ASSESSMENT OF CLIMATE CHANGE IMPACTS ON CROP YIELDS AND FARMERS' ADAPTATION MEASURES: a case of Rwanda

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CERTIFICATION

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DEDICATION

I dedicated this thesis to my Lord Jesus Christ, my wife Rachel Mutesi, parents and siblings for their support and encouragement.

ABSTRACT

Climate change, one of the challenges facing the world today, is increasingly affecting people's livelihood in Rwanda like in other developing countries. This research assesses the impacts of climate change on yields of major food crops and analyzes adaptation measures perceived and undertaken by smallholder farmers in Rwanda. Secondary data obtained from Ministry of Agricultural and Animal Resources (MINAGRI), Food and Agriculture Organization of the United Nations (FAO) and 16 stations under Rwanda Meteorological Agency (RMA) were collected to describe the trends in climatic and non- climatic variables and assess the impact of climate change on crop yield. In addition, a household survey of 350 households was conducted in 4 districts (Bugesera, Gicumbi, Nyabihu and Nyamagabe) to examine socio-economic characteristics that influence the choice of actual adaptation measures. To assess the impacts of climate change on crop yields, regression model was used after obtaining lagged values of model variables. Heckman probit selection and outcome models were employed to analyze farmers' perception on climate change in the first stage and farmers' adaptation to climate change in the second stage. Moreover, multinomial logistic regression model was used to determine the factors that influence farmers' choice of climate change adaptation option in the study area. Results from the analysis of time series data show that area harvested and annual rainfall are positively and significantly related to yields of selected crops while maximum temperature have a negative impact on beans, maize and Irish potato yields. Climatic variable like minimum temperature found to have a negative effect only on maize yield. Micro-level findings substantiate that farming experience and access to information on climate change have a positive and significant influence on farmers' perceptions of climate change at 1% level of significance. Other variables such as education, farm size and livestock ownership are positively and significantly related to the choice of adaptation measures. Further interventions should focus on how the knowledge of farmers about climate change can be increased and the established adaptation measures by government can be owned and maintained by farmers through their different mechanisms such as farmer cooperatives and other social capital mechanisms.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

ADP	Area Development Programme
AERC	African Economic Research Consortium
AfDB	African Development Bank
AGRA	Alliance for a Green Revolution in Africa
ARDL	Autoregressive Distributed Lag
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
CIAT	International Center for Tropical Agriculture
CIP	Crop Intensification Programme
CMAAE	Collaborative Masters in Agricultural and Applied Economics
DDP	District Development Plan
EAC	East Africa Community
EDPRS	Economic Development Poverty Reduction Strategy
EICV	Integrated Household Living Conditions Survey
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
FGDs	Focus Group Discussions
GDP	Gross Domestic Product
GEF	Global environment fund
GHGs	greenhouse gases
GoK	Government of Kenya
GoR	Government of Rwanda
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IPAR	Institute of Policy Analysis and Research
IPCC	International Panel of Climate Change
KIIs	Key Informants Interviews
LDCs	Least Developed Countries
LUC	Land Use Consolidation

MDGs	Millennium Development Goals
MIDIMAR	Ministry of Disaster Management and Refugees Affairs
MINAGRI	Ministry of Agricultural and Animal Resources
MINECOFIN	Ministry of economic planning and finance
MINIRENA	Ministry of Natural Resources and Environment
MNL	Multinomial Logistic regression model
MWLE	Ministry of Water, Lands and Environment
NAPAs	National Adaptation Programs of Actions
NGOs	Non-Governmental Organizations
NISR	National Institute of Statistics of Rwanda
PRB	Population Reference Bureau
PSTA	Strategic Plan for the Transformation of Agriculture
RAB	Rwanda Agriculture Board
REMA	Rwanda Environment and Management Authority
RMA	Rwanda Meteorological Agency
Rwf	Rwandan Francs
SEI	Stockholm Environment Institute
SIDA	Sweden International Development Cooperation Agency
SSA	Sub-Saharan Africa
SWC	Soil and Water Conservation
UNDP	United Nations Development Program
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations International Strategy for Disaster Reduction
USD	United States Dollars
VUP	Vision 2020 Umurenge Program

1. INTRODUCTION

1.1. Background

A number of studies have asserted climate change as one of the top devastating threats that has constrained global communities (Fischer et al 2002, Hansjurgens and Antes 2008 and (IPCC 2014). Great impacts of climate change associated with natural disasters such as severe floods, prolonged droughts, landslides, ice melting, storms and hurricanes usually lead to a massive loss of human life, agricultural and livestock production losses, soil degradation, etc and definitely affect people's livelihood negatively (Rwanyirizi and Rugema 2013). According to (IPCC 2001), global warming and precipitation patterns have gradually affected crop productivity and finally resulted in food insecurity of ever increasing population across the globe. Unfortunately, annual global mean temperature keeps increasing due to high emission of greenhouse gases (GHGs) into the atmosphere (World Bank 2010a). In this case, climate change and agriculture seems to be interrelated in such a way that climate change has direct positive or negative effects on agriculture through changes in temperature and precipitation while agriculture also affects climate through emissions of Greenhouse gases (GHGs) (Rosegrant et al 2008). This has been underlined by (Garnett 2012) that the emissions from agriculture account for up to 30% of the global total.

In developing countries where the majority of people reside in rural areas, the impacts of climate change on their livelihood are likely to be high because of high dependency, directly or indirectly, on rain-fed agriculture (Nyanga et al 2011), and agriculture sector reported by several studies to be one of the most vulnerable and sensitive to climate change and weather conditions (Nelson et al 2009). Evidences from different studies substantiate that population of developing countries is dramatically increasing. Therefore, climate change is also having continuous and serious detrimental impacts on agriculture on which most of people rely on especially food and employment (Cooper et al 2013) and (USAID 2014). In addition, a large number of farmers in developing countries is small-scale farmers, meaning that their land holding is too small compared to their households' size. This is attributed to high population growth which is linked to intensive land use in developing world (Rosegrant et al 2008) and (Gerstter C et al 2011). As long as adaptation to climate change is more concerned, understanding of climate change impacts on crop yield and of farmers' adaptive capacity (technical and financial) remains incomplete, comprehensive researches and information on impacts climate change on crop yield are few and even lacking due to inadequacy financial resources more specifically in developing countries (UNFCCC 2007). Thus, most of developing countries often need international financial assistance in order to be able to tackle climate change impacts.

Sub-Saharan Africa (SSA) is among the most vulnerable regions to climate change chocks and hazards. Like other developing world, SSA is characterized by high population growth, high dependence of the region's population and economies on rain-fed agriculture. This makes SSA to be more confronted with the adverse impacts of climate change which result in food crises for human and livestock (Chuku and Okoye 2009). The facts and figures reported by Alliance for a Green Revolution in Africa (AGRA 2014) ascertained that agriculture sector has a noticeable role in economic development of SSA countries. On average, it accounts for 34% (ranging between 10% and 70%) of the total Gross Domestic Product (GDP) and about 65% of total population is engaged in agriculture. Reliance on natural resources for subsistence in SSA leads to land degradation, desertification and further food insecurity. This is attributed to the limited adaptive capacity to climate change impacts. A research done by (AGRA 2014) argued that the severity of climate change impacts on agriculture is mostly caused by poor infrastructure (small scale irrigation), low use of modern agricultural technologies, inability to adapt due to poverty and weak institutions.

Currently, the East Africa Community (EAC) is composed of six member countries; Burundi, Kenya, Rwanda, South Sudan, Tanzania and Uganda, with different agro-ecological zones and topography, reason for being affected by extreme climatic events differently. Like other SSA countries, EAC population and GDPs mainly depend on agriculture. The majority of farmers in EAC countries is reliant on rain-fed and smallholder agriculture, characterized mainly by poor irrigation, for their livelihoods (Liwenga et al 2014). However, agriculture sector is the main sector that contributes, on average, about 40% of the total region's GDP and employs about 80% of the total of its population (Seitz and Nyangena 2009) it remains exposed to extreme climatic events like floods due to high intensive rainfall. (Kandji and Verchot 2007) revealed that EAC region threatened by the impacts of climate change due to severe floods and droughts devastated a large part of the region and had adverse impacts on agricultural productivity. For instance, Government of Kenya in its National Climate Change Action Plan report indicated that Kenya has experienced serious damages that affected the people’s livelihood and country’s economic development (GoK, 2013) In Uganda, floods and long dry spells posed serious damage to the agricultural productivity in such that the vast majority of smallholder farmers obtained less crop production than anticipated and in addition these events had impacts on grazing potential especially within cattle corridor (MWLE 2007) and (Hepworth 2010b). According to (Hepworth 2010a) , Tanzanian farmers have been affected by a string of droughts events that undermined the crop productivity and reduced grazing lands while the floods events led to soil erosion, land degradation, and even reduction of crop yield (Hepworth 2010a) and (FAO 2014).

Rwanda’s economy is mainly depends on rainfed agriculture and its climate varies between humid tropical and dry across the country with high variation in weather conditions (rainfall and temperature). Therefore the country is more exposed to the extreme climatic events and their impacts (GoR and SSEE 2011). In line with its Vision 2020 report developed in 2000, several programmes, policies and strategies in all sectors of economy have been put in place in order to make the country a middle income (per capita income of about 900 USD per year) by 2020. Among others, Economic Development and Poverty Reduction Strategy (EDPRS I and II) has been developed and used as a framework for achieving Vision 2020 and Millennium Development Goals (MDGs). Climate change is among EDPRS cross-cutting issues that have been integrated in all programmes (MINECOFIN 2000) and (MINECOFIN 2013). The EDPRS also indicated that economic impacts of climate change have increased due to frequent droughts, floods and soil erosion that have caused serious damages especially in agriculture sector. According to the Ministry of Disaster Management and Refugees Affairs (MIDIMAR), the frequency and intensity of natural hazard-induced disasters, particularly floods and droughts have significantly increased the economic and environmental losses (MIDIMAR 2012).

As the impacts of climate change are increasingly affecting the country’s economy, studies on assessing the impacts of climate change have been conducted to come up with different adaptation measures at national and community levels. For instance, Rwanda Environment and Management Authority (REMA) carried out a study to assess the impacts of climate change disasters (especially floods) on economic sectors including agriculture. The findings of the study indicated that the estimated economic losses caused by the May 2012 flooding were 1.4 % of the overall GDP for the period 2011/2012. During this period, the heavy rains caused widespread flooding, severe soil erosion, landslides, crop and livestock loss, destruction of road infrastructure and property countrywide and in some parts, the highest cost of human life (REMA 2013). With reference made to the recent study conducted to assess the effects climate change on food security in Rwanda (case of Bugesera District), decline in the food crop productivity has been found to be the main effects caused by extreme climatic events (Rwanyirizi and Rugema 2013). Despite Rwanda being highly vulnerable to climate change extreme events due to its topography, studies at farm level on farmers' perception of and adaptation to climate change are limited. Moreover, other climate change gaps in Rwandan agriculture sector include lack of knowledge on climate change; lack of mitigation and adaptation strategy and lack of geo-information data for the agriculture sector that could lead to more generalized adaptation measures.

The past studies argued that one way of reducing the vulnerability and severity of climate change impacts is through adaptation measures (UNFCCC 2011) and (IFAD 2014). Other scholars such as (Wang et al 2010) and (Apata 2011) described adaptation to climate change as a two-step process, which initially requires the farmer to perceive the changes in temperature and precipitation and followed by the action that the farmer takes as a response to the changes in the form of adaptation measures. However, the adaptive capacity of developing countries is limited, the countries members of Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)[1] have developed coping strategies in the face of unanticipated extreme climatic events using various adaptation options in different sectors detailed in their respective National Adaptation Programs of Actions (NAPAs)[2] integrated into their Poverty Reduction Strategy Papers (PRSPs) in order to cope with the climate change impacts effectively

[1] Country members of this association include Burundi, Democratic Republic of Congo, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania, and Uganda

[2] NAPAs are documents prepared by Least Developed Countries (LDCs) that identify urgent and immediate activities useful for coping with climate change.

