yield data were obtained from the Department of Planning Services of Agriculture for the same period from 1987 to 2016.

5.2.3 Model selection approaches for projected climate data

Two models were chosen from the GCM models that performed best in the study weather station, CSIROMk3.0 provided by Australia's Commonwealth Scientific and Industrial Research Organization NOAA-ESM2M-RCP4.5 provided by National Oceanic and Atmospheric Administration (NOAA) offices in the United State of America. The projected climate data was downloaded from the CODEX website (ESGF). The data was bias corrected using CMhyd software using Distribution mapping command (Lobell and Gourdji, 2012).

5.2.4 Regression model for yield prediction

The yield response of each crop to annual precipitation, average minimum and maximum temperatures, average relative humidity and average sunshine duration using statistical models were generated from 1987-2016. Statistical models were used in this study due to inadequate data for process-based models for the staple crops considered in this study. The most important use of models is their strength to account for a wide variety of mechanisms that affect yields in changing weather. The statistical model used in this study was modified from (Lobell and Gourdji, 2012). Firstly, annual rainfall, annual average minimum and maximum temperature, relative humidity and sunshine duration were computed for Jenoi weather station for the period 1987-2016. For the yield of rice and maize, the region-wise time series was computed by taking the average yield of each crop.

The yield models were tested by estimating yield from the observed data using the period from 1997-2006 and validated with data from 2007 to 2016. A t-test was run to compare the means (Appendix A). It was assumed that when there is a significant difference at 5 % level of significance between the means, the model will not be good to project future yield (see Appendix A). The rice model underestimated yield whilst maize model overestimated the yield. This could be due to the determined coefficient of the error terms especially rainfall and temperature which are the major factors of yield.

Table 5.1: Statistical yield models used for yield projection in this study

Crop	Equation	R^2
Rice		*0.62*
Maize		*0.51*

Y represent yield (kg/ha), rf *rainfall, tmin minimum temperature, tmax maximum temperature, rh Relative humidity, shd Sunshine duration*

Percentage yield losses of maize and rice were computed using equation 5.1

2 U F $ U
Š ƒ L• % ‡ H s r r å ä ä A
M Q = P : w ä s ; E K J
$ U

Where:

Py = Predicted yield

By = Baseline yield

5.2.5 Data analysis

The ordinary least square regression models were applied to the annual simulation of rainfall, minimum and maximum temperatures, relative humidity and sunshine duration from the two GCMs for 2021-2050 to assess the influence of future climate change on yields. The percentage loss was analysed using Excel version 2016 during the 30 year period from 2021-2050.

5.3. Results

5.3.1 Historical (1987-2016) and projected (2021-2050) temperature and rainfall trends in the Lower River Region of The Gambia

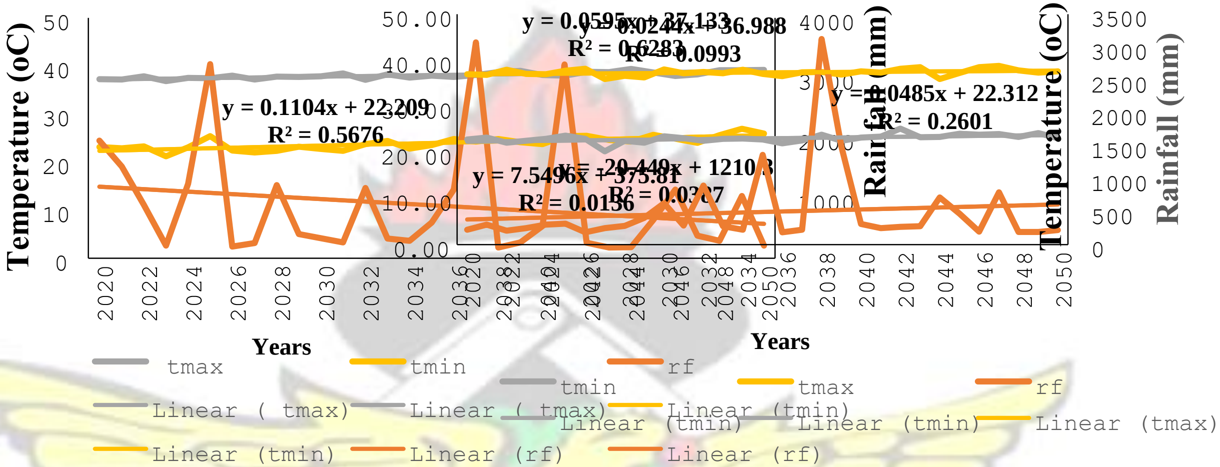
Seasonal rainfall, as well as total rainfall amount in the Lower River Region of The Gambia, appear to be increasing over time (Figure 5.3) although the annual variability is erratic. On the other hand, the mean minimum temperature appears to decrease with a decreasing trend whilst mean maximum temperatures shows an increasing trend (Figure 5.3). The projected rainfall by CSIRO-RCP4.5 shows a decreasing trend towards midcentury (2050) whilst NOAA-RCP4.5 shows an increasing trend of rainfall (Figure 5.1 and 5.2). Contrary, the projected mean minimum, and maximum temperatures show an increasing trend towards the mid-century (Figure 5.1 and 5.2).

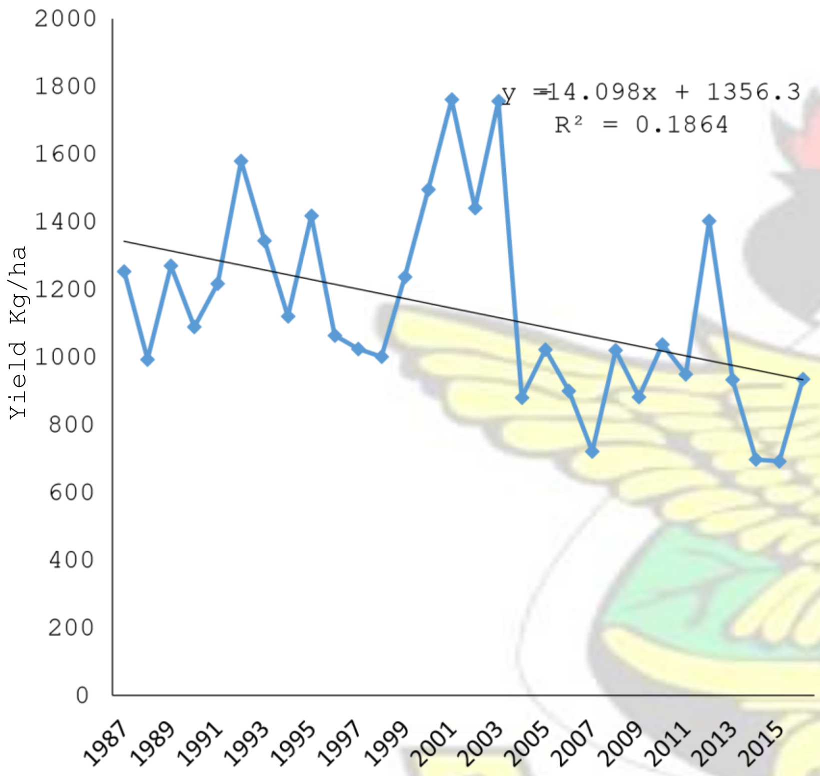
5.3.2 Effects of future climate variability on the yield of maize and rice

Historically, the actual maize yield showed a decreasing trend for the past 30 years (19872015) Figure 5.4. The highest average baseline maize yield (1761 kg/ha) was observed in 2001 whilst the lowest average maize yield 692 kg/ha was in 2015. However, the coefficient of determination showed that about 19 % of the yield decline was due to climate variability, indicating that other non-climate variable also accounts for yield reduction. Furthermore, the future projection of maize yield showed a contrasting trend as the projection period increased, under both scenarios from the trend curve of Figure 5.5. The average annual yield under CSIRO-RCP4.5 showed the highest increase of 2232 kg/ha in 2050 and the lowest was observed in 2024 (631 kg/ha). The projection for NOAA-RCP4.5 showed the highest recorded value of 1974 kg/ha in 2049 whilst the lowest yield of 292 kg/ha was recorded in 2038. The trends showed some consistency for the 2 GCM models. However, in 2038, while one model projected a rise in the yield of maize, the other predicted a fall.

The historical time series crop yield is a field data, which took into consideration all the parameters that affect yield. Meanwhile, the projected crop yield is dependent on the model variables for yield estimate. The values of the coefficient in the equation also affect the results. Base on this reason that one model shows a decreasing trend whilst the other model is showing an increase.

0


Temperature (oC)
y = 0.1104x + 22.209
R² = 0.5676
Years
tmax
tmin
rf
Linear (tmax)
Linear (tmin)
Linear (rf)
y = 0.0595x + 27.133
R² = 0.6283
y = 0.0244x + 36.988
R² = 0.0993
y = 7.5496x + 375.81
R² = 0.0156
y = 20.449x + 1210.3
R² = 0.0347
y = 0.0485x + 22.312
R² = 0.2601
Rainfall (mm)
Temperature (oC)
Rainfall (mm)
Years
Linear (tmax)


y = -14.098x + 1356.3
R² = 0.1864
Yield Kg/ha
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015