(Nzuma et al 2010). (Fussel 2007) revealed that human activities have already influenced weather vagaries that impacted agricultural productivity, but much effort should be put on adaptation options. In agriculture, adaptation efforts focus on implementing options that help to build rural livelihoods that are more resilient to climate extreme events. Adaptation options to climate change have very large benefits in reducing its present and future damages. Without adaptation options, climate change would adversely affect agriculture sector, but with adaptation, vulnerability to climate change could be significantly weakened.

1.2. Problem Statement

Climate change is a global concern but especially in developing world. Rwanda is among developing countries that have experienced the impacts of climate change on agricultural productivity. Rwanda is located in the region of great lakes characterized by variations in seasonal precipitation and temperature. Due to its topography, climate of Rwanda varies according to the regions in which it lies. Eastern region is dominated by dry climate, temperate climate in the Western region, tropical climate in the Northern region which is mountainous while humid tropical climate in the Southern region of the country. Being a country comprising of different climate, Rwanda has experienced changes in its climate since 1930s. The changes that have been observed and experienced include: high average temperature, heavy rainfall lasting for a short period and prolonged dry season especially in Eastern and Southern province of Rwanda. These changes have translated into extreme weather events such as prolonged drought, severe periodic floods and landslides countrywide. Like in other developing countries, Rwandan agriculture is one of the most vulnerable and exposed sectors to the potential adverse impacts of climate change. Despite tremendous progress and improvement towards Government programmes and sector strategies aims at improving agriculture and environment sector, still vulnerability among rural farmers remains a challenge as it is linked to food insecurity and poverty. Climate change is well recognized to be one of the anxieties for rural farmers as their available ability to coping with the prolonged drought period, floods and other extreme weather events is limited.

Usually, to adapt to climate change requires cost, and the moment farmers adapt to, the economic costs of climate change impacts reduced to some extent. The issues that raise is that in developing countries including Rwanda, the adaptive capacity of the vast majority of farmers is limited due to financial and sometimes technical constraints. It is very crucial to assess the impacts of climate change on yield of major food crops most grown mainly for consumption in order to improve yield vis a vis climate change. Unfortunately, there are some gaps in researches or studies underlining the impact assessment of climate change on yield of major crop. Since the occurrence of extreme climate events, several impacts have been noticed both at farm and national levels. At national level, the country's GDP expected to be allocated to other development plans were used, unpredictably, in adapting to climate extreme events that affected a number of sectors of the economy such as agriculture, environment, infrastructure and health while at farm level, extreme climate events have suddenly reduced crop productivity specifically to those farmers who have not adapted.

1.3. Objectives of the research

Main objective

The main objective of the research is to assess the impacts of climate change on yields of major food crops, understand the long term farmers' perceptions of climate change and analyze actual adaptation measures undertaken by smallholder farmers in Rwanda.

Specific objectives

a) To assess the impacts of rainfall and temperatures, floods, droughts and area harvested on yields of major food crops in Rwanda
b) To analyze the factors that influence farmers' perception of and adaptation to climate change and variability in Rwanda
c) To determine the factors that influence choice of adaptation options by smallholder farmers in Bugesera, Gicumbi, Nyabihu and Nyamagabe districts.

1.4. Research Hypotheses

a) Area harvested, climatic variables (rainfall and temperature) and events (floods, droughts) significantly impact yields of major food crops in Rwanda;
b) Socio-economic and institutional factors significantly influence farmers' perceptions of climate change and variability;
c) Socio-economic characteristics of the household head, agriculture characteristics and institutional factors significantly influence smallholder farmer's choice of adaptation measures to climate variability.

1.5. Rationale of the research

Empirical evidence indicates that Rwanda has experienced climate change and variability, as a result of changes in average temperature and annual precipitation (SEI 2009) and (REMA 2013). In Rwanda, like in other Sub-Saharan African countries, the potential impacts of climate change and variability on human, environmental and economic systems require a cost that can, to some extent, be avoided by taking appropriate actions to adapt to the changes in temperature and rainfall. Hence, this research was undertaken in order to give insights into the impacts of climate change and variability on yields of major food crops over the past 45 years (1970-2015), the farmers' perception of and adaptation options to climate change and variability in Rwanda. The research intends to provide a guide on how the mentioned impacts should be assessed and actual adaptation options be taken into account and strengthened, if necessary, by government institutions in partnership with development partners and policy makers in order to come up with good outcomes in terms of crop production. There has been a few studies focusing on impacts assessment of climate change on crop yield in Rwanda, but little is known on economic impacts of climate change and variability on crop yield and adaptation measures undertaken by smallholder farmers. Therefore, this research assesses the impact of some weather variables such as temperature and precipitation and non-weather variable like harvested area on yields of major food crops in Rwanda. The results from this study will help the government and development partners to take appropriate actions needed to tackle the impacts of climate change in Rwanda.

1.6. Scope of the research

The research is divided into five chapters. Chapter one presents a general introduction of climate change impacts at global, regional and national context, the problem statement, objectives of the research and hypotheses of the research to be tested. Chapter two defines some key terms and concepts of the research. It gives also a depth understanding of climate change impacts on agriculture sector at global, regional and national contexts. It also describes preferable adaptation options in Eastern African region, theoretical and conceptual frameworks related to the research. Chapter three emphasizes on methodological approaches used in to assess the impacts of climate change on yields of major food crops, the factors that influence farmers' perception and those determining the choice of adaptation options by smallholder farmers. It also describes the study area, sampling procedure, the nature and sources of the data used in the study. The relevant methods of analysis and models are explained in this chapter. Chapter four includes sections providing results and discussions of primary and secondary data used in the study. Different models used to assess the impacts of climate change on yields of major food crops, analyze farmers' perception and actual adaptation options used by farmers are presented and analyzed in this chapter. Chapter five finally states conclusion and recommendations of the research.

2. LITERATURE REVIEW

2.1. Introduction

This chapter describes the impacts of climate change and variability on crop yield in developing countries with more focus to Rwanda. To better understand the research, this chapter defines the key concepts about climate change and adaptation measures based on previous related studies. Much emphasis is to find out the existing impacts of climate change on crop yield; the extent to which these impacts affect smallholder farmers' livelihood and the existing mechanisms or measures undertaken by farmers to deal with these impacts. This chapter gives an overview of climate change impacts on agriculture productivity in developing countries focusing mainly on Rwanda and its neighboring countries. It describes the effects of increase in temperature and rainfall on main crops grown in Rwanda, farmers' perception of the occurrence of climate change phenomena and outlines adaptation measures adopted at national level to cope with climate change impacts on agriculture sector in general.

2.2. Definition of key concepts

This sub-section provides definitions of key concepts relating to climate change and adaptation measures. According to (IPCC 2014), **climate change** refers to a change in the change in the state of the climate that can be identified by changes in the mean and/ or variability of its properties and that persists for an extended period of time. Impacts of climate change are consequences of extreme weather events that undermine not only agricultural productivity but also infrastructure and human being livelihoods directly or indirectly.

(FAO 2012a) report defines **climate variability** as the variations in the mean state of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). Some scholars defined **perceptions of farmers** regarding the long-term changes in temperature and precipitation as farmers' ability to understand climate change phenomena based on their own knowledge. Several studies pointed out some factors that influence farmers' perceptions including farmers' age, education, farming experience and sometimes access to climate information among others (Gbetibouo 2009) and (Ndambiri et al 2013).

(IPCC 2014) defined **adaptation** as a process of reducing damages or harm that are associated with extreme weather events such as floods, droughts, landslides, storms, etc. Adaptation includes all actions intended to respond to the existing or anticipated climatic stimuli and their impacts. Adaptation depends significantly on the adaptive capacity or adaptability of an affected system, region, or community to cope with the impacts and risks of climate change. The adaptive capacity of communities is determined by their socioeconomic characteristics. According to (Burton et al 2007) adaptive capacity is the potential or ability of a system, region or community to adapt to the impacts of climate change. Other scholars defined adaptation in terms of the actions or strategies that households and communities undertake to enhance resilience of vulnerable systems and reduce climate change associated damages in order to meet their livelihood needs (Rennie and Singh 1996) and (Scheraga and Grambsch 1998).

2.3. Overview of climate change impacts on agriculture

Agriculture as a major source of food is very exposed to extreme weather events that lead to a reduction of agricultural production worldwide. Climate change impacts on agriculture can be either by increasing water demand or reducing water availability in the areas suitable for irrigation (IPCC, 2007 and Kang et al, 2009). Although climate change is weakening agricultural productivity in different dimensions and developing countries are undergoing a series of extreme weather events that require high adaptation cost, agriculture is receiving more attention world-wide in terms of adapting to the negative impacts in order to meet the needs of poor people who depend directly on agriculture for food (World Bank 2010a) (SIDA 2010) and (FAO 2012b). Globally, arable land used for crop cultivation is about 1.4 billion ha compared to over 200 million ha of arable land under irrigation (FAO 2012a). According to the report released by (FAO 2012a), out of 2.5 billion people in less developed countries (LDCs) 1.5 billion people depend on smallholder agriculture which is more susceptible to the climate change related disasters such as more frequent and prolonged droughts and severe floods. In some instances, climate change impacts are linked to the growing population particularly in developing countries in the sense that population growth is the main driver behind increased GHGs emissions. Some evidences indicated that population of East Africa region has increased to the unexpected extent between 1961 and 2011. Likewise, the population projection in this region is somehow problematic as the impacts of climate change associated with population growth are unpredictably affecting the region (Cooper et al 2013) and (FAO 2012a).

Table 1: Actual and projected human population trends in selected East African countries (millions)

EA Countries	**Period (years)**					
	1961	1971	1991	2011	2031	2050
Burundi	3	3.6	5.7	8.6	11.6	13.7
Kenya	8.4	11.7	24.2	41.6	67.4	96.9
Rwanda	2.9	3.9	6.9	10.9	18	26
Sudan	11.8	15.2	27.2	44.6	68.1	91
Uganda	7	9.7	18.3	34.5	61.1	94.3
Tanzania	10.4	14	26.3	46.2	84.2	138.3
Total	**43.5**	**58.1**	**108.6**	**186.4**	**310.4**	**460.2**

Source: FAOSTAT

Cropping systems in which the majority of Africans depend on is mostly rain-fed farming and different scholars asserted that smallholder farmers or the primary producers of agricultural output in Africa like in other developing countries, are among the most disadvantaged and vulnerable groups to the impacts of climate change due to land shortage and no access to reliable irrigation. Since these groups practice subsistence agriculture, occurrence of extreme weather events destabilize crop yield and have further effects on food security of their households (Altieri and Koohafkan 2008) and (AGRA 2014). According to (UNISDR 2011), Africa accounts for over 20% of all the weather and climate related disasters that occurred globally while the economic set-back was only 0.6% of global economic losses.

The East Africa region is characterized by arid and semi-arid spells. This makes the region to be more susceptible to the effects caused by rising in temperature and rainfall patterns. The fact that the region has a large number depending heavily on rain-fed agriculture and the major food crops are mainly seasonal crops, changes in temperature and precipitation will definitely affect their seasonal crops. For instance, from 1996 to 2003, a decline in seasonal rainfall of 50-150 mm led to a reduction of production of some seasonal like maize and sorghum in the region(Seitz and Nyangena 2009). According to (Kandji and Verchot 2007) the East African Community (EAC) found to be vulnerable to extreme weather events due to the factors such as topography, poor inadequate infrastructure, low use of modern agricultural technologies and weak institutions.