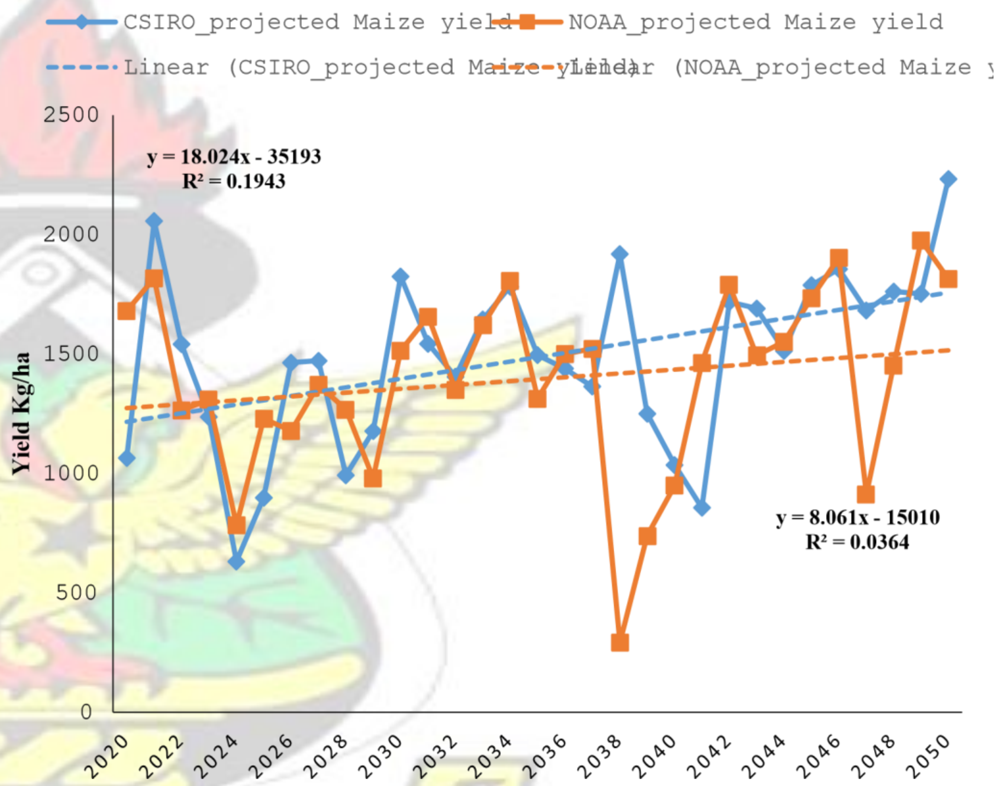

CSIRO_projected Maize yield
NOAA_projected Maize yield
Linear (CSIRO_projected Maize yield)
y = 18.024x - 35193
R² = 0.1943
y = 8.061x - 15010
R² = 0.0364
Yield Kg/ha
2500
2000
1500
1000
500
0
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050

Figure 5.4: Baseline maize yield trends in historical rainfall, Figure 5.5: Projected maize yield due to biennial trends in rainfall, minimum and maximum temperatures, relative humidity and minimum and maximum temperatures, relative humidity and sunshine sunshine duration from 1987-2016. duration from 2021-2050. The trends of maize in blue color is CSIRORCP4.5 and brown color for NOAA-RCP4.5

Contrary, the baseline (1987-2016) rice yield showed contrasting results using the same climate variables (Figure 5.6). The highest average rice yield (2083 kg/ha) was in 1988 and the lowest yield in 2014 with a yield of 646 kg/ha. The influence of climate variability on rice yield was seen since 1989 and showed a sharp decreasing trend towards the end of the baseline period (2015). It was observed that 50 % of yield decline in rice was caused by climate variability. However, the projection showed a similar pattern as compared to maize yield with the same explanatory variables (Figure 5.7). Climate variability affected rice yield as the projection continues towards the middle of the century. Rice yield reduces drastically as seen in the annual trend under NOAARCP4.5 from 1389 kg/ha to 402 kg/ha and increases for CSIRO-RCP4.5 going from 786 kg/ha to 1375 kg/ha. However, it was observed that by 2047 rice yield might have reached up to 1389 kg/ha as the highest record from NOAA-RCP4.5 scenario making it more beneficial than CSIRO-RCP4.5 for that year. In addition, CSIRO-RCP4.5 showed a better trend in the future than NOAA-RCP4.5. However, some notable deviations occurred in 2031 and 2044.

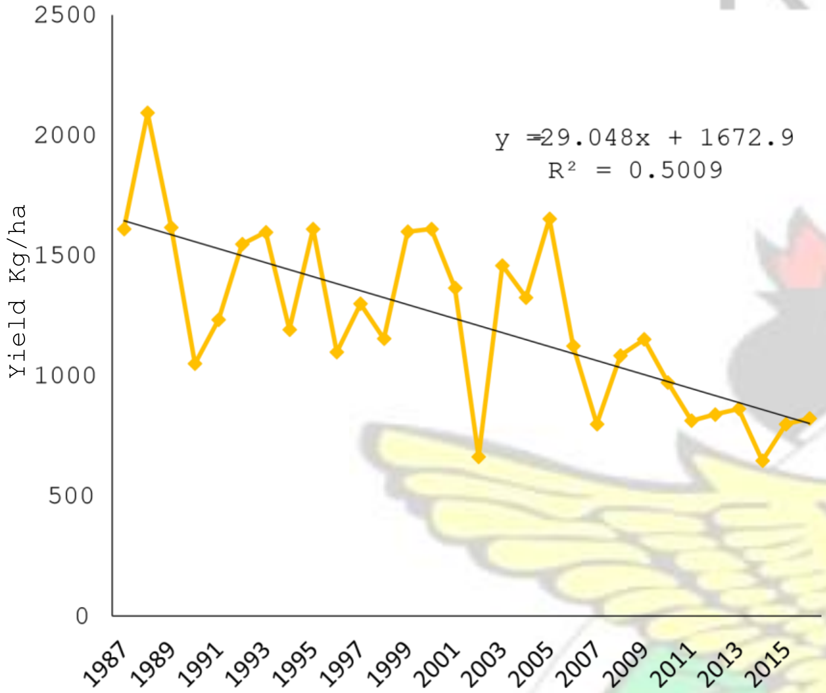


Figure 5.6: Baseline rice yield trends in historical rainfall, minimum and maximum temperatures, relative humidity and n sunshine duration from 1987-2016.

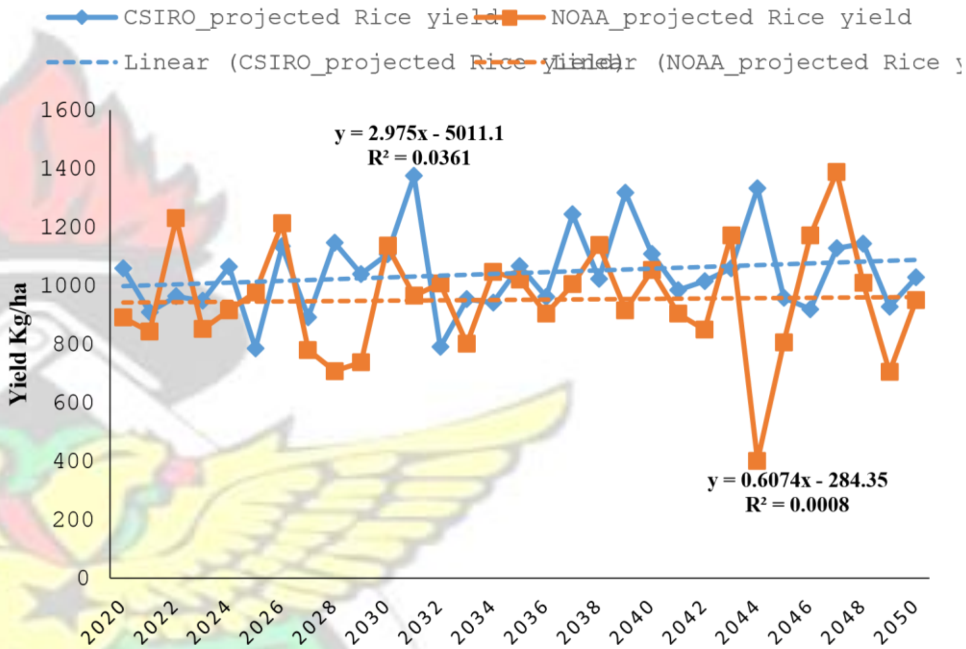


Figure 5.7: Projected rice yield due to biennial trends in rainfall, minimum and maximum temperatures, relative humidity and sunshine duration from 2021-2050. The trends of maize in blue color is CSIRO-RCP4.5 and brown color for NOAA-RCP4.5

Further results revealed that the average baseline yield data for maize and rice yields were 1138 kg/ha and 1223 kg/ha respectively. These were average yields obtained from the 30-year historical data (1987-2016). Percentage changes as compared with the projected yield were computed in (Equation 5.1). These changes are presented in Figure 5.8 and 5.9 for maize and rice respectively.

However, the 10-year temporal trends in rainfall, minimum and maximum temperatures, relative humidity and sunshine duration are assessed, for three interval-starting points in future 2021-2030, 2031,2040, 2041-250) on the yield of maize. The first decadal period from 2021-2030 under NOAA-RCP4.5 showed a yield increase of 12 % whilst under CSIRO-RCP4.5 yield adjusted to 17 %. In the second decadal period (2031-2040) under RCP4.5-CSIRO had a better projection of about 31 % than NOAA-RCP4.5. Similarly, during the last decadal period (2041-2050), both scenarios projected increase in maize yield but most importantly under CSIRO-RCP4.5 of about 48 % depicting a positive impact within the last decadal period (Figure 5.8).

Contrary, the emission scenarios projected different results for rice yield as compared to maize yield in the future (Figure 5.9). During the period 2021-2030, NOAA-RCP4.5 projected yield losses of -23 % whilst CSIRO-RCP4.5 projected a decline of -18 %. The subsequent decade 2031-2040 showed a slight recovery of rice yield most importantly under CSIRO-RCP4.5 of about -12 %, which is still inadequate. Furthermore, in the last decade, the scenarios projected a decrease in rice yield from 2041-2050. The projection by NOAA-RCP4.5 showed a tremendous decrease in rice yield by -23 % and by -14 % under CSIRO-RCP4.5 scenario respectively. It is observed that the projected rice yield in the future showed a substantial reduction of yield loss by the year 2050.