Many African scholars recorded the occurrence of extreme weather events that caused great damages in some of EAC countries. In Kenya, the recent severe droughts recorded in the years of 1997, 2000, 2004 and 2005 while the years 1997/98 and 2002 were characterized by devastating floods that hit many areas of the country. In Tanzania, recent extreme weather events have caused severe damage to the economy. The prolonged and severe droughts recorded in the years 1971, 1975-76, 1983, 1985, 1987, 1992, 1996-97, 1999-2000 while the flooding in the years 1993, 1997/98 and 2000/01 (Seitz and Nyangena 2009). In Uganda, rainfall patterns led to floods occurred in the years 1961/62, 1997/98, 2007 and 2010. The prolonged and severe drought recorded in the years 1999/2000 and 2005 resulted in water shortage, and finally led to loss of animals and low production of milk in the cattle corridor (Seitz and Nyangena 2009) and (Hepworth 2010b). These extreme climatic events have had direct and indirect impacts on agricultural productivity and they have been linked to catastrophic landslides, infrastructure damages, death, displacement and destruction of livelihood assets (Mutimba el al 2010) and GoK, 2013). Over the next decades, it is predicted that developing countries including Africa will experience the effects of climate change differently, not only because of differences in the projected change of climate events but also because of vulnerabilities and adaptive capacities that vary greatly between nations and regions (Mertz et al 2009). A study of the United Nations Development Program (UNDP) predicted that by 2020, up to 250 million people in Africa will be exposed to greater risk of water stress. Other impacts include an increased risk of severe floods, sea level rise inundating coasts worldwide and completely inundating some small island States, and an increased severity and frequency of tropical cyclones (UNDP 2008). Some studies by have summarized the most important projected impacts of climate change on water, agriculture sectors in the developing regions (Ludwing et al 2007) and (Altieri and Koohafkan 2008) as shown in Table 2 below.

Table 2: Summary of the most important projected impacts of climate change on the water and agriculture sectors in developing countries

Sector	Africa	Asia	Latin America
Water	• More frequent droughts, especially in Southern Africa • More frequent low water storage in reservoirs and lakes • Reduced run-off in Northern and Southern Africa; increased run-off in East Africa • More frequent floods, especially in East Africa • Increased water stress due to both climate change and increased demand • Increased water scarcity could trigger more conflicts • By 2025, approximately 480 million people in Africa could be living in water-scarce or water stressed areas.	• Disappearing glaciers reduce summer stream flow of most large rivers affecting more than one billion people • Snowmelt earlier in the season will increase risk of spring floods • Increased water shortages during the dry season in South and East Asia • Higher flood risks during the monsoon season in South East Asia and the Indian subcontinent • Likely increase of water stress due to a combination of increased population growth, higher per capita water demands and climate change. • By the 2050s, freshwater availability in Central, South, East, and Southeast Asia, particularly in large river basins, is projected to decrease	• Rapid increase of number of people affected by water stress due to a combination of climate change and increased demand. By 2050, between 60 and 150 million people will experience water stress. • Re-treat of glaciers and reduction in mountain ice and snow cover will severely reduce water availability in some countries. • By 2030, 60% of the people in Peru will experience reduced water availability due to disappearing glaciers • In Chile the delivery of water to several coastal cities could be comprised in the near future due to melting snow packs and disappearing glaciers. • Reduced hydropower generation capacity • The combined effect of land clearing and more intense rainfall events is likely to increase the number of landslides. • More frequent and intense cyclones will increase the number and severity of floods in Central America

Sector	Africa	Asia	Latin America
Agriculture	• Severe impact on food production and security • Agriculture in several marginal semiarid regions will become unsustainable • Increased poverty of small scale farmers • Small increases in productivity in regions with mild climate change where rainfall is increasing • Changing season will make agriculture more difficult, e.g. changed sowing dates due to later or earlier start of wet season • Less predictable water availability will make nomadic agriculture more difficult • By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50 percent Agricultural production; including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition	• Increased climate variability will generally increase the number of crop failures due to either floods or droughts. • In areas where rainfall is predicted to increase agricultural production is likely to improve. • Irrigated agriculture which depends on run-off from snowmelt and/or glaciers is likely to be affected; snow will melt earlier in the season which will reduce water availability during the (late) summer when irrigation is most needed. • Agricultural production in low lying coastal areas such as large parts of Bangladesh will be affected by increased flooding and salt water intrusion. • Likely increase of diseases and pests affecting both plant and animal production systems.	• Reduced yield of annual crops such as wheat, maize, rice and soybean in several regions due to higher temperatures and shorter growing seasons. • In some regions such as central Argentina wheat yields could increase due to more precipitation. • Regions most suitable for coffee production will move to a different location; coffee yields and quality are likely to change already with small temperature increases (1-2°C). • Specifically coffee but also other crops are likely to be affected by more diseases and pests. • Disappearing glaciers and reduced snow melt is likely to reduce water availability for irrigation. • Likely increased land degradation and salinisation in the drier part of the continent

Source: Ludwig et al., (2007), Altieri and Koohafkan (2008)

2.4. Climate change and Rwandan agriculture

Rwanda is a small landlocked country of 26,338 Km^2 in area with a size of resident population of around 11,262,564. Its population density, of about 445 inhabitants per square kilometer, is the highest among other African countries, (NISR 2015). The economy of Rwanda is also highly dependent on agriculture which contributes 33% to the GDP and employs about 72% of the population in subsistence agriculture. The total area of the arable land used for the farming is estimated to be 2,173,167 hectares with per capita agricultural land size estimated at 0.5 hectares

(NISR 2015). The fact that Rwandan agriculture is rain-fed, it makes the country to be more vulnerable to changes in weather patterns particularly rainfall (Warner et al 2015).
Due to changing climate of Rwanda, any extreme weather event can have huge consequences mostly on water resources and agricultural productivity and on rural farmers' livelihood especially (MINIRENA 2006). In Rwanda, climate change threatens agricultural production and climate change associated impacts found to be a main challenge for rural poor farmers dominating the agriculture sector because of their limited adaptive capacity to cope with these impacts (MINAGRI 2013). In the past three decades, Rwandan agriculture has undermined, unpredictably, by a series of extreme weather events in terms of their intensity, frequency and persistence. These events resulted in a decline of agricultural production which led to socio-economic impacts and finally impacted economic growth of the country. Moreover, a study carried out by REMA demonstrated that Southern and Eastern regions of the country situated along Akagera and Akanyaru valleys were more sensitive and prone to extreme weather events particularly floods (REMA 2011).

Furthermore, Plan Stratégique pour la transformation de l'agriculture (PSTA)[3] phase III report released by the MINAGRI substantiated that climate change and variability related disasters led to an unexpected decline in agricultural productivity mostly in the prone areas across the country. Climate change reported to have noticeable impacts on food crops and some cash crops where in the year 2009/10 changes in climate affected coffee plantation and its production reduced by 26%. In Eastern province also, maize produced decreased due to the unpredicted droughts (MINAGRI 2013). (Warner et al 2015) ascertained that the impacts of climate change on crop cultivated in Rwanda vary according to type of crop and its requirement in terms of rainfall and precipitation. For instance, cassava, as the main food crop and income generating crop reported to be a rare commodity because of declining yields due to low soil moisture. Because of government intervention through crop intensification program (CIP) cassava production picked up.

Some studies revealed the occurrence period of major floods and droughts events in Rwanda. The period of severe floods recorded in the years 1997, 2006, 2007, 2008, 2009, and 2012 where rainfall resulted in destruction of infrastructure (roads, irrigation systems), fatalities, landslides,

[3] Strategic Plan for the Transformation of Agriculture

crop and livestock losses, soil erosion and environmental degradation. A part from floods, cropping systems in some regions of the country suffered from prolonged droughts that occurred in the years 1999/2000 and 2005/6. Production impacts from El Niño Southern Oscillation (ENSO)[4] related drought events in 1997 and 2000 show losses in maize, bean and animal production, particularly in Eastern and Southeastern regions (SEI 2009) and (REMA 2010).

2.5. Effects of climate variables on crop yield

2.5.1. Effects of increase in temperature

The global mean temperature is gradually increasing and agriculture continues to be the main responsible for emitting a large proportion of GHGs into the atmosphere (Ludwing et al 2007) and (FAO 2012a). According to the IPCC recent report, average global temperature increased between 1.8 and 4.0 ^{o}C during the period of 1980 to 1999 and expected to increase between 1.1 and 6.4 ^{o}C during the 21st century (IPCC, 2007). Other scholars substantiated that minimum temperature increased about two times (0.204 ^{o}C per decade) as fast as maximum temperature (.141^{o}C per decade). Global warming to some extent could reduce markedly crop productivity in equatorial and tropical countries, but increase crop productivity in temperate countries where ambient temperature is lower than temperature existing in the regions surrounding by equatorial and tropical climate (Vose et al, 2005 and Tang et al, 2013).

Historical occurrence of increase in temperature in Rwanda

As evidenced by the Ministry of Disaster Management and Refugees Affairs (MIDIMAR), Rwanda has continuously experienced impacts caused by increase in temperature translated into droughts, if it lasts for a long period, in the last ten (10) decades. Recently, MIDIMAR recorded a series of droughts events since 1910 up to 2014 in the report released last year. The prolonged droughts occurred in the years resulted in crop development failure and food shortage where the worst situation of lacking food was recorded in December 1989. In this period about 237 people died due to famine (MIDIMAR 2015). In rural areas where people depend on agriculture, farmers face substantial risk of crop failure and famine when drought hit. Table 3 below provides more details on droughts events period, affected zones and damages.

[4] El Niño – Southern Oscillation (ENSO) and La Niña, are associated with extreme rainfall and flooding and droughts (respectively) in the region of East Africa.

Table 3: Historical drought events

Event period	Affected zone	Death	Damages
1910	Kibungo/ Zaza	0	
1976-1977	National	0	Famine, Crop failure
October 1984	National	0	Famine, Food shortage
December 1989	Gikongoro[5], Gitarama and Butare	237	Famine, Crop failure
1996	Gikongoro	0	Famine, Food shortage
November 1999 - Early 2000	Umutara, Kibungo, Kigali (Central), Gitarama, Butare and Gikongoro	0	Famine, Food shortage
March 2003	Kigali Rural (Gashora and Bugesera), Kibungo, Umutara, Butare, Gikongoro and Gitarama	0	Crop failure
February 2005	National	0	Famine, Crop failure
March - September 2006	Kibungo, Umutara, Bugesera, Butare, Gikongoro and Gitarama	0	Famine, Food shortage
June 2014	Bugesera and Kayonza Districts	0	Crop failure

Source: (MIDIMAR 2015).

2.5.2. Effects of changes in rainfall patterns

Rainfall patterns can result either into crop yield increase or decrease depending on its intensity. About 20% of the world's populations live in river basins that are likely to be affected by excess of precipitation. An increase in rainfall intensity could increase the risk of floods in wetlands occupied mostly by farming (IPCC, 2007). It is ascertained that a heavy and uncertain rainfall that can be translated into floods is a limiting factor for crop production in developing countries. This pushed farmers to adapt through switching crops, crop diversification and planting trees (Ziervogel et al, 2006 and Ludwing et al. 2007). The regions surrounded by the tropics and hemispheres, where SSA countries located, experience decreased amount of rainfall, of about 20%, due to a prolonged of dry spell. This could result in loss of arable land that can be caused by decreased in soil moisture, increased aridity, increased salinity and groundwater depletion (Vose et al, 2005, IPCC, 2007 and Oyiga et al 2011).

[5] Gikongoro is currently Nyamagabe district

Historical occurrence of increase in rainfall in Rwanda

In Rwanda, heavy rainfall has led to severe erosions, floods and landslides in Northern Western regions resulting in the losses in food production and displacement of human lives, leaving people homeless and without food (Mutabazi et al., 2013). Recently, MIDIMAR reported on the historical events of landslides and floods (table 4 and 5) in Rwanda to illustrate how climate change related disasters have devastated the livelihood of people especially farmers who earns their living from agriculture (MIDIMAR 2015).

Table 4: Historical landslides events

Event period	Affected zone	Death	Damages
1987	Gitarama	0	Fields destroyed
May 1988	Ruhengeri	0	3 houses destroyed. debris avalanche at Nyagitaba
Nov 2006	Kigali	24	
2011	Nyabihu, Burera, Rutsiro	25	17 Houses destroyed or damaged
2012	Ngororero	2	19 Houses destroyed or damaged and 54 ha of Crop lands affected
	Nyabihu	5	147 Houses destroyed or damaged and 305 ha of Crop lands affected
	Gasabo	2	6 Houses destroyed or damaged
	Nyamagabe	0	2 Houses destroyed or damaged
	Rulindo	0	1 house damaged and 40 ha crop lands affected
	Nyamasheke	3	1 house damaged
	Burera	2	
2013	Gasabo	2	47 Houses destroyed or damaged
	Nyarugenge	4	87 Houses destroyed or damaged
	Kicukiro	0	22 Houses destroyed or damaged
	Rutsiro	3	18 Houses destroyed or damaged
	Rulindo	12	79 Houses destroyed or damaged and 257 ha crop lands affected
	Gakenke	2	41 Houses destroyed or damaged
	Gicumbi	3	52 Houses destroyed or damaged
	Nyamagabe	0	8 Houses destroyed or damaged
	Burera	2	19 Houses destroyed or damaged
	Ngororero	0	4 Houses destroyed or damaged
	Rubavu	2	
	Karongi	0	2 houses damaged

Source: (MIDIMAR 2015).

Like other climate change disasters, floods have been found to have huge impacts on humanity's livelihood. Due to its climate profile and changes, Rwanda is prone to various risks of floods (Douglas et al 2008). This has been reiterated by MIDIMAR report showing how Rwanda is more threatened by periodic flooding due to dense river network, large swamps and marshlands. Sometimes during the rainy season, floods damage crops and other agricultural activities located in swamps and marshland. Therefore, farmers cultivating on lowland plots are forced to use intensively the upland plots/ areas that are also prone to soil erosion and landslide (MIDIMAR 2015).

Table 5: Historical flooding events

Event period	Affected zone	Death	Damages
6-9 May 1988	Ruhengeri, Kibuye, Gisenyi, Gitarama and Gikongoro	48	1 225 houses & 19 bridges destroyed, 7 roads cut off
21 Nov 2000	Gisenyi	0	More than 200 houses destroyed; crops & roads damaged
22 Sept 2001	Gikongoro	10	
30 Oct. - 2 Nov. 2001	Gisenyi, Kibuye, Ruhengeri, Byumba, and Gikongoro	2	More than 100 houses, 60 schools & crops destroyed
26 April - 28 May 2002	Kibuye, Cyangugu, Byumba and Kigali	69	
16 Aug 2005	Kigali	2	
16 Aug 2005	Ruhengeri and Byumba	25	5 000 houses & 3 000 Plantations flooded
12-20 September 2007	Rubavu and Nyabihu	20	678 partially & 342 houses completely destroyed
3-16 February 2007	Rubavu and Nyabihu	10	
12 Sept 2007	Nyabihu and Gicumbi	15	37 houses destroyed, 562 families homeless
Oct 2008	Western and Southern	0	2 000 Ha crops damaged
6 Oct 2008	Western and Northern	0	More than 500 homes submerged; 2000 ha crops destroyed, as well as bridges, roads, pylons & schools

Event period	Affected zone	Death	Damages
Sep 2009	Rubavu	0	Houses and crops destroyed
23-24 February 2010	City of Kigali	3	Industrial sites submerged (around Rwandex co-factory), damage to constructions and crops
2011	Nyabihu	1	19 houses and 87 ha of land affected
2012	Bugesera	2	
	Burera	1	
	Gicumbi	2	
	Musanze	1	
	Nyagatare	0	65 ha of land affected
	Rubavu	7	252 houses and 58 ha of land affected
	Rusizi	3	341 houses and 125 ha of land affected
	Kicukiro	3	
	Nyamagabe	1	
2013	Karongi	5	2 houses affected
	Nyabihu	2	35 houses and 4 ha of land affected
	Rubavu	3	65 houses affected
	Nyaruguru	2	
	Ruhango	0	48 houses and 12 ha of land affected
	Gasabo, Kicukiro	0	49 and 8 houses affected respectively
	Nyarugenge	3	20 houses affected
	Musanze	0	39 houses and 395 ha of land affected

Source: (MIDIMAR 2015).

2.6. Perception of climate change

Climate phenomena (more specifically temperature and rainfall) variability is significantly challenging small scale farmers who directly depend on rain-fed agriculture in the developing countries (Moyo et al, 2012, Simelton et al, 2013). Many African scholars (Deressa et al 2008, Gbetibouo. 2009, Apata, 2011, Ndambiri et al, 2013, Montle and teweldemedhin. 2014 and Mugula and Mkuna, 2016) assessed perceptions on climate change and variability to understand the level of smallholder farmers in perceiving the changes in temperature and rainfall. Despite the low levels of education of the majority of smallholder farmers, they perceive climate change based on their local knowledge and farming experience (Nyanga et al, 2011, Okonya et al 2013 and Amadou et al 2015). Other scholars confirmed that farmers' knowledge about climate change has been influenced by some institutional factors such as media (newspapers, radio and television) and access to farmer-to-farmer extension services which may facilitate farmers to easy access information on climate change (Moyo et al, 2012, Ndambiri et al 2012 and Amadou et al 2015). Moreover, socio-economic factors such as age of the household, farm income have been mentioned to have influence on perception of climate change (Deressa et al, 2008). We can find out additional factors that influence farmers' perception on climate change but only little studies were revisited just to point out that it is possible for farmers to perceive changes in temperature and rainfall variability.

2.7. Adaptation to climate change

The ever increasing of global warming (expected to be 2^oC in the middle of the century) is resulting in a higher incidence of extreme weather events such as severe floods and persistent droughts caused by intense rainfall and prolonged dry spell respectively. As they are having a greater impacts on people's livelihood, households, communities, and planners from developed and developing countries need to take measures that "reduce the vulnerability of natural and human systems against actual and expected climate change impacts (World Bank 2010a)

Based on the empirical evidences from the impacts of current and past extreme weather events, developing world is highly vulnerable to climate change and variability. Continuous and persistent threats that climate change and variability pose to the socio-economic development of developing countries and the livelihoods of smallholder farmers call for farmers and institutions' attention in the form of adaptation (Chambwera and Stage 2010) and (UNEP 2010a). To choose appropriate adaptation measures to cope with climate change impacts requires vulnerable groups' perception ability (Gbetibouo 2009). A number of scholars argued that to reduce the future climate change damages, vulnerable communities have different adaptation measures depending on the context of in which climate change event occurs, geographical location, asset base and livelihood strategies (Adger et al 2009) (Kirrane et al 2012) and (IFAD 2014).

2.7.1. Adaptation to climate change in Africa

Climate change is a big challenge that the current generation is facing. Africa is more vulnerable to climate change impacts than other continents (UNISDR 2011). To tackle inevitable impacts caused by extreme weather events in Africa, long term effective adaptation measures are required. However, agriculture is more sensitive sector to climate change and smallholder farmers are more vulnerable, the need for adapting to climate change impacts is too higher while the adaptive capacity is still limited in terms of human capacity and financial resources almost in all developing countries (UNFCCC 2007) and Chambwera and Stage, 2010). The recent UNEP report revealed that some African states have undertaken and adopted various national, regional and international initiatives and programmes to reduce the vulnerability of climate change towards vulnerable community and systems (UNEP 2010b).

Like in other developing countries, extreme weather events undermine agricultural productivity in SSA countries. The reason of huge impacts is due to the low use of modern agricultural technologies and poor infrastructure that enhance adaptation to climatic change and increase productivity among smallholder farmers (AGRA 2014). As there no other option of making a living than agriculture, SSA countries has prioritized adaptation to climate change to sustain the living of smallholder farmers who depend on agriculture for their livelihoods (UNFCCC, 2007). (World Bank 2010b) asserted that the impact of climate change on human, environmental and economic systems is a cost that can to some extent be avoided by applying more effective adaptation strategies; however the cost associated with adaptation measures to be undertaken is too high compared to the human and country's capacity. Recent study by Sherman et al (2013) estimated global adaptation costs for climate change impacts to be between USD 4 billion to USD 109 billion on annually basis of which USD 18 billion is for Sub-Saharan Africa countries.

The impacts of climate change in Africa is increasing overtime due to the emissions of Western developed countries. This is a burden for African countries in terms of adapting to the arising impacts of climate change as most of the countries still rely on foreign aid and assistance. In order to reduce vulnerability to climate change satisfactorily, African countries needs at least US$ 20-30 billion per annum over the next 10 to 20 years. Therefore, there is need for financial and technical assistance from international organizations to support African countries to cope with huge impacts of climate change (AfDB 2011).

Table 6: Sources of adaptation finance received by Africa

Source of funding	Funding approved (US$ m)	Funding received (US $m)
Least Developed Countries Fund	95.7	64.5
MDG Achievement Fund – Environment and Climate Change thematic window	20.0	15.6
International Climate Initiative	12.1	12.1
GEF Trust Fund - Climate Change focal area (GEF 4)	3.3	3.3
Strategic Priority on Adaptation	9.6	9.6
Special Climate Change Fund	28.2	20.5
Global Climate Change Alliance	51.6	1.0
Pilot Program for Climate Resilience	113	1.5
Adaptation Fund	15.1	3.8
Total	**349**	**132**

Source: (AfDB 2011).

2.7.2. Types of climate change adaptation measures

Climate change impacts can be adapted at community or institutional levels depending on the severity of extreme weather event. In this regard, adaptation measures are divided into two types namely autonomous and planned adaptation measures. Autonomous adaptation refers to the adaptation the response taken by vulnerable individuals and households in order to cope with climate change hazards and impacts without any external technical or financial assistance (Kirrane et al 2012). Whereas the planned adaptation measures refers to the strategies and decisions made by government institutions to lessen the impacts of climate change on vulnerable people (Stern 2008).

Table 7: Examples of adaptation types

Type of response to adaptation	Examples by type	
	Autonomous	**Planned or policy driven**
Short run	• Making short-run adjustments, e.g. changing crop planting dates • Spreading the losses, e.g. pooling risk through insurance	• Developing greater understanding of climate risks, e.g. researching risks and carrying out a vulnerability assessment • Improving emergency response, e.g. early warning systems
Long run	Investing in climate resilience if future effects are relatively well understood and benefits easy to capture fully, e.g. localized irrigation on farms	• Investing to create or modify major infrastructure, e.g. larger reservoir storage, increased drainage capacity, higher sea walls • Avoiding the impacts, e.g. land-use planning to restrict development in floodplains or in areas of increasing aridity

Source: (Stern 2008).

Study by (Ngigi 2009) indicated that the vulnerabilities of climate change occur at various scales and successful adaptation depend on actions taken at different levels either at national or farm levels. The agricultural sector is particularly vulnerable to climatic variability and extreme weather events. Adaptation in this sector is most likely a reflection of these extreme weather events rather than the cumulative effects of climate change (Ngigi 2009).

This study outlined some examples of national climate change adaptation measures used in agricultural sector:

- **Technological innovations:** improved crop varieties, early warning systems, land and water management, integrated pest management, etc.
- **Government subsidies:** agricultural subsidy among other farmers' support services to cushion famers against the impacts of climate variability
- **Farm production practices:** farm production, land use, land topography, irrigation, and timing of operations

- **Farm financial management:** crop insurance (in case of crop failure related to variations in weather conditions), crop shares and futures, income stabilization programs, and household income (diversification schemes)”

2.7.3. Adaptation measures in East African Countries

The EAC region is more likely to be vulnerable to the changes in rainfall and temperature due to region’s topography. The main sector that significantly contributes to the region’s people’s livelihood and economies is very risky because of consequences of climate change. Changes in temperature and rainfall have negative seasonal effects on crop yields of subsistence crops, cash crops and on livestock production (FAO 2014). To address the adverse impacts of climate change on agricultural productivity in EAC member countries, several adaptation measures have been discussed and put in place by the governments in order to intensify agriculture sector and further improve economic growth. Table 8 below provides further information about adaptation measures undertaken by EAC countries.