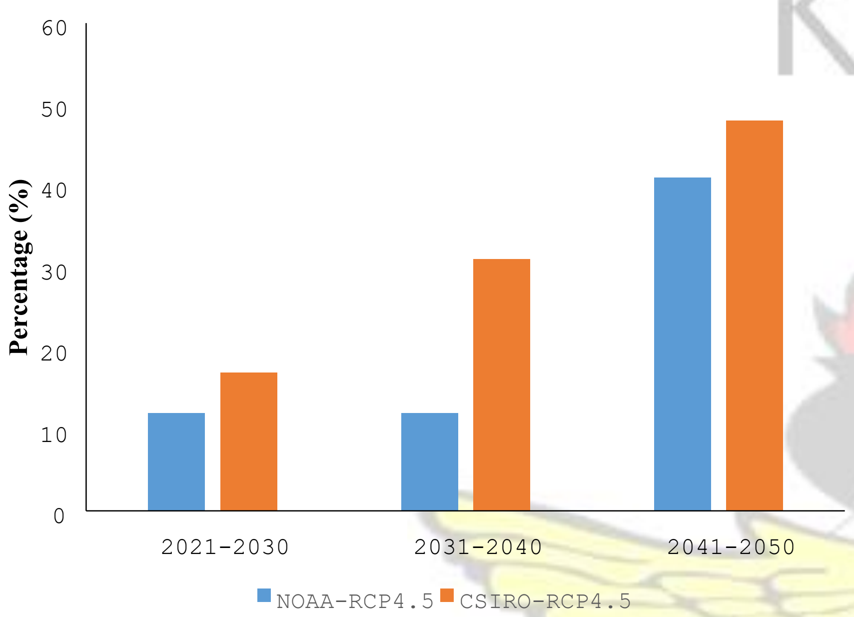


Figure 5. 8: Barplots of maize yield losses of a given magnitude due to 10-year trends in climate variability under CSIRO-RCP4.5 in brown color and NOAA-RCP4.5 in blue color. Three bars are shown using three different periods (2021-2030, 2031-2040 and 2041-2050)

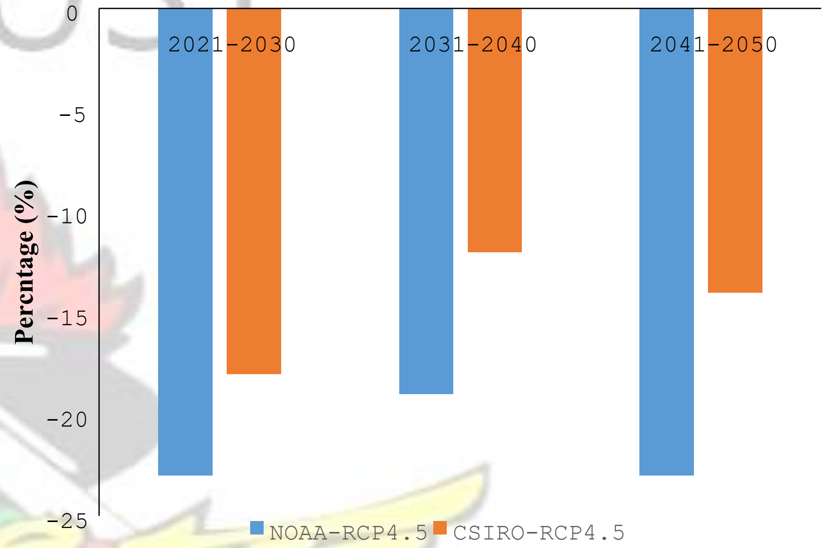


Figure 5. 9: Barplots of rice yield losses of a given magnitude due to 10-year trends in climate variability under CSIRO-RCP4.5 in brown and NOAA -RCP4.5 in blue color. Three bars are shown using three different periods (2021-2030, 2031-2040 and 2041-2050)

5.4 Discussion

From the results obtained, the expected changes in staple food crop yields of two major crops showed that remarkable achievement from mitigation would be needed towards the middle of the century, in order to reduce the magnitude of yield losses. When comparing scenarios for projection over a long-term period (2021-2050), mitigating climate variability according to CSIRO-RCP4.5 is more beneficial than NOAA-RCP4.5 for maize yield. This finding is in agreement with Tebaldi and Lobell (2015) who reported that RCP4.5 is considered better for future projection of crops in terms of climate change mitigation.

However, the maize yield results showed an erratic trend for the 30-year period (20212050) for the future, showing that there is an inconsistent weather pattern influencing the yield. The model is limited to only climate variables and that mitigation will enhance the opportunity to increase yield using NOAA-RCP4.5 compared to CSIRO-RCP4.5 (Peters *et al.*, 2013). Contrary, rice yield exhibits different results in terms of model projection in the future. This could be because rice growing ecologies are hydrophilic environments and any chances of moisture deficiency will affect the yield, which could trigger model inconsistency. This finding was similar to a study conducted by Kropff *et al.* (2001) who reported that rice could be vulnerable to erratic rainfall below normal during the growing season and will have a negative impact during grain filling. This model results may not show the entire picture since from this angle, the model results may reveal nonlinearities hence the confounding variables like soil fertility, pest, disease and climate extremes
(drought and flood) which may likely influence crop yields are not included in the model (Jing *et al.*, 2012).

For rice yield assessment, losses of yield are substantially significant and increase towards the mid of the century (2050). A projected decrease in rice yield by the midcentury (2050) showed that climate change might likely have an impact on food security; hence, rainfed rice production may not be feasible to supply the growing population food demand. In a similar study, Dawson *et al.* (2014) concluded that "under the 2050 scenario, wheat, maize, and soybean were projected to have an overall mean reduction of up to 40, 50 and 50 % respectively when compared to baseline productions with some variation between the GCMs and regions spatially".

Concerning the findings, rice yield is expected to decrease in the future for the locations within the study area by 2050 for all scenarios using CSIRO-RCP4.5 and NOAARCP4.5. Such information is vital hence, there is no single factor responsible for yield reduction and farmers' decision to adapt to such changes is inadequate. Even though some studies claimed that cereal yields will be reduced in the future, the results for maize yield showed an increase in the future for both scenarios (Cairns *et al*., 2013; Fitzgerald, 2016). This study contradicts the findings of Cairns *et al*. (2013) who claimed that any accumulated increase in mean temperatures above 30° C in the future may lead to a reduction of maize yields. The increase in maize yield as seen in both GCM (CSIRORCP4.5 and NOAA-RCP4.5) scenarios could be some coping mechanism practiced by farmers using improved varieties. Increase in the emission scenarios in the future may lead to global warming, which could trigger sea level rise, which may affect rice growing ecologies. From this study, it was observed that rice yield will decrease drastically towards the mid-century which might be due to sea level rise affecting rice growing ecologies in the future (Clark *et al*., 2016). For future adaptation, farmers need to integrate many farming strategies including the mitigation of climate risk. However, barriers impeding poor farmers and policy implementation on adaptation in sub-Saharan Africa still presents a daunting challenge (Antwi-Agyei *et al.*, 2013).

5.5. Conclusion and Recommendations

From the current study, it is concluded that rice yield will reduce whilst maize yield will show an increase because of the projected increase in climate variables. The Fluctuation of yields was observed over decadal periods from 2021-2050, which showed the fluctuation of climate in the future. Higher yield losses impacted by climate pattern projected by both CSIRO-RCP4.5 and NOAA-RCP4.5 was seen towards mid-century (2050) for rice indicating future climate risk on rice yield. In this study, the findings did not account for the non-climate variables, therefore, cannot make any conclusion that yield variations are attributed to only climate variability. Future projections should, therefore, consider climate and no-climate variables. The benefits of climate change adaptation to offset the negative effect of climate change are still ambiguous and that required for additional research in order to benefit from the positive impact as noted by several authors (Antwi-Agyei *et al*., 2013; Vermeulen *et al*., 2013). Further research should be carried out to develop new extra early rice and maize cultivars to offset the negative effects of climate variability in the future.

CHAPTER SIX

ADAPTATION PRACTICES TO CLIMATE VARIABILITY OF SMALLHOLDER FARMERS IN THE LOWER RIVER REGION, THE GAMBIA

Abstract

Climate change and variability present challenges to food security in the Gambia. Yet, it is not clear how smallholder farmers in the Gambia are adapting to climate change and variability. This study explored the extent of climate variability and the adaptation practices of smallholder farmers in the Lower River Region of The Gambia. The study used questionnaire surveys (with 180 households) to assess the perception of smallholder farmers on rainfall and temperature patterns. The study used climate data from 1981 to 2016 and employed the modified Mann-Kendall test to understand the extent of climate variability in the study area. The results showed that there is a significant increasing trend of mean annual rainfall during the last 30 years in the study area and temperature records showed no trend pattern. All respondents experienced inconsistent rainfall pattern and increased temperature showing that farmers are aware of climate change and variability. The results further showed that the majority (72 %) of farming households studied used drought-tolerant crops, 67 % adopted changing planting date and 92 % fallow their land as on-farm adaptation strategies. Despite these strategies, more than half (51 %) of male farmers in Kiang practised temporal migration, 62 % of female farmers practised petty trading in Jarra and only a few relied on remittance. The study concludes that smallholder farmers in the study communities were knowledgeable about climate fluctuations, and have adopted appropriate practises to address these changes. The study recommends strengthening the capacity of smallholder farmers through skill acquisition to manage future consequences of climate change and variability.

6.1 Introduction

Climate change and variability will continue to adversely affect economic development in many economies across the African continent. The recent special report by the Intergovernmental Panel on Climate Change (IPCC) suggested that climate change would adversely affect sustainable development and poverty reduction efforts (Roy *HW DO*., 2019). This could increase inequality and leads to enhanced vulnerability of marginalized socio-economic groups including women, children and the elderly. Africa contributes about 4 % of the world's total greenhouse gas emissions globally (Raupach *HWDO* 2015). This notwithstanding, the continent is the most vulnerable region to extreme climate events (IPCC, 2014). This vulnerability is partly attributed to its livelihood dependence on seasonal rainfall and weak adaptive capacity (Cooper *HW DO*., 2008). Global circulation model (GCM) analyses have projected a decrease in productivity of all major crops in sub-Saharan Africa due to increased temperature, rainfall variability, increased potential evapotranspiration (PET), runoff and drainage by the year 2075 (Msowoya and Madani, 2016). Climate projections suggest a reduction of seasonal rainfall amount, which is possible in the Sahel to Sudano-Sahelian zone of The Gambia, particularly during the only unimodal growing season June to October (Sylla *HWDO*, 2010). This will skew the inter-annual rainfall distribution from normal leading to a reduction of rainy days (Nicholson, 2000).

Agriculture, the backbone of The Gambian economy is negatively impacted by climate change and variability and this is manifested in low productivity of major crops in recent years and increasing household food insecurity (Kutir, 2015). Challenges associated with climate change and variability in the Gambia are more severe in the Sahel and the

Sudano-Sahelian zones of the country (Sanneh *et al*., 2014). The annual temperature of The Gambia has risen by historic records, approximately 1.0 ^{0}C since 1960 and is expected to increase by between 1.1 and 3.1 ^{0}C by 2060 (Amuzu *et al*., 2018). Erratic weather patterns that describe the climate in The Gambia coupled with other challenges such as low soil fertility, salinization, poverty, food insecurity, and inadequate policies in agriculture exacerbate development in agriculture. Based on these biophysical and climate variations, adaptation practices need to be integrated into the farming communities to manage the adverse effects of climate change and variability.