Table 8: Adaptation measures adopted in agriculture sector (EAC)

Countries	Adaptation measures
KENYA	• Drilling boreholes in Nairobi and other parts of the country. To date, 50 boreholes have been sunk in Nairobi; there are plans to sink a total of 200 boreholes. • Using water tanks to supply water in slum areas in Nairobi and other cities and towns. • Using water kiosks as alternatives for ensuring a constant water supply. Also, cattle troughs are to be constructed in various parts of the country for watering animals. • Providing seeds and fertilizer to farmers to improve production. • Placing about 40,000 hectares under irrigation. • Continuing programs that provide emergency food supplies to vulnerable people Providing emergency relief to hard-hit livestock farmers, especially pastoralists, during drought season • Conserving water, especially by protecting water towers and supporting and encouraging the use of water-harvesting techniques in towns and rural areas

Countries	Adaptation measures
BURUNDI	• Growing crops most sensitive to fungal diseases during seasons with low rainfall or even dry seasons; growing crops resistant to diseases and plant pests during seasons with heavy rain • Growing crops such as cowpeas, pigeon peas, and groundnuts in some areas to supplement the protein-leguminous plants whose production is in continuous reduction • Encouraging planting of soybeans and sunflowers as well as market gardening, all of which are becoming more significant • Conserving genetic resources (for example, saving ears or dry seeds in attics or repetitive transplanting or propagation by cuttings) for some drought-tolerant crops
RWANDA	• Promotion of non rain-fed agriculture • Increased use of modern agricultural techniques • Cultivation of drought-tolerant crops in arid and semiarid zones • Introduction of precocious (early-maturing) varieties in arid and semiarid zones • Promotion of value addition and other postharvest techniques for agricultural products • Reinforcing early-warning and rapid intervention systems
TANZANIA	• Improving small-scale irrigation • Increasing research and development for drought-tolerant seed varieties • Increasing agricultural extension activities • Diversifying agriculture by growing different types of crops on different land units • Adopting water-harvesting techniques • Using terracing, contour farming and manure
UGANDA	• New crop and livestock husbandry practices (for example, manipulating livestock grazing and watering to cope with feed and water scarcity and high temperatures, or shifting farming and staggering cropping calendars) • Promotion of the use of underused food resources such as yams, honey, and wild fruits • Promotion of intensive agriculture and productivity to prevent farmers from encroaching on forests and protected areas • Promotion of indigenous knowledge of food use (for example, sun drying, using herbal plants and ashes to store food, and using honey to preserve meat and smoking meat) • Development and promotion of drought-tolerant and early-maturing crop species • Bush-burning by pastoralists to improve pastures and by hunters to trap wildlife

Source: (Nzuma et al 2010)

2.8. Theoretical framework

This research is grounded on the following theories respective to its objectives.

The foremost model and tests used to assess the impacts of climate change on yields of major food crops in Rwanda was regression model. In this model change in crop yield ($\Delta \ln Y$), with current and lagged (past) values was regressed on explanatory variables with lagged values also (Damodar N. Gujarati 2004). A number of scholars, (Blanc 2012 and Ayinde et al 2013), estimated the impact of climate change on crop yield in Sub-Saharan Africa (SSA) and Niger respectively. Findings from (Blanc 2012) substantiated that area harvested for millet, maize, sorghum and cassava had a negative and significant effect on crop yields, change in temperate found to have a negative and significant effect on crop yields except for cassava yield. In addition, change in annual temperature found to have a positive and significant impact on millet, maize and sorghum. Results by (Ayinde et al 2013) revealed that humidity had a negative and significant effect on rice production while minimum temperature had a positive and significant effect on rice production. Maximum temperature and rainfall were not significant in explaining the effects of climate change on rice production.

Other scholars (Deressa et al 2008), (Apata 2011) and (Ndambiri et al 2013) analyzed farmers' perceptions of and adaptation to climate change using Heckman Probit selection model composed by two models: selection (perception) and outcome (adaptation) models indicating the two-step procedures of analyzing farmers' perceptions and adaptation to climate change at once. For the selection model the dependent variable used was a binary variable concerned with whether or not a farmer perceived climate change while outcome model used a dummy variable indicating whether or not farmers have adapted to climate change. A study by (Deressa et al 2008) in the Nile Basin of Ethiopia, results revealed that age, farm income, information on climate change, farmer to farmer extension, number of relatives in 'Gote' and local agro ecology 'Dega' influenced farmers' perception of climate change. Other variables such as education of the head of the household, household size, and gender of the head of the household being male, livestock ownership, extension on crop and livestock production, availability of credit and temperature found to have a positive and significant influence on adaptation to climate change (Deressa et al 2008).

A study conducted by (Ndambiri et al 2013) in Kyuso District, Kenya showed that age of the household head, gender, education, farming experience, household size, access to irrigation water, distance to the nearest market, local agro-ecology, access to information on climate change, access to extension services and off farm income influenced the possibility of a farmer to perceive climate change and those from outcome model indicated that age of the household head, education, farming experience, household size, distance to the nearest market, local agro-ecology, farm income, access to information on climate change, access to credit and changes in temperature and precipitation influenced the possibility of a farmer to adapt to climate change

In Southwest Nigeria, (Apata 2011) used the Heckman's probit selection and outcome models to analyze the two-step process of farmer's perceptions and adaptation measures to climate change. In this study, the results from the selection model indicated that age of the head of the household, farm income, information on climate change, farmer-to-farmer extension, ratio of number of consumers to number of labors in the farm household and agro-ecological settings affected the perception of climate change. In the outcome model, variables that positively and significantly influence adaptation to climate change include education of the head of the household, household size, gender of the head of the household being male, livestock ownership, extension for crop and livestock production, availability of credit, and temperature. On the other hand, farm size and annual average precipitation are negatively related.

To analyze or determine the factors that influenced the choice of climate change adaptation measures by smallholder farmers, some scholars used multinomial logistic regression model. The dependent variable used in the empirical estimation was the choice of an adaptation option from the set of actual adaptation measures reported by farmers while he explanatory variables included socio-economic characteristics of the household, institutional factors and agro-ecological characteristics. For instance, (Shongwe et al 2014) used this model to analyze factors influencing the choice of climate change adaptation strategies by households in Swaziland: A

Case of Mpolonjeni Area Development Programme (ADP). The results indicated that occupation of the household head, social group membership, access to credit and high input prices significantly influenced the choice of adapting to climate change using all strategies (drought tolerant varieties, conservation agriculture, shifting planting time and irrigation).

2.9. Conceptual framework

As mentioned in the previous sections, there is a lot of concern about the GHGs emissions from human activities into the atmosphere which cause changes in temperature and precipitation. An extended period of one of these climate variables results into lower and more rainfall respectively. The distribution of lower and more rainfall across the country result in extreme weather events that always pose serious damages on agriculture. These impacts can be addressed by effective adaptation measures at community and institutional levels in order to achieve good outcomes; otherwise it will lead to poor national development. The following conceptual framework provides further understanding on climate change impacts and the effective actions that could be undertaken to reduce the vulnerability.

Conceptual framework

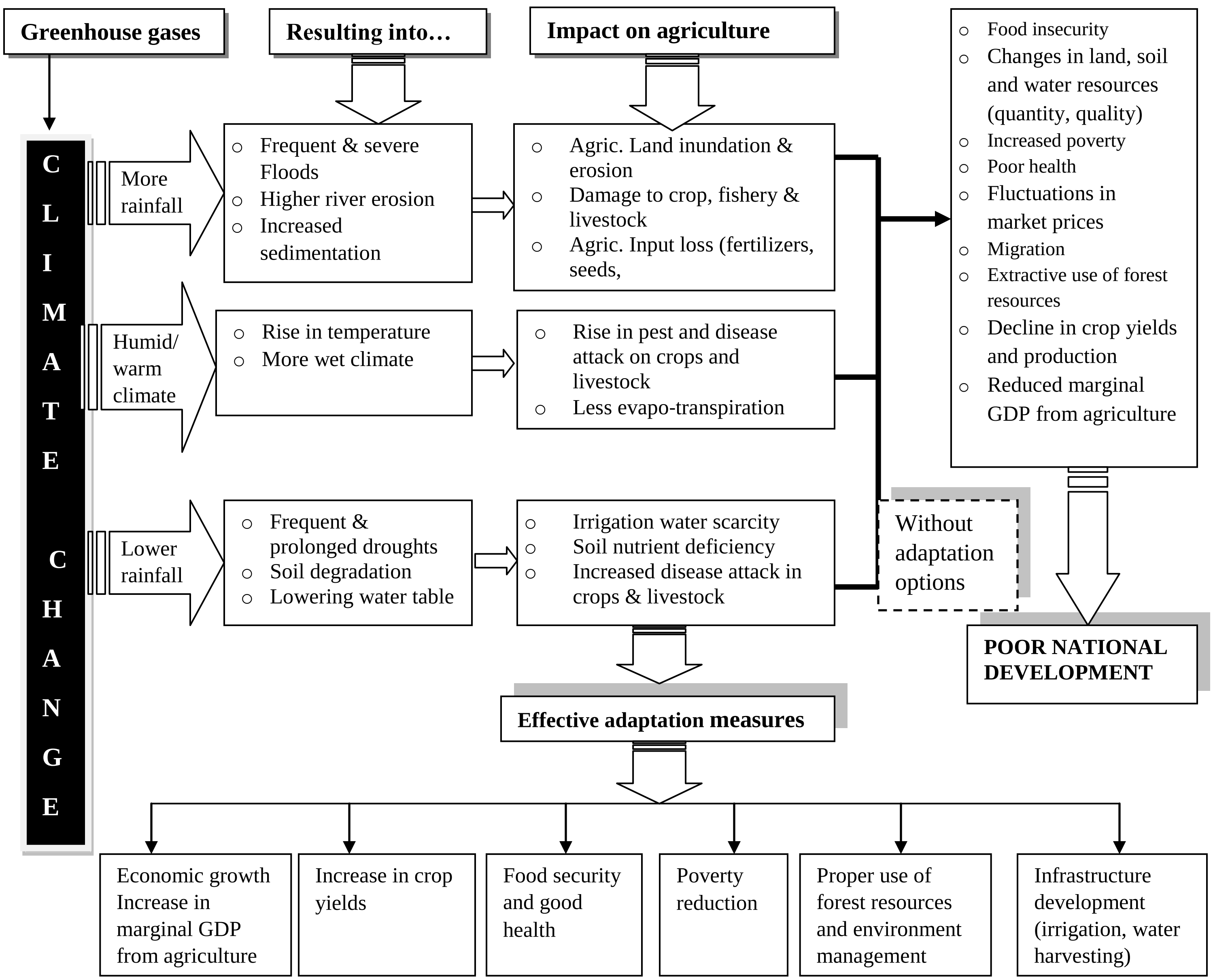


Figure 1: Climate change impacts on agriculture sector and adaptation measures

Source: Adapted from (REMA 2011)

3. METHODOLOGY

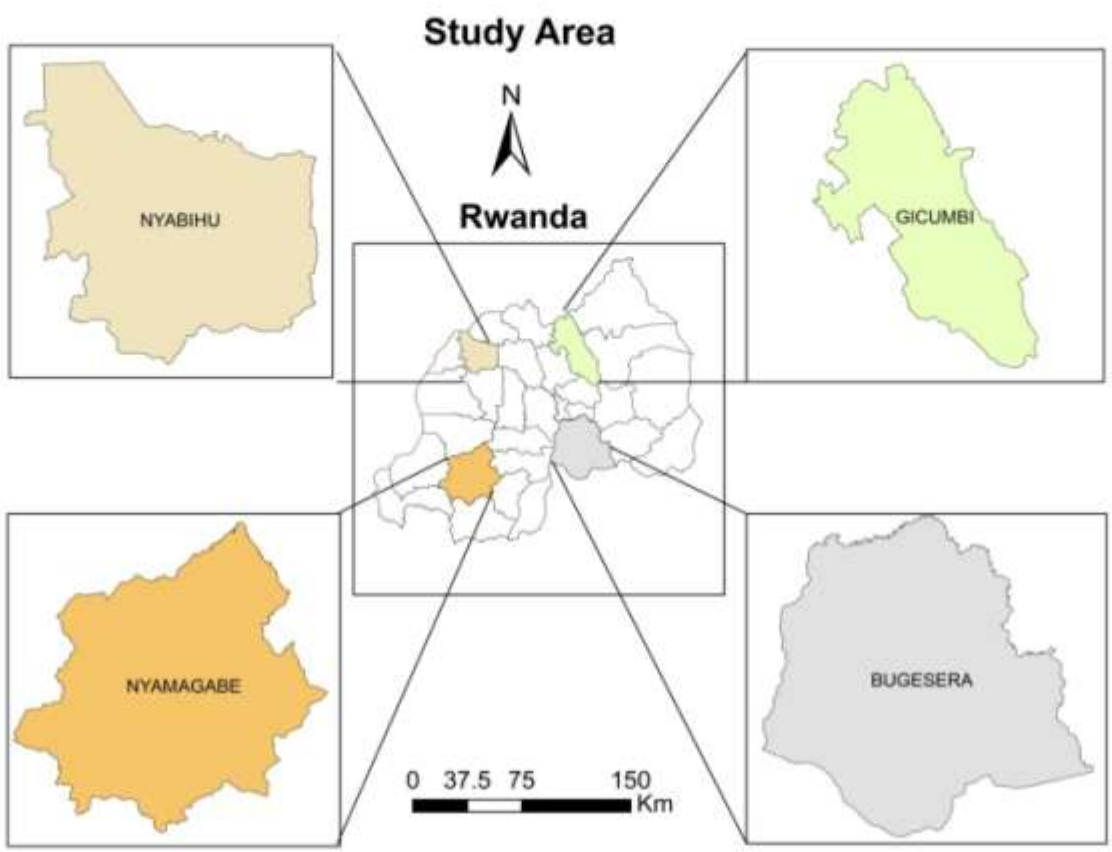
3.1. Description of the study area

Rwanda is a small landlocked mountainous country located 2° south of the equator in central Africa bordered by Uganda, Tanzania, Burundi and the Democratic Republic of Congo. Rwanda covers a total surface area of 26,338 km^2 with resident population projected to 11,262,564 in 2013/14 (NISR, 2015). Rwanda has four provinces excluding Kigali city and thirty districts. It is also one of the most densely populated countries in Africa as its current population density stands at 445 people per square kilometer (NISR, 2015). Rwanda comprises four types of climate namely; temperate (West), dry (East), tropical (North) and humid tropical (South).

The Rwandan topography is hilly and mountainous with an average altitude of 1,700 meters. The highest point, on Mount Karisimbi, is 4,507 meters above sea level. Rwanda has volcanic mountains at the northern fringe and the western province extends over an unstable mountainous area while the central plateau is dominated by undulating hills (MIDIMAR, 2015). The average altitude ranges from 900 meters in the South-East of the country to 4,500 meters in the regions of the North-West. The average altitude in the central plateau where Kigali is located lies between 1500 and 2000 meters while in the Eastern plateau towards the border with Tanzania, it is less than 1500 meters. More than 40% of the area is located at elevations of between 1,500-1,800 mm. The average temperature for Rwanda is around 20°C, The warmest annual average temperatures are found in the Eastern province (>21°C) and Bugarama Valley (20-21°C), and cooler temperatures in higher elevations of the central plateau (17.5-19°C) and highlands temperature is less than 17°C (REMA, 2013). Annual temperature increases from the West to the East. The annual rainfall goes high in the Northern Western and Western side of the country. Annual rainfall varies across the country, with the highest totals in Western Rwanda (>1600mm) and then diminishing towards the East (<900mm). The study was carried out in 4 districts out of 30 districts of Rwanda. A number of criteria were considered to choose the districts in which the household survey must be conducted. The leading criteria include:

(a) High rate of vulnerability to climate change and variability
(b) High proportion of smallholder farmers residing in critical agro-ecological zones where climate is high varying and unpredictable
(c) Past experience in terms of climate change disasters such as prolonged droughts and frequent floods
(d) Existence of hydrological network (rivers, swamps and basins)

Selection of the districts, in different provinces, was done purposively following the listed criteria above. It is in this context that Nyabihu district in the Western province, Nyamagabe in the Southern, Gicumbi in the Northern and Bugesera in the Eastern province were chosen (see Map 1).



Source: Own mapping
Map 1: Selected districts for the study

Bugesera is a lowland district comprising one the districts located in Eastern province. Due to its topography Bugesera has experienced prolonged period of droughts many years ago. The average temperature ranges between 26 and 29 °C. Because of low population density, the average of arable land per household of 0.88 ha is too high compared to other districts. Most of the farmers residing in this district claim for being affected by droughts at high extent due to lower rainfall and shortage of water for irrigation (NISR 2011). Gicumbi district is characterized by mountains with altitude of between 1,200-1,500mm. The average temperature is between 15 and 16°C. The district is more vulnerable to landslides and soil erosion a result of its topography. Therefore, the government and other international organizations have established projects that facilitate farmers to protect the soil against landslides and soil erosion. The total land protected against soil erosion is 89.8% of the district land while land irrigated is still accounts for 1% of the total land (NISR 2012a).

Nyabihu is one of the coldest districts in Rwanda because of its temperate climate. It is located in Western province where the altitude ranges between 2000 and 2850 m. The fact that it is surrounded by mountains and some volcanoes, Nyabihu district experiences devastating floods which undermine crop production at lowland. Despite the fertile soil types (sandy, clay, laterite and volcanic) found in this district, crop production continue to decrease due to the fact that farmers do not irrigated their lowland plots (NISR 2012b) and (GoR 2013a). This pushes farmers to cultivate on high risky areas more susceptible to landslides and soil erosion. Nyamagabe district, closer to the national park of Nyungwe, has a humid tropical with acidic soil which not rich in soil nutrients. This type of soil results in low crop production and affects many farmers who depend on agriculture for their livelihoods. According to the district profile and district development reports (NISR 2012c) and (GoR 2013b), Nyamagabe district is ranked last (worst) with 73% of its population identified as poor (including extremely poor) countrywide. Due to high rate of poverty, small scale farmers from Nyamagabe district have received more government interventions including soil and water conservation (SWC) measures that have been implemented in order to prevent or reduce the effects of soil erosion, water loss and run-off, to maintain the quality of soil and to increase crop production (Bizoza and Byishimo, 2013). As a result of SWC measures the land protected against erosion has been expanded up to 91. 3% of the total cultivated land. But still the percentage of households owning land less than 0.3 ha is too low compared to other district under this study. Further useful information describing the case study is presented in Table 9 and 10 below.

Table 9: Demographic and environmental characteristics

	Nyabihu	**Nyamagabe**	**Gicumbi**	**Bugesera**
Population	295,580 inhabitants	330,000	572,000.	391,000
Location (Province)	Western	Southern	Northern	Eastern
Total number of HH	68, 000	71, 000	113, 000	80, 000
Altitude	2000- 2850m	1800-2700 m	1,500-1,800 m	1,100-1,780m
Average Temperature	15°C or less	18°C	15-16°C	26-29°C
Main soil type	Sandy and clay, laterite and volcanic.	Generally acidic (pH ranging from 3.6 - 5)	Lateritic soils and granites	Generally sandy
Climate	Temperate	Humid tropical	Tropical	Dry
Rainfall	Close to 1400 mm per year	1300-1450 mm	1,200-1,500mm	800-1600 mm

Source: NISR (2012): EICV3 District profile reports

Table 10: Land characteristics and poverty indicators

	Nyabihu	**Nyamagabe**	**Gicumbi**	**Bugesera**
Land characteristics				
Total cultivated land area (ha)	30,000	36,000	54,000	68,000
Average arable land (ha per HH)	0.46	0.51	0.49	0.88
% HHs with < 0.3 Ha	49.9	57.6	44.4	30.3
Land protected against soil erosion (%)	94.1	91.3	89.8	76.4
Land irrigated (%)	0.0	2.9	1.0	3.7
Poverty indicators				
Non-poor (%)	71.4	26.7	50.7	52
Poor (%)	28.6**	73**	15.4	20
Extreme-poor (%)			33.9	28

Source: NISR (2012): EICV3 District profile reports **: poor including extremely poor people.

3.2. Analytical framework

The analytical framework for assessing the impacts of climate change and variability on yields of major food crops, evaluating the farmer's perception on climate change and variability and determining the factors that influence choice of adaptation measures by smallholder farmers in Rwanda was formulated following the objective of the study. Table 11 provides a summary of analytical methods (models) used for each objective, types of data required for specific variables (dependent and independent variables) employed in the data analysis and suitable analytical software for each model. Three models used to address objective 1, 2 and 3 included regression model, heckman probit selection and outcome models and multinomial logistic regression model respectively.

Table 11: Analytical framework

Objectives	Type of data and data requirements	Analytical models, tests	Analytical software
To assess the potential impacts of climate change and variability on yields of major food crops in Rwanda	*Dependent variable:* Change in annual crops yield *Independent variables:* Changes in area harvested, annual rainfall, maximum and minimum temperature Type of data: Time series (1970-2015)	Regression model	EViews and STATA
To evaluate the factors that influence farmer's perceptions of climate change and variability in Rwanda	*Dependent variable (Dummy variable):* Whether or not a farmer perceived climate change. *Explanatory variables:* Education, farming experience, gender, crop income, livestock income, off-farm income, access to agricultural credit, access to water for irrigation, livestock ownership, household size, farm size, market access, distance to the nearest market, age, access to climate information, local agro-ecology Type of data: Cross sectional data	Heckman probit selection and outcome models	STATA
To determine the factors that influence choice of adaptation measures by smallholder farmers in Nyabihu, Nyamagabe, Gicumbi and Bugesera districts.	*Dependent variable*: Choice of adaptation option *Independent variables:* Household size, age, education, farm size, farming experience, crop income, off-farm income, gender, livestock ownership, access to extension services, to agricultural credit and to water for irrigation. Type of data: Cross sectional data	Multinomial Logistic regression Model	SPSS

3.3. Research project design

This research project employed both quantitative and qualitative research design. To address objective 1 time series quantitative data on crop yield, harvested area, amount of rainfall, maximum and minimum temperatures were used. During the survey, quantitative data were collected to compute crop production loss due to seasonal effects caused by climate variability extreme events. Objective 2 and 3 were addressed by quantitative and qualitative design. Household level data (quantitative and qualitative) were employed to evaluate the factors that influence farmer's perception of climate change and variability and to determine the factors that influence farmers' choice of adaptation measures in the sampled districts.

3.4. Data collection methods and procedures

This study employed two types of data. Time series data (secondary data) included data on crop production, area harvested and climate variables (rainfall and temperatures) over the past 45 years (1970-2015). Cross sectional data (household level data) were collected during the survey using a structure questionnaire. Both primary and secondary data were collected and used to provide in-depth analysis of climate change impacts on crop yield, perceptions of and adaptation measures to climate change and variability. In this study a number of data collection tools including household survey questionnaire, key informants interviews (KIIs) and focus group discussions (FGDs). During the household survey, about 350 household heads were selected randomly and interviewed accordingly in sampled districts.

3.4.1. Sampling procedures and sample size

Sampling procedure followed two important steps. The first step was a purposive selection of Districts based on the criteria mentioned in the first sub-section of this section. The districts sampled for this purpose included Bugesera, Gicumbi, Nyabihu and Nyamagabe. Secondly, a stratified sampling of respondents following the three sub-steps has been made: (1) mapping of all areas with greater likelihood of being affected by extreme weather events (in consultation with district staff in charge of land survey and agriculture), (2) a participatory GIS approach used to map, within the selected districts, sectors and cells mostly affected by the recent extreme weather events (See appendix 4), and (3) In the third step was to sample areas for FGDs and household interviews.