Adaptation has been defined as an adjustment in ecological, social or economic systems in response to actual or expected stimuli and their effects or impacts" (Smit and Wandel, 2006). Based on their timing, adaptations can be anticipatory or reactive and depending on their degree of spontaneity, they can be autonomous or planned (Smit and Wandel, 2006). Previous studies (including Elum *et al*., 2017; Antwi-Agyei *et al*., 2014, Codjoe *et al*., 2014) have shown that, in many parts of sub-Saharan Africa, changing planting date and crop mixed are farm adaptation strategies used along with the application of intensive inorganic fertilizer application practised by local farmers.

Adaptation strategies are anticipated long-term plans for future climate consequences whilst coping strategies are those immediate actions taken to offset the challenges related to climate variability (Makuvaro *et al*., 2017). Berman *et al*. (2012) reported that institutions play a key role by regulating the services of markets, community resource management, and land resources, which are important for adaptation and coping strategies of rural communities.

Studies on climate change adaptation dwell on how individuals develop and maintain strategies as self-asset, and how such individual asset improved household livelihood (Malik *et al.,* 2010; Alemayehu and Bewket, 2017). Calzadilla *et al.* (2013) observed that adaptation is viewed as individual obligations to offset any risk associated with an external sock. From the individual perspective, Reid *et al*. (2003) proposed that individual resources can influence climate change adaptation but may not be enough to build resilience at the community level.

Several studies have highlighted the value of adaptation practises to address the adverse impacts of climate change. For instance, Antwi-Agyei *et al.*, (2014) explored the livelihood adaptation options available to farming households in Ghana. Others studies including Neset *et al*. (2018) and Antwi-Agyei *et al.* (2018) have examined the sustainability of adaptation practices of smallholder farming households. Yet, despite agriculture being reported as the sector most affected by climate change and variability, empirical evidence on autonomous adaptation practices of smallholder farmers in the Gambia is largely lacking, making it difficult to identify appropriate strategies to address climate risks. The aim of this study was to understand the extent of climate variability and the key adaptation practices employed by smallholder farmers in the SudanoSahelian agro-ecological zone in the Lower River Region of The Gambia. To achieve this aim, the study seeks to answer the following research questions:

1. What is the extent of climate variability in the Lower River Region of the Gambia?
2. What is the awareness level of smallholder farmers to climate variability in the study communities?
3. What are the adaptation practices employed by smallholder farmers to address climate variability in the study communities?

6.2 Materials and Methods

6.2.1 Description of the study area

The study was carried out in the Lower River Region (LRR) of The Gambia, which is located between latitudes 13^0 and 14^0 N and longitude 16^0 and 13^0 W (Figure 1.1). The region has an agrarian economy and more than half of its inhabitants are directly or indirectly involved in crop production. LRR was identified as the study area because of its geographical location in the Sudano-Sahelian zone of The Gambia characterized by inadequate potential irrigation opportunity during the dry season and depend largely on rain-fed agriculture (Sillah, 2013). Loum and Fogarassy (2015) identified that cereal production will be affected by climate change in the Sudano-Sahelian zone. LRR is characterized by a high rate of bush fires and poor soil amendments (Peters, 2000).

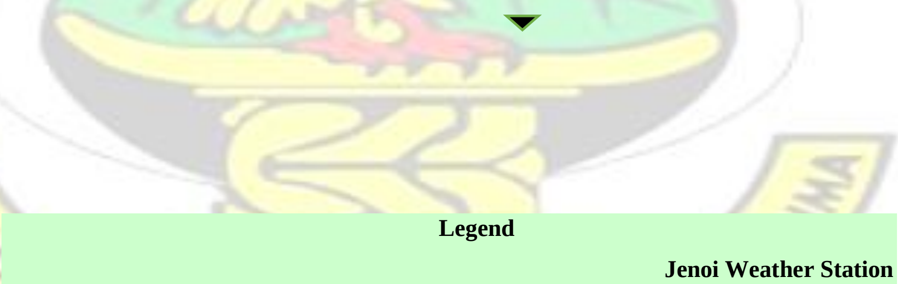


Figure 6. 1: Location of sample villages in Lower River Region of The Gambia

The two administrative areas were selected from the study area divided into two kingdoms called Kiang and Jarra (Table 6.1) based on the geographical scope of the south bank designed by the British (Touray, 2016). The kingdom of Kiang is classified into Kiang West, Central and East districts whilst Jarra West, Central and East districts were classified as Jarra kingdom. The two kingdoms fall within the same agro-ecological zone but have different socio-economic activities. Hence, households in these farming communities face different climate variability challenges, giving an opportunity to study a range of household adaptation options. The selection of the kingdoms was based on their geographic proximity to river Gambia influence by tidal swamps in rice production to meet the growing population demand for food security. During the World Food Program (WFP) vulnerability assessment, Lower River Region was identified as the most vulnerable region to food insecurity in The Gambia due to climate change (UN-WFP, 2016).

Table 6. 1: Key demographic and socioeconomic characteristic of the study Kingdoms

Characteristics	Kiang	Jarra
Mean annual rainfall (mm)	550-800	600-900
Rainfall patterns	Uni-modal	Uni-modal
Farming system	Predominantly family farming	Predominantly family farming
Major crops grown	Maize, Groundnut, Millet, Rice Fonio, sorghum	Rice, Groundnut, Maize
Main livelihood activities	Agro-pastoralist	Agro-pastoralist
Average Temperature	Min 20 °C, Max 36 °C	Min 20 °C, Max 36 °C
Population	30,168	52,193
RAD head office	0	1
Agricultural population (%)	53	52
Food poverty (%)	71	50
Ethnic composition	Majority “Mandinka”	Majority “Mandinka”

Data compiled from Department of Water Resources of The Gambia, Regional Agricultural Directorate

(LRR) and Population data from Gambia Bureau of Statistics (GBOS, 2013)
RAD: Regional Agricultural Directorate
Family farming: is a farming system where farming household commute to the farm outside their homes and return after work. This is a common practice in rural Gambia.
Food poverty: "Is the insufficient economic access to an adequate quantity and quality of food to maintain a nutritionally satisfactory and socially acceptable diet as a result of low agricultural productivity" (O'Connorm *et al.,* 2016).

6.2.2 Data Sources and Methods

The annual time series data on rainfall and temperature were obtained from the Department of Water Resources of The Gambia for three weather stations in Lower River Region namely, Jenoi, Kwenella, and Kiang Karantaba. The time series rainfall data used for the study was for the period of 1981-2016 for Jenoi, 1991-2016 for Kwenella and Kiang Karantaba weather stations.

6.2.3. Research methods

Data presented in this study was collected in August 2017 using a mixture of different approaches; focus group discussions, household survey, and key informant interviews. Data collection started with a consultation at the Regional Agricultural Directorate to prepare a checklist of communities close to the riverbank. Then the two kingdoms were visited through trekking in consultation with the community heads and the agriculture extension agents to collect the data. A questionnaire survey was used as a tool to collect information on socio-demographic, climate change perception and key adaptation options. It is assumed that major decisions about production take place at the household level. This is why household was selected as the main target to obtain relevant information. In each kingdom, nine communities were selected in Kiang and nine from Jarra (Figure 6.1). Ninety questionnaires were administered in each of the kingdoms, giving 180 households.

A sampling of respondents involved stratification of households into different gender groups, based on farming practices and a systematic random sampling technique was then applied to target rice and maize growers. These farmer groups were the target respondents based on the low productivity of the staple food, due to the influence of climate change and variability with observed yield reduction in past decades (Bojang *et al.,* 2016). To reduce biases, a key informant was used to identify active farmers involved in rice and maize farming. To justify the key issues highlighted during household questionnaire surveys, five focus group discussion (FGD) were conducted in the surveyed kingdoms, five from male and female groups. The respondent from the FGDs were those farmers who have experience in farming and environmental change. Four key informants were selected from different institution dealing with agricultural activities.

6.2.4. Data analysis

A non-parametric test (Mann Kendall test) was performed to analyse the time series climate data which assumed that the data is normally distributed (Basarir *et al.*, 2017). The test is set out with two hypothesis; that is the null hypothesis H0: which assumed that there is a trend in the data whereas the Alternative hypothesis H1, on the contrary, assumed that there is no trend in the data (Basarir *et al.*, 2017).

The computation of the analysis was performed using XLSTAT 2016 plug-in for Microsoft Excel, exploring the climate variables monthly rainfall and temperature from June-October 1981 to June-October 2016 duration using Mann Kendell test (Karmeshu, 2012).

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< O L ^ r B K N 5 L r……………………….equation. (6.1)

"The test statistic Zs is used as a measure of the significance of the trend. In fact, this test statistic is used to test the null hypothesis, H0. If (Zs) is greater than Zα/2, where α represents the chosen significance level (e.g.: 5 % with Z 0.025 = 1.96) then the null hypothesis is invalid implying that the trend is significant"(Karmeshu, 2012).

The data from the questionnaire were input into Microsoft Excel (Version 2016), coded for quantitative data to be analysed using a Predictive Analytic Software (formerly Statistical Package for Social Sciences (SPSS)) to ensure ease of appropriate statistical analysis. Descriptive statistics for quantitative data were analysed from interview questionnaires coded numerically and reported the output as frequencies and percentages (Krippendorff, 2004). Arranging the main ideas allows the grouping of the answers and point out those that deviated from the mutual themes.

6.3. Results

This section describes the Mann Kendall statistics of mean annual temperature for Jenoi Lower River Region from 1981-2016 (Table 6.2). Jenio is the main and only weather station recording temperature data in this region (Figure 6.1). When Mann Kendall statistical test was performed on the time series temperature data, the results were not significant, indicating the null hypothesis is rejected. This implies that there is no significant change in the mean temperature even though Figure 6.2 shows an increasing trend. It was observed from the results that, a sharp decrease in mean temperature occurred in 2006.