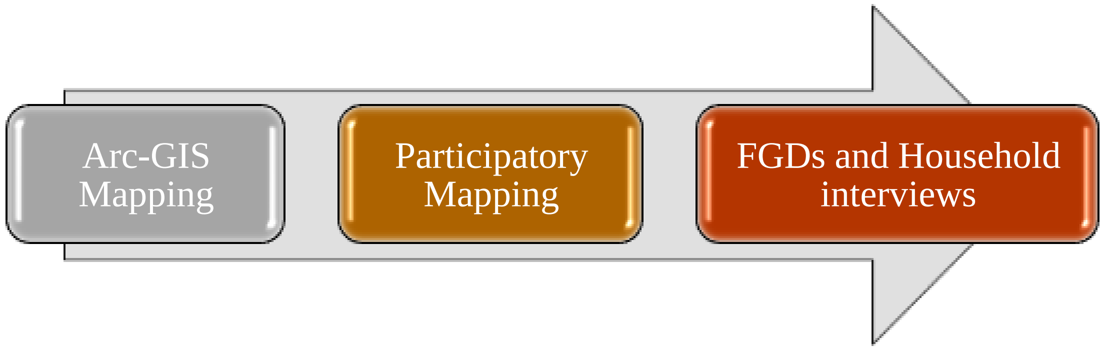


Figure 2: Sampling steps

A sample size for the study was 350 households. Subsequently, the simple random sampling process used to select one or two sectors depending on the incidence rate of extreme weather events in each district. From each sector, only vulnerable and exposed cell was chosen in order to gain information on the past and current impacts caused by climate change. Thereafter, two villages from each of one cell were selected in a random manner for household interview and FGDs. In each village, a total of 22 households were randomly selected and surveyed in consultation with village leaders. This means that a number of 44 and 88 household heads were interviewed in each sector and district respectively.

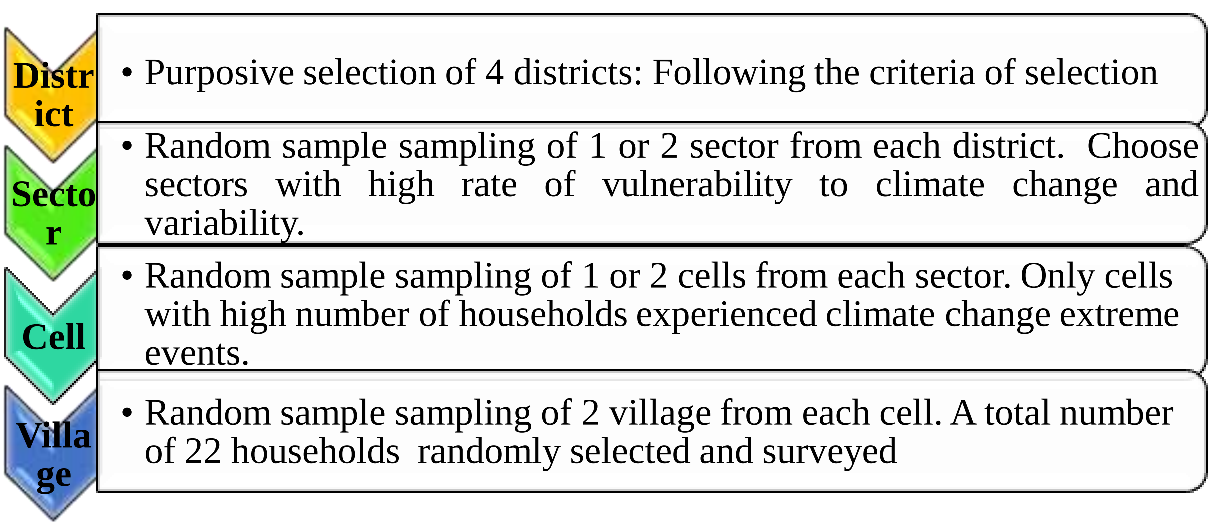


Figure 3: Sampling frame of the household survey

3.4.2. Secondary data collection

A set of secondary data on crop yield and area harvested were collected from the Ministry of Agricultural and Animal Resources (MINAGRI) and Food and Agriculture Organization Statistics (FAOSTAT) whereas climate variables (rainfall and temperatures) data from Rwanda Meteorological Agency (RMA). Data were used to present trend analysis showing the overtime variation in crop yield and weather variables. The flow of secondary data analysis was in line with reports, published papers, government policies and programmes which provide more details on the impacts of climate change and variability in Rwanda.

3.4.3. Primary data collection

Primary data were collected at household level by competent and experienced enumerators. Three main data collection tools were used: household survey questionnaire, KIIs and FGDs.

3.4.3.1. Household survey questionnaire

A household survey questionnaire was used as the main data collection tool to provide information that address objective 2 and 3 of the study. A total number of 350 questionnaires were administered to smallholder farmers residing in sampled districts. During the survey the interviewee was a household head or his partner. The key sections of the questionnaire were as follows: socio-economic characteristics of the household head, institution factors, land characteristics and crop production, perceptions of climate change and variability and adaptation measures that are more likely to be chosen by smallholder farmers.

3.4.3.2. Key informants Interviews

Much focus was on staff in charge of agriculture development and environment management, climate change specialists and data officers. Key personnel from MINAGRI, Ministry of Natural Resource and Environment (MINIRENA), Ministry of Disaster Management and Refugees Affairs (MIDIMAR), Rwanda Agriculture Board (RAB), Rwanda Environment Management Authority (REMA), RMA and one personnel from International Center for Tropical Agriculture (CIAT) Rwanda in charge of climate services for agriculture were consulted in order to gain more understanding on the impacts of climate change on agriculture.

3.4.3.3. Focus Group Discussions

FGDs were organized at community level. A group of smallholder farmers of between 8 to 10 with 18 years and above (men and women) were selected randomly to discuss on the existing and persistent impacts of climate change on crop yield, their perceptions on climate change and variability and actual adaptation measures used as response to cope with the impacts caused extreme weather events. With the help of village leaders, a sample of farmers able to answer the questions listed in the FGDs check list were identified. These FGDs included both men and women farmers, aged and young farmers. During the field survey 8 FGDs were conducted in 15 villages selected for the study. An appropriate protocol (check list) comprising questions to ask during FGDs and KIIs was employed to explore the views and opinions of experts and smallholder farmers on the impacts of climate change and variability. A number of questions on land characteristics, crop production, farmer's perceptions and adaptation measures on climate change and variability were asked in order to supplement to the household level data.

3.5. Data entry, cleaning and analysis

After data collection, EpiData 3.1 was used to design a data entry form for a household questionnaire. Household level data were entered and compiled in one file comprising all sections of the questionnaire. Data cleaning followed to ensure the removal of all mistakes and errors in order to have a clear data set ready to be used in the analysis. The cleaned data set were exported first to Microsoft Excel and from MS Excel to the statistical packages STATA, SPSS and EViews to come up with graphs and tables indicating the results to discuss on. The study employed 3 types of analysis: trend, descriptive and econometric analysis for both primary and secondary data.

3.6. Methods and models of analysis

3.6.1. Descriptive analysis

The descriptive statistics are presented in tables to describe the central tendency (mean, standard deviation, minimum and maximum) of the key variables under the study. To assess the impact of climate change on yield of major food crop (for the first objective), weather and non-weather variables described were crop yield, area harvested, annual rainfall, maximum and minimum temperatures (time series data). For the second objective, the descriptive statistics for a dummy variable indicating whether farmers perceived changes in climate or not were also presented and the third objective a key variable was the choice of adaptation measures with binary outcomes (whether farmers adapted to climate change and variability or not). Summary statistics of socio-economic variables, land characteristics and crop production under the threats of climate variability were also presented in the next chapter.

In addition, cross tabulations between sampled districts and socio-economic characteristics, farm characteristics and crop production, farmers' perceptions and actual adaptation measures was used to indicate the distribution of variables constituting these sections throughout the sampled districts.

3.6.2. Econometric analysis

Empirical models and methods were in line with the objectives of the study and addressed the hypotheses to be tested. This study employed three different econometric models respective to its objectives. A regression model (with lagged values) used to assess the impacts of climate change on yields of major food crops in Rwanda, Heckman's probit selection model to evaluate farmers' perceptions of climate change in the first step and then farmers' adaptations to climate change in the second step in the sampled districts and Multinomial Logistic regression model to determine the factors that influence choice of adaptation measures by smallholder farmers in the sampled districts. The fact that time series data were used to assess the impacts of climate change on crop yield in Rwanda, some preliminary tests such as ADF Unit root test for stationarity verification and Co-integration test were used as followed by other scholars like Blanc (2012) and Ayinde et al (2014) who used Co-integration test to check for relationship between crop yield and climate variables.

Regression model specification

In this study, regression analysis involves time series data comprising regression models that include lagged (past) values of the dependent variable and the explanatory variables. These models are called "autoregressive and distributed lag models."

- An autoregressive model is written as follows: $Y_t = \alpha + \beta X_t + \lambda Y_{t-1} + \mu_t$
- Whereas a distributed lag model is $Y_t = \alpha + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + ... + \beta_n X_{t-n} + \mu_t$

As the data series used in this study include the current and the past (lagged) values of both dependent and explanatory variables, there is need for calculating the changes (Δ) in dependent and explanatory variables over the period covered by the study and then regress them accordingly. Before running a regression model, changes in each variable were calculated by taking the difference between current values (at time *t*) and lagged values (at time *t-1*) (*see equations below*). Yield and area harvested data are used in their logarithmic form to provide convenient economic interpretations (elasticities) and to reduce the effects of outliers. Weather variables are not *ln*-transformed to allow the determination of the impact of a 1^{o}C increase in temperature and a 10 mm increase in rainfall.

$$\Delta \ln Y_{it} = \ln Y_t - \ln Y_{t-1}$$

Where: $\Delta \ln Y_{it}$ is the difference (change) between the current yield of crop i at time t and the lagged (past) yield of crop i at one period after (t-1).

$$\Delta \ln A_{it} = \ln A_t - \ln A_{t-1}$$

Where: $\Delta \ln A_{it}$ is the difference (change) between the current area harvested of crop i at time t and the lagged (past) area harvested of crop i at one period after (t-1).

$$\Delta R_{it} = R_t - R_{t-1}$$

Where: ΔR_{it} is the difference (change) between the current amount of annual rainfall in crop i areas at time t and the lagged (past) amount of annual rainfall in crop *i* areas at one period after (t-1).

$$\Delta MaxT_{it} = MaxT_t - MaxT_{t-1}$$

Where: $\Delta MaxT_{it}$ is the difference (change) between maximum temperatures in crop i areas at time t and the lagged (past) maximum temperatures in crop *i* areas at one period after (t-1).

$$\Delta MinT_{it} = MinT_t - MinT_{t-1}$$

Where: $\Delta MaxT_{it}$ is the difference (change) between minimum temperatures in crop i areas at time t and the lagged (past) minimum temperatures in crop *i* areas at one period after (t-1).

Thus, regression model is specified as follows:

$$\Delta \ln Y_{it} = \alpha + \beta_0 \Delta \ln A_{it} + \beta_1 \Delta R_{it} + \beta_2 \Delta MaxT_{it} + \beta_3 \Delta MinT_{it} + \mu_{it}$$

Where:

ΔY_{it}	: Change in crop *i* yield (tonnes/ha) at time *t*
ΔA_{it}	: Change in crop *i* Area harvested in hectares at time *t*
$\Delta MaxT_{it}$	: Change in maximum temperature (^oC) in areas of crop *i* at time *t*
$\Delta MinT_{it}$	: Change in minimum temperature (^oC) in areas of crop *i* at time *t*
ΔR_{it}	: Change in annual rainfall (mm) in areas of crop *i* at time *t*
α	: Intercept coefficient
β_0, β_1, β_2 and β_3	: Slope coefficient
t	: Period in years
μ	: Error term

For each crop, *the a priori* expectation is that yields of crops under the study need specific factors to change, such as changes in climate variables (rainfall and temperature) and changes in area harvested.

Table 12: A priori expectations of climate and non-climate variables impacts on yields of major food crops

Symbol	Variable Description	*A priori* expectations between the dependent variable and each independent variable	Expected sign
Explanatory variables			
ΔA_{it}	Change in area harvested	An increase in area harvested per crop reflects an increase in yield	+
$\Delta MaxT_{it}$	Change in maximum temperature	An increase in annual maximum temperature results in a decrease in crop yield	-
$\Delta MinT_{it}$	Change in minimum temperature	An increase in annual minimum temperature results in an increase or a decrease in crop yield	±
ΔR_{it}	Annual rainfall	An increase in annual rainfall result in an increase or a decrease in crop yield	±

To assess the factors that influence farmers' perceptions of climate change and variability in Rwanda, Heckman probit selection model was used. Farmers' perception as a dependent variable was a dummy variable to indicate whether a farmer has perceived climate change or not. To better understand the factors that determine farmers' perception of climate change and variability, the dependent variable regressed on a set of explanatory variables such as age of the household head, gender, education, farming experience, access to information on climate change, access to extension services and local agro-ecology.