Table 6. 2: Results of the Mann-Kendall test for mean temperature data from (1981 to 2016) for Jenoi Lower River Region

Region	Mann Kendall Test					
	Mann Kendell Test Statistics (Zs)	Kendall's Tau	Var (S)	p-value (two-tailed tests)	Alpha	Test Interpretation
JWS	1.9	0.2222	0.0000	0.059	0.05	rejected H0

Jenoi Weather Station (JWS)

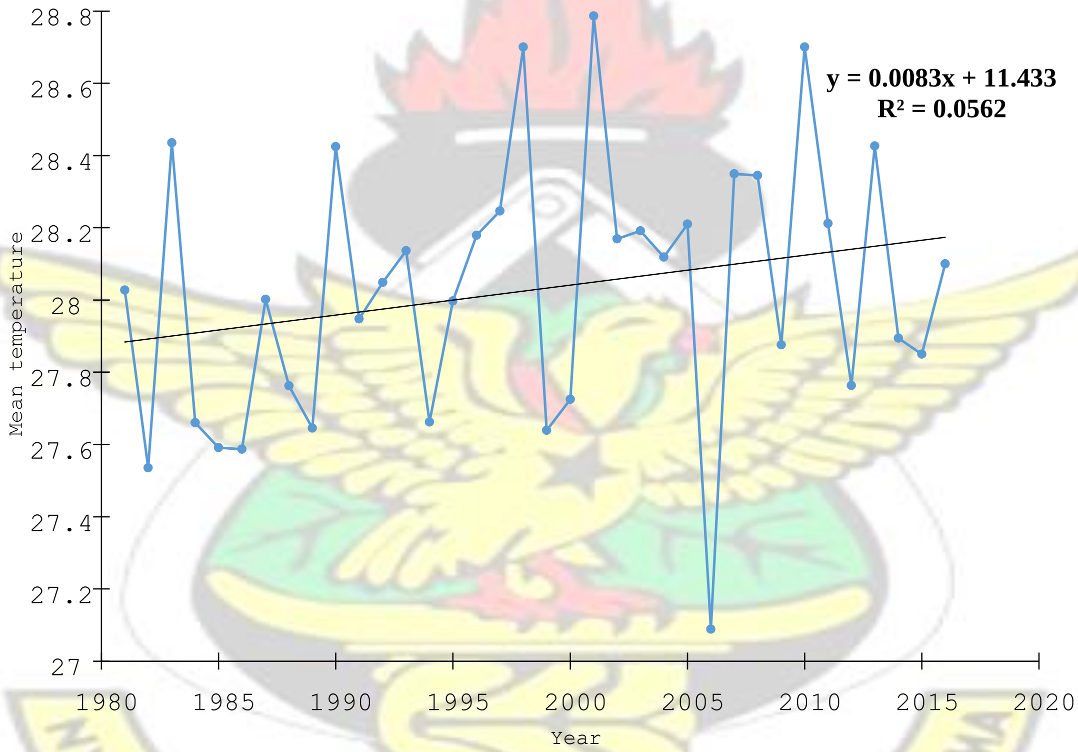

Figure 6. 2: Trend in annual mean temperature data for Jenoi LRR, The Gambia

Table 6.2 shows the results of Mann Kendall test on time series annual rainfall data for Jenoi, Kwenella and Kiang Karantaba weather stations in Lower River Region. Jenoi and Kwenella weather stations were statistically significant indicating the null hypothesis is accepted; while Kiang Karantaba weather station was not statistically significant, hence the null hypothesis is rejected indicating the absence of a trend in the precipitation. The linear trend line of the annual rainfall data depicted an increasing trend for Jenoi (Figure 6.3) and Kwenella (Figure 6.4) weather stations whereas Kiang Karantaba (Figure 6.5) weather station shows a decreasing trend.

Table 6. 3: Results of the Mann-Kendall test for Rainfall data for Jenoi, Kwenella and Kiang Karantaba weather stations Lower River Region, The Gambia

Region Weather Stations			**n Kendall Test**			
	Mann Kendell Test Statistics (Zs)	Kendall's Tau	Var (S)	p-value (two-tailed tests)	Alpha	Test Interpretation
JWS	3	0.3524	0.0000	0.0022	0.05	Accepted H0
KWS	2	0.2835	2057.3333	0.0448	0.05	Accepted H0
KKWS	-1.5	-0.2123	2057.3333	0.1355	0.05	Rejected H0

JWS= Jenoi Weather Station KWS=Kwenella Weather Station KKWS= Kiang Karantaba Weather Station

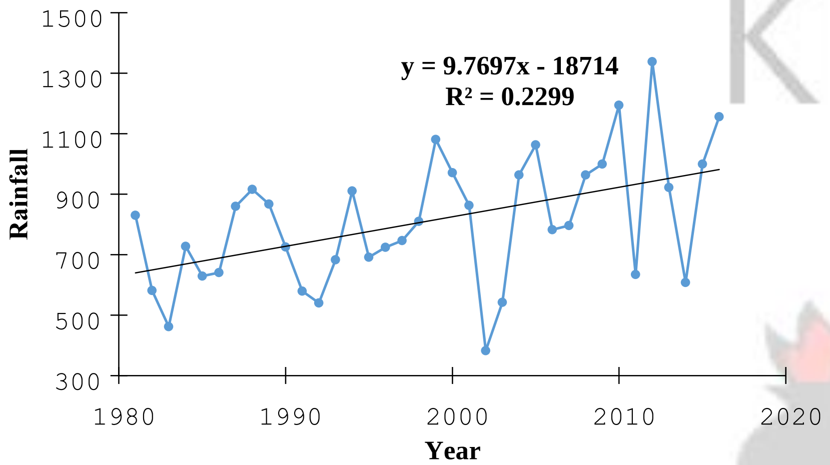

Figure 6. 3: Trend in annual rainfall data for Jenoi in LRR, The Gambia

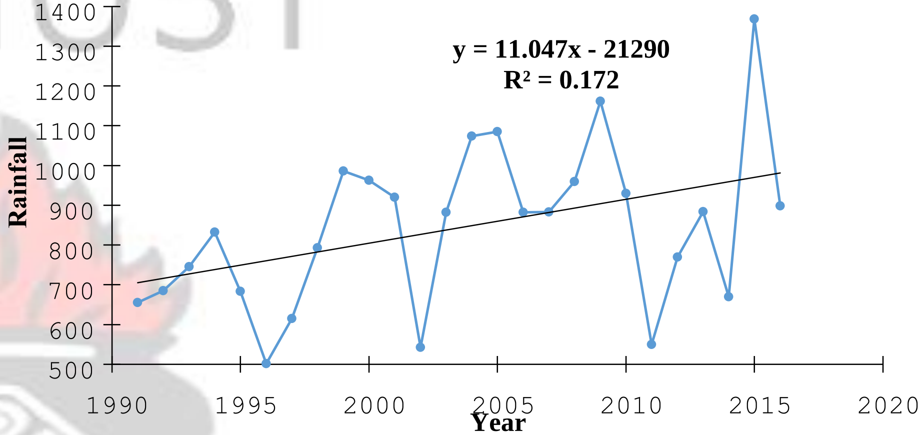

Figure 6. 4: Trend in annual rainfall data for Kwenella in LRR, The Gambia

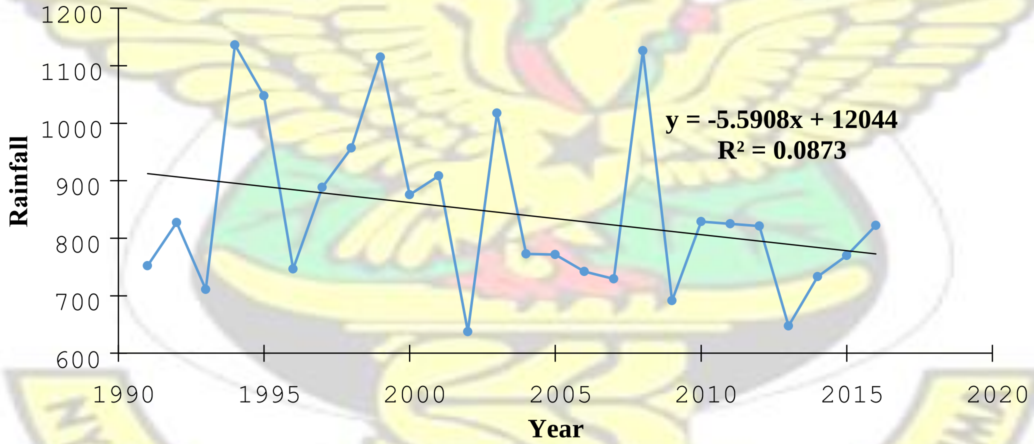

Figure 6. 5: Trend in annual rainfall data for Kiang Karantaba in LRR, The Gambia

6.3.1 Farmers' perception on temperature and rainfall patterns in Lower River Region

Table 6.4 presents how different households perceived changes in some of the climate variables within the two kingdoms of the Lower River Region. Majority (87%) of male farmers in Kiang perceived climate change as increased in temperatures presently as compared to when they started farming. An overwhelming majority (93 %) of their female counterparts also realized that temperatures have increased now than before. In the Jarra kingdom, 84 % and 98 % of male and female farmers respectively agreed that temperature is increasing. However, in Jarra, the perception differs between male and female farmers in terms of the length of growing season rainfall.

About 33 % of female farmers reported that the only reliable growing season rainfall has been reducing compared to during childhood whilst only 18 % of male farmers observed the shortening of the growing season in Jarra (Table 4). Rainfall events and duration were instances that farmers could easily remember. In terms of rainfall durations, the majority (83 %) of the farmers in the two kingdoms reported that rainfall duration during the farming season has reduced. In Kiang, majority (69 %) of male farmers have observed a considerable shift in the onset of the rains whilst the majority (80 %) of female farmers agreed to a shift in the onset.

Table 6. 4: Percentage of households that perceived changes in the temperature and rainfall patterns in the Kiang and Jarra, Lower River Region of The Gambia, over a 35-year period (1981 to 2016)

Variables	Kiang		Jarra		
	Male (n=45)	Female (n=45)	Male (n=45)	Female (n=45)	Total (n=180)
(a) Temperature					
Increased in temperature	86.67. (39)	93.33 (42)	84.44 (38)	97.78 (44)	90.56 (163)
(b) Rainfall					
Decreased in length of rainfall	35.56 (16)	33.33 (15)	17.78 (8)	33.33 (15)	30 (54)
Decreased in rainfall events	24.44 (11)	8.89 (4)	15.56 (7)	37.78 (17)	21.67 (39)
Decreased in rainfall duration	86.67 (39)	84.44 (38)	86.67 (39)	73.33 (33)	82.78 (149)
Shift in rain onset	68.89 (31)	80 (36)	73.33 (33)	60.00 (27)	70.56 (127)

Numbers in Bracket are counts and those not in Bracket indicate percentages of households
Numbers in Bracket are counts and those not in Bracket indicate percentages of households

6.3.2 Adaptation strategies adopted by the farmers to cope with climate variability

Table 6.5 gives an overview of the adaptation strategies and are categorized into two main groups. The first highlights on-farm adaptation strategies and refers to farming practises adopted by farmers during cropping with the aim of minimizing the risk of climate variability. The second one was, off-farm coping strategies refer to non-farming activities taken beyond the farm boundaries with the aim of supplementing food deficit and other living expenses in the household.

The values data from Table 6.5 showed different adaptation strategies used by male and female farmers in the study kingdoms. The adaptation strategies identified and being used by farmers in Kiang and Jarra kingdom include the planting of drought-tolerant crops, which is predominantly used by male and female farmers in Jarra (76 % and 78 %) and in Kiang 71 % and 64 % male and female farmers respectively. The use of early maturing crop varieties is used more by both male and female farmers in Jarra (82 %) than male and female farmers in Kiang (76 % and 62 %). Majority (62 %) of male farmers and few (48 %) of female farmers in Jarra reported they have been using mixed/diversification of crops whilst only a few male (38 %) and female (40 %) farmers, in Kiang practise crop diversification. The changing of planting date because of delay in rain onset is used more by male farmers (76 %) and female farmers (60 %) in Jarra. Majority of male farmers (69 %) and female farmers (62 %) in Kiang have adopted changing planting date. Supplementary irrigation is not a common practice in this region hence farmers' capacity to provide such resources are limited.

It was reported during the survey that majority 69 % of male farmers practise fallowing as against 53 % of female farmers in Jarra whilst in Kiang, a higher proportion of male (73 %) farmers use the same strategies compared to their female (62 %) counterpart. Crop rotation is used by majority (67 %) of male farmers and few female farmers (38 %) in Kiang, whilst majority of female farmers (60 %) and male farmers (53 %) in Jarra adopted the same strategy. Integrated Pest Management is a conventional pest control measures used to manage pest and disease outbreak. From the findings, it was observed that few female farmers (40 %) in Jarra adopted the use of IPM than male farmers (31 %) and that only few 18 % of the male and 36 % of the female farmers in Kiang use IPM respectively. Contour farming, agroforestry, and zero tillage are techniques to maintain the fertility of the soil and minimize erosion. It was observed that most of these strategies reported during the survey were mostly used by female farmers in Kiang whilst in Jarra male farmers used more of these strategies than female farmers did. A focus group participant from female focus group discussion in Kiang alluded on the characteristic of changing farming practises to the identified strategies.

Since the colonial era (1960) in The Gambia, rice nursery was planted in late May and by the time it was early June the first rain for transplanting came. That sequence continued until the late 80s when the onset started changing to late June. Even that is not certain, whether the rain will be enough for the rice crop. This led to agricultural research intervention to develop early maturing and drought-tolerant crops to offset the consequences of late onset of the rain [Focus group member, Kiang. August 2017].

In the male focus group, a participant mentioned that the rainfall situation in the area is erratic and that they have to think of ideas to cope with the changing rainfall pattern. “Before independent when I used to work with my grandfather, we used to experience heavy rains continues for a week with good soil. Now all the fertility of the soil is gone and we started changing to early maturing cowpea varieties and maize disseminated by agricultural extension services. This helps us to avoid total crop failure due to erratic rainfall distribution when these crops mature before the season ends [Focus group member Jarra, August 2017]”.

Off-farm coping strategies reported by study respondents include petty trading (29 %) by male farmers and 31 % by female farmers in Kiang whilst a few (43 %) male farmers in Jarra and majority (62 %) of female farmers trade for livelihood options. However, few (33 % and 38 %) of both male and female farmers respectively rely on remittance from family members, relatives or philanthropies in Kiang whilst in Jarra, only a few (27 % and 29 %) male and female farmers respectively rely on remittance. Temporal migration is a common practice in the rural Gambia where farmers move elsewhere for a short period to look for livelihood support. The findings from the survey revealed that in Kiang more than half (51 %) of male farmers migrate in search of better livelihood options than female farmers (36 %), contrary to situation in Jarra, where only a few (42 %) of males were more involved in migrating to search for livelihood options than female farmers (58 %). One of the common practise, which arose recently from 2003 to date in these two kingdoms, is logging for firewood and charcoal production. It was observed from this survey that farmers in Kiang kingdom involved more into firewood selling and charcoal production than farmers in the Jarra Kingdom.

A key informant from regional agricultural directorate mentions that households in these two kingdoms have now shifted attention to non-farm income jobs than during the early 1980s. Previously in the 1980s, most of the farmers in these two kingdoms produced bumper harvest and were considered as the food basket of the country alongside with raising livestock. With the advent of climate change and migration of youths as the labour force to abroad in search of greener pasture, most vulnerable household began selling firewood and charcoal that are non-rain dependent to supplement their household needs [Key informant, August 2017].

Table 6. 5. Summary of farming households who reported using a particular adaptation strategy (%) in Kiang and Jarra Kingdom of The Gambia

	Kiang		Jarra		
Adaptation practices	**Male (n=45)**	**Female (n=45)**	**Male (n=45)**	**Female (n=45)**	**Total (n=180)**
(a) On-farm adaptation practices					
	71.11 (32)	64.44 (29)	75.56 (34)	77.78 (35)	72.22 (130)

Drought tolerant crops					
Early maturing crops	75.56 (34)	62.22 (28)	82.22 (37)	82.22 (37)	76.00 (136)
Alley farming	37.78 (17)	33.33 (15)	31.11 (14)	37.78(17)	35.00 (63)
Diversification of crops	37.78 (17)	40.00(18)	62.22 (28)	48.49 (22)	47.22 (85)
Fallowing	73.33 (33)	62.22 (28)	68.89 (31)	53.33 (24)	64.44 (116)
Changing planting date	68.69 (31)	62.22 (28)	75.56 (34)	60 (27)	66.67 (120)
Supplementary irrigation	24.44 (11)	35.56 (16)	24.44 (11)	46.67 (21)	32.78 (59)
Crop rotation	66.67 (30)	37.78 (17)	53.33 (24)	60 (27)	54.44 (98)
IPM	17.78 (8)	35.56 (16)	31.11 (14)	40 (18)	31.00 (56)
Contour farming	26.67 (12)	33.33 (15)	26.67 (12)	28.89 (13)	28.89 (52)
Agroforestry	42.22 (19)	46.67 (21)	40.00 (18)	37.78 (17)	41.67 (75)
Zero tillage	24.44 (11)	26.67 (12)	26.67 (12)	8.89 (4)	21.67 (39)
(b) Off-farm coping practices					
Petty trading	28.89 (13)	31.11 (14)	40 (18)	62.22 (28)	40.56 (73)
Remittance	33.33 (15)	37.78 (17)	26.67 (12)	28.89 (13)	31.67 (57)
Temporal migration	51.11 (23)	35.56 (16)	42.22 (19)	57.78 (26)	46.67 (84)
Charcoal production	26.67 (13)	31.11 (14)	11.11 (5)	17.78 (8)	21.67 (40)
Firewood selling	26.67 (12)	28.89 (13)	13.33 (6)	15.56 (7)	21.11 (38)

Numbers in Bracket are counts and those not in Bracket indicate percentages of households
IPM: Integrated Pest Management

During the focus group discussions from the two kingdoms, Jarra kingdom had better livelihood opportunities than Kiang kingdom because of the presence of the regional capital and daily and weekly markets that enable farmers to go into trading. The focus group discussions (FGD) held in both kingdoms highlighted lack of climate information, good quality seed, inputs as well as the absence of agricultural banks and irrigation facilities as the challenges to the implementation of adaptation strategies. The survey results showed that different households within the kingdoms incline to participate in diverse adaptation strategies based on their social and cultural circumstances (see Table 6.5).

6.4. Discussion

6.4.1. The extent of climate variability in the study area

Increased in temperature was observed from the Lower River Region in 35 years' time interval and showed a positive trend, which raises concern for agricultural production and the attainment of the Sustainable Development Goal 2, achieving food security. Changes in temperature pattern in a positive direction may lead to a high rate of evapotranspiration and an increase in water demand for many crops (Juana *et al*., 2013). Elsewhere in sub-Saharan African, Msowoya and Madani (2016), concluded that increased in temperature may induce evapotranspiration especially in the Sahel region leading to ecosystem desiccation. Increased temperature can also cause extreme heat waves, which can trigger a delay in the cropping cycle and species reproduction (Salvo *et al*., 2013).

Regarding the output of the analysis of Mann Kendall test of total annual rainfall in LRR, it's worthy of concern to explore the ecosystem impacts that could be triggered if torrential rains persist in some parts and a deficiency in other parts of the LRR in the future. For swamp agro-ecologies, vulnerability to flooding may cause detrimental submergence of rice if increased rainfall continues in the future whereas on the contrary, if below annual rainfall level continues, it may trigger high salinity effect in the swamp ecologies, leading to crop failure (Tanaka *et al*., 2017). Such results corroborate previous studies by Atherton and Slobodan (2013) who reported that a reduction in rainfall in the coastal area may lead to high salinity effect in rice growing ecologies. Increased rainfall can adversely affect crops that are sensitive to waterlogging conditions and can cause destruction of structures, an outbreak of mosquitoes and water-borne diseases (Rieckmann *et al*., 2018). An increased heavy downpour of rainfall may lead to water erosion, runoff, and leaching of nutrients beyond the rooting zones of crops (Bostick *et al.*, 2007). The experience of high rate of decreasing trend observed in Kiang Karantaba during the 36 years period of the rainfall time series data calls for attention; if the situation should persist in future, food security and poverty rate will be high in this part of the region.

6.4.2. Farmers' perception of climate variability in the study communities The findings from the perception of farmers on temperature and rainfall variability are consistent with the meteorological data in terms of temperature variability (e.g. Smit *et al.* 2001; Shah and Dulal, 2015). Climate change perception informed farmers about current behaviours of weather patterns within their system of operation and how they will respond to based on their level of exposure (Mertz *et al.*, 2009; Simelton *et al*., 2011). Based on timing, rural farmers have vast knowledge and do share socio-ecological knowledge about early warning signs for weather forecasting; this is the most relevant part of the coping mechanism and adaptation practises to climate variability (Kristjanson *et al.*, 2012). Similar studies have shown that sub-Saharan African farmers have used their local knowledge to predict the weather which can be relevant for climate change adaptation (Mertz *et al*. 2009; Antwi-Agyei, 2012; Waha *et al., 2013;* Simelton *et al*., 2011).

6.4.3. On-farm adaptation and off-farm coping strategies practised by gender The findings further suggest that farmers employ a host of on-farm adaptation practises, including alley farming, supplementary irrigation, crop rotation, agroforestry, zero tillage and changing planting date. The identified practises are similar to those practised in other parts of sub-Saharan African used by smallholder farmers to tackle recent climate variability (Antwi-Agyei *et al.*, 2014; Guan *et al*., 2017; Kumasi *et al*., 2017). However, our findings revealed that generally the number of adaptation options identified regarding on-farm practises were limited and may not be able to support production in the future. This could be due to the fact that farmers choice of using a particular strategy depend on how easy and less labour it required (Smit and Wandel, 2006). Access to basic resources and assets as well as government programs may be limiting factors, which could further compound household vulnerability to climate variability (Yesigat *et al.*, 2015; AntwiAgyei *et al*., 2015).

In most parts of sub-Saharan Africa, contour farming is a technique used to minimize soil nutrient loss hence controlling erosion (Gis *et al.*, 2013; Bera *et al*., 2016). Contour farming is said to mitigate nutrient movement by erosion, increase soil conservation, boost productivity and reduce the cost of inputs for production and is predominantly practised by male farmers in the study area (Sonko *et al.*, 2016). Male farmers are predominantly upland dwellers where they grow cash crops and coarse grains, which is said to demand more labour than rice production. Inadequate access to inputs and poor soil fertility in some of the communities have driven some male farmers, particularly experienced farmers, to shift into border areas to secure fertile farmlands and till savannah woodlands into croplands in Kiang kingdom (Rurinda, 2014). Due to the high incidence of poverty in these regions (Nkechi *et al.*, 2018), there are often severe limitations on smallholder farmers' capacities to effectively adapt to the worsening soil and climatic conditions. Consequently, these farmers were forced to shift to alternative options to adapt such as involving in business during the dry season (Loum and Fogarassy, 2015). The challenges that both men and women experienced when struggling to fulfil their roles were among the causes of variation in perceiving the change in climate (Zampaligr *et al.*, 2014).

The empirical evidence from the survey results revealed that households in the study kingdoms engaged in a range of off-farm coping practices to have a better livelihood option from climate risk associated with crop failure. Most of the farmers in Kiang Kingdom reported relying on social support in the form of remittance from family members in the cities and other philanthropies. Receiving remittance as livelihood options have been skyrocketing for the past decades where households sell assets to send their youths in search of better livelihood elsewhere in the Europe and America (Kuye *et al.*, 2006). These findings supported the study by Kebbeh (2014), who reported that remittance support from emigrants outside The Gambia accounts for 4 % of the youth population most of whom are from the rural Gambia. A similar study in Malawi identified climate change as the driving forces of youth migration from rural-urban or cross border migration in search of better livelihood options to support families in the form of remittance (Murray *et al*. 2016).

6.5. Conclusion and Recommendations

The extent of rainfall trend in Lower River Region indicated that the distribution is erratic and not uniform within the region. Increased temperature was observed over the 35-year period within the study region as indicated by the meteorological data. These could trigger the seasonal climate effect, thereby affecting seasonal crop yields. Both men and women perceived that climate is changing, and these perceptions were consistent with available climate data. Based on the erratic nature of rainfall and temperature variability in the Lower River Region of The Gambia, farmers employed various on-farm adaptation and off-farm coping practices to address the consequences of climate variability on livelihoods. The key on-farm adaptation practices include the use of drought tolerant crops varieties, changing planting date, planting of early maturing varieties, irrigation and land fallowing. In terms of off-farm adaptation practices, smallholder farmers were engaging in livelihood diversification, temporary migration, charcoal production, and firewood selling. The adoption of drought tolerant crops and early maturing crop varieties by rice and maize growing farmers are considered as national adaptation plan of action. The study recommends that policymakers should incorporate climate change adaptation practices into rural policies that will improve rural food security. For example, community driven development project that will decentralize local training on food processing and trading into the rural areas so that households can be directly involved. Therefore, farmer associations should be strengthened to foster the spread of climate adaptation information to areas vulnerable to climate change and variability.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The following conclusions can be drawn from the study in line with the specific objectives set:

Specific objective 1: Assess the extent to which food crops (rice and maize) yields are vulnerable to climate variability

This study consistently agreed with previous studies in sub-Saharan African on climate change effect on cereal yields. CO_2, maximum temperature and sunshine duration were found to be significant and negatively affecting rice yield except for maximum temperature. The Ordinary Least Square regression applied on the time series climate and crop yield confirmed this trend, highlighting a significant difference in the impact of each variable effect either positive or negative. However, the effect of climate on maize yield showed a contrasting result. Maximum temperature and sunshine duration were significant and negatively affected maize yield, whilst rainfall and minimum temperature positively affect maize yield and showed a significant trend. The extent to which climate variability influenced rice and maize yields is crucial and may exacerbate food security.

Specific objective 2: Assess the effect of soil fertility and properties on the yields (of rice and maize) in the LRR, The Gambia

Soil nutrients, which perceived to be a driver of crop production, play a vital role during the productive stage of crops. The mean comparison test for soil physical and chemical properties showed a contrasting result. NPK levels at the productive soil depth (0-15 cm) of both swamp and upland are very low (less than 1 %) and decreased towards the inland from the riverbank. Generally, the mean soil test for EC showed that soils are saline (4.8 dS/m) and the pH content is low 4.7. Organic matter content is generally low but higher in the swamp fields than the upland fields. The overall soil physical properties of upland maize field are sandy loam whilst the swamp fields are silty loam.

Specific objective 3: Evaluate the yield response of rice and maize to future climate variability and change

The future climate projection for maize and rice yield showed contrasting results by different GCM scenarios, CSIRO-RCP4.5 and NOAA-RCP4.5. The annual projected maize yield will increase by 2232 kg/ha in 2050 by projection using RCP4.5-CSIRO whilst NOAA-RCP4.5 showed a projected increase in rice yield of 1389 kg/ha by the year 2049. The percentage yield changes from 2021 to 2050 over a 30-year period in the study area present a decreasing trend for rice yield whilst an increase for maize yield (see Figure 5.8 and 5.9). The projected percentage change observed for maize yield from 2031 to 2040 is about 48 % by CSIRO-RCP4.5 whilst rice yield is projected to be reduced at a percentage change of -23 % by 2050 as projected by NOAA-RCP4.5. The projected results showed that rice yield would be highly influenced by change climate and variability than maize yield.

Specific objective 4: Assess the adaptation practises used by local farmers to address the adverse impacts of climate variability

The local perception of climate variability and farmers adaptation strategies showed that local communities are aware that the climate is changing. The main climate variables mentioned by farmers, an indicator of climate variability is rainfall and temperature. The study confirmed that farmers' perception of climate variability corroborates with the result of the climate data analysed which showed an increasing trend. Despite the current erratic nature of the climate, which is expected to increase in the future, the results demonstrate that farmers are already adapting to climate variability. Strategies used by farmers include drought-tolerant crops, changing planting dates, planting early maturing crops and fallowing. To supplement the negative effect of climate beyond the farm, farmers also adopted off-farm coping strategies such as petty trading, temporal migration, charcoal production, firewood selling and receiving remittance to improve their living standard. The strategies identified being used by farmers to climate variability is not enough to intensify rainfed agriculture to feed the growing population. It is noted that most of the adaptation strategies alluded by farmers refer to farming practises, highlighting the link between livelihoods and conservation issues in food security.

7.2 Recommendations

7.2.1 Recommendation for policy

This thesis confirmed that the adaptation and coping strategies identified appears to be inadequate to combat food security in the study area and that climate variability and soil fertility remains the main obstacles of rainfed agriculture. Based on the results, the following recommendations were identified for policy consideration:

Water harvesting technologies should be introduced through government projects to increase the capacity of farmers to fight against climate extremes (e.g. drought and flood).

In terms of soil fertility status, the results showed that the productive soil depth is highly deficient in organic matters and becomes degraded because of salinity and acidic condition. The government should invest in concrete embankment to protect coastal rice farming from seawater inundation. Therefore, crop residue and soil fertility management should be strengthened through agroforestry systems into the farming system to increase organic matter deposit into the soil. In order to sustain rice and maize as the staple food of The Gambia, the government needs to involve the private sector to invest in agriculture in order to promote value addition.

Local adaptation strategies should be addressed through a bottom-up approach and should be integrated into national adaptation plan of action (NAPA) to enhance farmers decision to adopt adaptation strategies through farmer field schools. Farmers need to be involved in designing climate change adaptation strategies in order to capture the real problem on the ground.

7.4.2 Recommendations for further research

This study provides baseline information about climate variability in The Gambia. The results showed that staple crops are vulnerable to climate change and variability. The biophysical deterioration that motivated climate change adaptation for rainfed agriculture is still predominant.

As argued on the feasibility of climate change adaptation, there is a need to develop new crop varieties that will have resistance to the changing climate**.** Looking at the proximity of the study communities to the river, salt-tolerant rice varieties should be released to the farming communities for continuous crop production. Further research should consider other agricultural and non-agricultural parameters in the regression model, which may also affect crop yields in the study area.

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APPENDICES

APPENDIX 1A

T-test paired two sample means for maize yield (1997-2006)

t-test Outcome	Actual maize yield	Estimated maize yield
Mean	1277	1000.213
Variance	122661	326287.5

observation	10	10
Pearson correlation	-0.064	
Hypothesized mean Difference	0	
Df	9	
t Stat	1.205	
P(T<=t) one-tail	0.131	
t Critical one-tail	1.859	
P(T<=t) two-tail	0.263	
t Critical two-tail	2.306	

T-test paired two sample means for rice yield (1997-2006) t-Test Outcome Actual rice Estimated rice yield yield

Mean	878.654	807.629
Variance	22357.462	48762.82
observation	10	10
Pearson correlation	-0.275	
Hypothesized mean Difference	0	
Df	9	
t Stat	0.751	
P(T<=t) one-tail	0.236	
t Critical one-tai	1.833	
P(T<=t) two-tail	0.472	

APPENDIX 1B

FARMERS HOUSEHOLD SURVEY QUESTIONNAIRE

EVALUATION OF THE ADAPTATION OPTIONS USED BY LOCAL FARMERS TO COPE WITH CLIMATE VARIABILITY

This research survey questionnaire is designed for academic purposes with the aim of assessing the ‘perception, technological development, government programs, on and offfarm adaptation strategies, level of adaptation supports, challenges to climate adaptation and socio-demographic. You are assured of the confidentiality of any view expressed in relation to this research. I therefore appeal to you to provide information as possible for a relevant result. Thank you for your cooperation.

Questionnaire Number…………………………………………………………………………

Name of main interviewer…………………………………………………………………...

Name of main Interviewee……………………………………………………………………

Date of interview……………………………………………………………………….

Region………………………………………………………………………………………….

District………………………………………………………………………………………

Community/village…………………………………………………………………………

GPS Coordinate point Latitude: …………………. Longitude……………………….

Mobile No. of the interviewee:……………………………………………………………..

SECTION A

Socio-Demographic Information Household

structure 1a.

Names of the household head and members	Sex (**code 1**)	Age of the respondent	Marital status (**Code 2**)	Source of Household income (**code3**)	Number of years of residence in the village	Educational level (**code 4**)	Main activity (**code 5**)	Secondary activity (**code5**)

Code 1: Sex	**Code 2: Marital status**	**Code 3: Source of household income**	**Code 4 Educational level**	**Code 5: Activities**
1 = Male	1 = Married	1 = Subsistence farming	1= Literate/Islamic	1 = Farming
2 = Female	2 = Single	2 = Commercial	2 = Primary	2 = Animal husbandry
	3 = Divorced	3 = Off-farm jobs	3 = Junior	3 = Fishing
	4 = Widow/widower	4 = Vegetable production	4 = High school	4 = Business
	5 = Separated	5 = Remittance	5 = Tertiary	5 = Labourer
		6 = Civil servant		6 = Employed

SECTION B

PERCEPTION OF FARMERS ABOUT CLIMATE CHANGE

1b. Are you aware that the climate is changing? 1. Yes, 2. No

1.1b. If yes, indicate what have been the changes.

S/N	Long-term changes in mean climate variables	Response 1. Yes 2. no
1.2b	Increased temperature	
1.3b	Increase in rainfall duration	
1.4b	Increase in number of rainfall events	
1.5b	Increase in rainfall intensity	
1.6b	Decrease in rainfall duration	
1.7b	Decrease in number of rainfall events	
1.8b	Decrease in rainfall intensity	
1.9b	Shift in the onset of rain	

1.10b If no, what are you aware of ?..

2b. Did climate change have positive impact? 1. Yes, 2. No

3b. If yes, Which of these positive impact have you observed for the last 10 years? 1: Flood water harvesting for irrigation 2: Improved groundwater flow 3: Floods increase fish harvest 4. None of the positive impact 5.Others (specify)……………

4b. How will you capitalize on these opportunities in the future for better farm productivity?

1: Adopt irrigation practice 2: Irrigate more 3: Shift to Aquaculture

4: Others (Specify)……………………………………….

Farm Production Practices

5b. Do you know about this recommendation on-farm adaptation strategies?

On-farm adaptation strategies	**1. Yes, 2. No**	**Are you practicing it 1. Yes, 2. No**	**ranking**
6b. Planting crops tolerant to dry spell			
7b. Planting short duration crops			
8b. Practicing Alley farming			
9b. Diversification of crops			
10b. Fallowing			
11b. Changing planting time			
12b. Supplementary irrigation			
13b. Crop rotation			
14b. Using integrated pest crop measures			
15b. Practicing contour farming			
16b. Using agro-forestry practices			
17b. Zero tillage			
18b. Mechanized farming			
Off-farm adaptation strategies			
19b. Petty trading			
20b. Relying on remittance			
21b. Temporal migration			

22b. Changing diets			
23b. NGOs support			
24b. Government assistance			
25b. Skill jobs			
26b. Charcoal mining			
27b. Selling firewood			

Please rank them in order of importance (1=extremely important 2=Very important 3=Important 4=Not very Important 5= Not important

SECTION C

FARMERS ADAPTATION OPTIONS TO CLIMATE CHANGE

Technological development

1c. Over the last 10 years, have you practice these recommended technologies as adaptation options

Technological development	**1.Yes** **2.No**	**If no, why?**
2c. Mixed farming		
3c. Alley farming		
4c. Relay farming		
5c. Mixed cropping		
6c. Intercropping		

7c. Agroforestry		
8c. Contour farming		

9c. Are you practicing water-harvesting techniques in your field? 1. Yes, 2. No

10c. If yes, which water harvesting technology do you use in your farming? 1. Ridging 2. Bunding 3. Half-moon 4. Ponding 5. Other (Specify)…………

11. If no, why not?...

12c. which of the improved varieties and breeding strategies do you use? 1. High yielding varieties 2. Early maturing cultivars

3. Drought tolerant varieties 4. Others (Specify)…………………….

13c. Have you encountered soil affected problems in your field in the past 10 years? 1. Yes, 2. No

14c. If yes, what problems do you encounter? 1. Soil salinity 2. Low soil nutrient 3. Soil erosion 4. Termites infestation 5. Others (Specify)………… ……..

15c. How did you address the problems in **question 14c**? 1. Use of Inorganic fertilizer

2. Use of Compost 3. Use of organic fertilizer 4. Use of farmyard manure

5. Use of dykes 6.Other (Specify)…………………… ….

16c. Have you encountered pest and disease problems in your field for the past 10 years? 1. Yes, 2. No

17c. If yes, how did you address the problems?

1. Use of Herbicides 2. Use of Insecticides 3. Use of biological agent

4. Use of cultural method 5. Others (Specify)……… ….

18c. which of the Recommended agricultural- practices do you practice as farming system options?

1. Harrowing 2. Conservation agriculture 3. Planting during recommended period 4. Planting in rows 5. Others (Specify)………….. …………

19c., which adaptation strategies do, you used for the management of your field.

1. Soil conservation 2. Irrigation 3. Reduced farm size 4. Contouring 5. Others (Specify……………………………………)

20c. which mitigation strategies do, you used to the management of your field. 1. Reduce chemical usage 2. Planting trees 3. Establish fire belt 4. Planting cover crops 5. Others (Specify)…………………………………

21c. How do you forecast the rainy season?

1. Through local indicators 2. Through National weather stations

3. Through national television 4. Others (Specify)………… ….

22c. Do you address moisture deficiency during dry spell? 1. Yes, 2. No

23c. If yes, how did you address moisture deficiency? 1. Supplementary irrigation 2. Development of integrated drainage system 3. Land contouring 4. Creation of reservoirs 5. None 6. Others (Specify)……………………………………

24c. If no, what is your challenge?

....

....

Government programs as planned adaptation

25c. Do you receive any agricultural subsidies from the government? 1. Yes, 2. No

26c. If yes, which kind of agricultural subsidy do you receive from the government? 1. Farm inputs 2. Loans 3. Insurance 4. Others (Specify)……………

27c. How do you obtain seeds for planting? 1. Purchase 2. From another farmer 3. Certified Seed growers 4. Neighbouring countries 5. NARI 6. NGOs 7.Others (Specify)………………………………

28c. How does government help in the marketing of farm produce?

1. Buying seeds 2. Policy in pricing control 3. Tax reduction 4. Do not help in marketing 5. Others (Specify)…………………….................

29c. Is there any government policy on land use regulations? 1. Yes 2. No

30.1c If yes, please give examples…………………………………………………

……………………………………………………………………………………………

31.2c If No, why not?..

....

SECTION D

LEVEL OF ADAPTATION SUPPORT RECEIVED BY FARMERS

1d. Have you received any external support for your adaptation options for the past 10 years? 1.Yes 2. No.

2d. If yes, please indicate the type of support

Adaptation support	Condition (Code 1)	Duration (Code 2)	Frequency (Code 3)	Organization (Code 4)	Order of importance (Code 5)	If No, what are the challenges
2.1d Inputs						
2.2d subsidies						
2.3d Extension services						
2.4d Research support						
2.5d NGO support						

2.6d Financial support						
Loan						

Code1 **Code2** **Code3** **Code4** **Code5**

1. Free 1. 1-5 yrs. 1. Once every year 1. Government 1. Extremely important
2. Not Free 2. 6-10 yrs. 2. Twice every year 2. NGO 2. Very important
3. 11-15 yrs. 3. Once every two yrs. 3. Philanthropies 3. Important
4. 16-20 4. Once every three yrs. 4. UN 4. Moderately important
5. Others 5. Others (Specify) 5. Others (Specify) 5. Not Important

3d. Do you receive any regular climate information? 1: Yes 2: No

4d. If yes, what form and where do you receive the regular information and technical assistance?

1: Extension service 2: Agricultural research 3: Television 4: Radio

5: NGOs 6: Others (Specify)…………………………………….

5d. If no, why not?...

6d. what five needed services, investments, or development support would you want the government, the NGOs, the community or the private sector to do for you in your efforts to adapt to climate change?

6.1d Issue (key)	6.2d Who (key)	6.3d Ranking
6.1.1d	6.2.1d	6.3.1d
6.1.2d	6.2.2d	6.3.2d
6.1.3d	6.2.3d	6.3.3d
6.1.4d	6.2.4d	6.3.4d
6.1.5d	6.2.5d	6.3.5d

Key for 6.3 Please rank them in order of importance (1=Extremely important 2=Very important 3=Important 4=Not very Important 5= Not important

Key for 6.1 – Issues: 1: Climate information 2: Irrigation 3: Provision of Credit facilities 4: Agricultural machinery 5: procurement of land 6: Health facilities and services 7: c

Key for 6.2 – Who: 1: Central government 2: Local government 3: Local community 4: Private sector 5: NGOs 6: Others (Specify)………………………………………...

SECTION E

CHALLENGES TO ADAPTATION

1e. Do you have any difficulties in changing your farming system? 1. Yes, 2. No

1.1e If yes, what were/are the main constraints/difficulties in changing your farming system?

1.2e Difficulty	Rank (order of severity)	Suggestion/solution
1.3e Educational level		
1.4e No access to information		
1.5e Lack of Extension services		
1.6e Lack of credit facilities		
1.7e Sustainability		
1.8e Land tenure		
1.9e Topography of the land		
1.10e Labour intensive		
1.11e Low soil fertility		
1.12e High cost of inputs		
1.13e Lack of climate insurance		
1.14e Lack of improved varieties		
1.15e Sociocultural barriers		
1.16e Long dry spell		

1.17e Inadequate agro-industries		
1.18e others		

1. Very severe 2. Severe 3. Less severe 4. Not severe