According to Ndambiri et al. (2013), the algebraic representation of the Heckman's probit selection model was given as:

$$M_i = (\alpha X_i) + \varepsilon$$

Where:

M_i: the perception by the i^{th} farmer that climate is changing,

X_i: the vector of explanatory variables of probability of perceiving climate change by the i^{th} farmer,

α: the vector of the parameter estimates of the regressors hypothesized to influence the probability of farmer is perception about climate change and ε the error term.

Consequently, the linear specification of the Heckman's probit selection model was given as:

$$M_i = \alpha_0 + \alpha_1 Age + \alpha_2 Gender + \alpha_3 Education + \alpha_4 FarmExperience + \alpha_5 AccesstoInfo \\ + \alpha_6 Extensionserv + \alpha_7 localagroe + \varepsilon$$

The model specification of the Heckman's probit outcome model was given as:

$$T_i = (\phi X_i) + \varepsilon$$

Where:

T_i: the adaptation by the i^{th} farmer to climate change.

X_i: the vector of explanatory variables of probability of adapting to climate change by the i^{th} farmer.

Φ: the vector of the parameter estimates of explanatory variables hypothesized to influence the probability of farmer is adaptation to climate change.

Therefore, the linear specification of the Heckman's probit outcome model was given as:

$$T_i = \phi_0 + \phi_1 Education + \phi_2 FarmExp + \phi_3 Gender + \phi_4 CropInc + \phi_5 LivstInc + \phi_6 Off - incom \\ + \phi_7 Accesscrdt + \phi_8 Irrig + \phi_9 Livstown + \phi_{10} HHsize + \phi_{11} Farmsize + \phi_{12} Market + \phi_{13} DistMarkt + \varepsilon$$

Table 13: A priori expectations of factors that influence farmer's perception of climate change and variability

Variables	Variable measurement	Expected effect
Dependent variable		
Perception of climate change	Binary outcomes: 1 if perceived and 0 otherwise	
Independent variable		
Age of the household head	Continuous, age of the household head in years	±
Gender of the household Head	Dummy variable which takes the value of 1 if male and 0 otherwise	-
Education attained by the head of the household	Continuous, number of years of formal education of the household head	+
Farming experience	Continuous, number of years of farming experience of the household head	+
Access to climate information	1 if household head get information about weather or climate from extension officer or any media and 0 otherwise	+
Access to extension services	Dummy, equals 1 if the household head had access and 0 if otherwise	+
Local agro-ecology (highland or lowland)	Dummy, equals 1 if highland and 0 if otherwise	±

To analyze the determinants of smallholder farmer's choice of adaptation measures to climate variability in sampled districts the study employed Multinomial Logistic regression model (MNL). According to different scholars such as (Hassan and Nhemachena, 2008), (Magombo et al 2011) and (Shongwe et al 2014), MNL model for choice of adaptation strategies specifies the relationship between the probability of choosing an adaptation option and the set of explanatory variables.

The dependent variable in the empirical estimation was the choice of an existing adaptation option. The actual adaptation measures reported by farmers were: increase irrigation, use of drought resistant crop, use of different varieties, agro-forestry, soil and water conservation and planting time (early and late). All these actual adaptation measures were regressed on a set of explanatory variables including: household size, household head age, gender, education, farming experience, farm size, crop income, off-farm income, livestock ownership, access to extension services, access to agricultural credit and access to water for irrigation. The reference category in this model was no adaptation option.

Table 14: Expected signs on how the explanatory variables will influence adaptation to climate change

Explanatory variable	**Definition**	**Measure**	**Expected sign**
Socio-economic			
HH_ EDU	Education of household head	Continuous	+
HH_ Gender	Gender of household head	Dummy, takes the value of 1 if male and 0 otherwise	±
HH_ Age	Age of household head	Continuous	±
HH_ size	Size of household	Continuous	±
EST_ crop income	Estimated crop income (USD)	Continuous	+
EST_ off-farm income	Estimated off-farm income of the household (USD)	Continuous	+
LVOWN_ Livestock ownership	Livestock ownership by household	Dummy, takes the value of 1 if male and 0 otherwise	±
Land and agriculture characteristics			
F_ size	Farm size in Square meter (m^2)	Continuous	+
Farm_ Exp	Farming experience	Continuous	
Institutional characteristics			
Ext_ Services	Access to Extension services	Dummy, takes the value of 1 if male and 0 otherwise	+
Access_ Agric. credit	Access to agricultural credit	Dummy, takes the value of 1 if male and 0 otherwise	+
Access_ Irrig _Water	Access to water for irrigation	Dummy, takes the value of 1 if male and 0 otherwise	+

4. RESULTS AND DISCUSSIONS

This chapter provides results of key variables of the study on the subject of agriculture and climate variability in Rwanda. The aim of the chapter is to provide more details on each section herein. The chapter has sub-sections such as demographic and socio-economic characteristics of the sampled farming households, livestock production, farms characteristics and level of food crop production of smallholder farmers although the cultivation of these crops is under threat by climate variability events (usually floods and prolonged drought), micro and macro levels impacts of climate change on major food crops in Rwanda, descriptive and econometric analysis of farmers' perceptions of and adaptation measures to climate change.

4.1. Demographic and Socio-economic characteristics of the farming households

This sub-section emphasizes on demographic and socio-economic characteristics of the household that play important role in agricultural and livestock production such as gender, age, household size, marital status, education level, farming experience, employment status and household income per district.

<u>Gender of the household head</u>

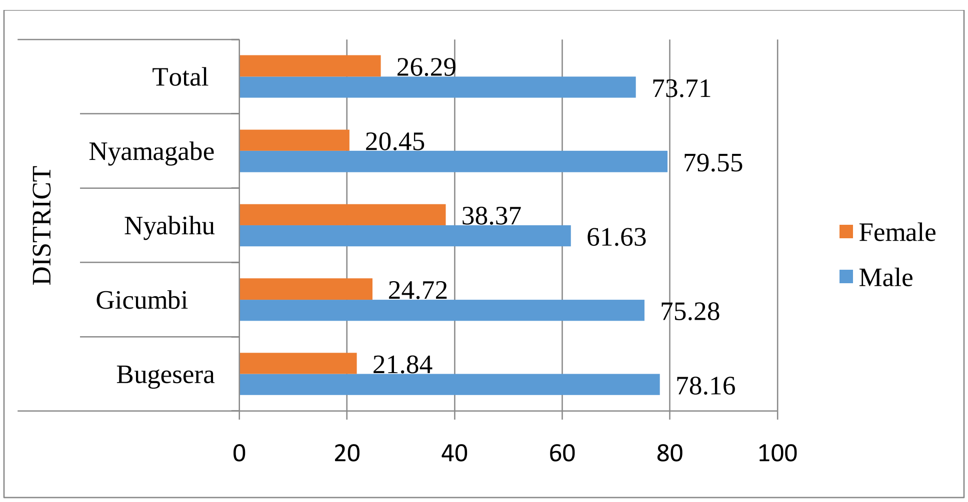


Figure 4: Gender of the household head

Figure 4 indicates the proportion of males and females interviewed during the survey. The results show that 73.71% were male while 26.29% were female in sampled districts. Gender of the household head plays a critical role in farming decision making. Some studies have shown that gender is an important variable affecting adoption decision at farm level (Nhemachena and Hassan 2008) and (Deressa et al 2009) confirmed that Male-headed households are more likely to get information about new technologies and undertake risky businesses than female-headed households. Moreover, (Tenge et al 2004) argued that having a female head of household may have negative effects on the adoption of soil and water conservation measures, because women may have limited access to information, land, and other resources due to traditional social barriers.

Age of the household head

Table 15 below shows the average age of the household head visited in sampled districts. The mean age of farmers from Bugesera district is the highest (about 48 years) while those from Nyabihu is the lowest average age (about 44 years). Overall, the average age of farmers interviewed is about 46 years and the ages lie between 23 and 84 years.

Table 15: Average age of the household head by district

Variable	Observation	Mean	Std. Dev.	Min	Max
Age_ Bugesera	87	47.7931	13.05991	26	76
Age_ Gicumbi	89	47.06742	13.82422	23	84
Age_ Nyabihu	86	43.94186	15.15439	23	84
Age_ Nyamagabe	88	45.40909	14.0325	23	80
Overall	350	46.06286	14.05195	23	84

The distribution of age of the household head is presented in Table 16. The table reveals that the highest proportion of farmers (33.43%) lies between 35 and 50 years while the lowest constituting 9.43% were over 65 years in general. At district level, the majority of farmers are between 35-50 years and 50-65 years. This means that both young (physically active) and old people involve in farming. In some studies, age of farmers has direct bearing on the availability of able-bodied manpower for agricultural production and also on the ease of adoption of climate change adaptation strategies (Adebayo et al 2012). Also (Montle and teweldemedhin 2014) showed that age of household head has influence on agricultural production. The older the farmer, the more experienced he/she is in farming and more exposure he/she has had to the past and present climatic conditions over longer periods of time (Deressa et al 2009) added that age of the household head can be used to capture farming experience. Here the authors showed a positive relationship between number of years of experience in agriculture and the adoption of improved agricultural technologies. A study by (Nhemachena and Hassan 2008)found age to have no significance in influencing the choice of an adaptation strategy to climate change.

Table 16: Age group of farmers per district

Age group	District				
	Bugesera	Gicumbi	Nyabihu	Nyamagabe	**Overall**
20-35	21.84	23.6	36.05	29.55	27.71
36-50	35.63	37.08	30.23	30.68	33.43
51-65	31.03	31.46	22.09	32.95	29.43
> 65	11.49	7.87	11.63	6.82	9.43

<u>Household size</u>

The household size has been defined as the total number of household members living in the same house and having all rights on household matters. The findings from the survey show that the average household size is 5.1 persons per household slightly larger than the national average which is 4.6 persons per household according to EICV4 (2013/14) report released by NISR. Some studies show that large household size might have positive impact in the improvement of the productivity especially if members fully participate in farming activities and those households are more likely to adapt to climate change (Mugula and Mkuna 2016). Also Gbetibouo (2009) showed that household with large size are more willing to choose soil conservation techniques as adaptation measures that are labor- intensive especially in small scale farming.

Table 17: Average household size per district

Variable	Observation	Mean	Std. Dev.	Min	Max
Bugesera	87	5.183908	1.701769	2	9
Gicumbi	89	5.146067	1.825019	1	11
Nyabihu	86	4.883721	1.887536	1	9
Nyamagabe	88	5.306818	2.26598	1	11
Overall	**350**	**5.131429**	**1.929973**	**1**	**11**

Marital status of the household head

Results indicate that 71.43% of the heads of households are married. (Tenge et al 2004) argued that this group is the most influential people and decision makers at both the village and household levels. The group of widows follows with about 22.29% of the heads of households. As the majority of household heads are married, there is advantage for these households to increase their levels of crop production and come up with efficient adaptation measures to climate change and variability than other household heads (single, divorced, separated and widowed), because they share their ideas on how to improve their main economic activity which is mainly agriculture.

Table 18: Marital status of the household head

	District				
Marital Status	Bugesera	Gicumbi	Nyabihu	Nyamagabe	Total
Single	1.15	0.00	3.49	0.00	1.14
Married	**75.86**	**71.91**	**59.3**	**78.41**	**71.43**
Divorced	2.3	1.12	0.00	0.00	0.86
Separated	1.15	4.49	5.81	5.68	4.29
Widowed	**19.54**	**22.47**	**31.4**	**15.91**	**22.29**

Education of the household heads

Table 19 below shows the average number of years in formal education of the heads of household. Overall, the results indicate that about 252 out of 350 farmers reported to attend formal education. The average number of years is approximately 6 years of primary education. As confirmed by (Deressa et al. 2009), education of the head of household increases the probability of adapting to climate change. Also (Komba and Muchapondwa 2015) have shown that farmers with more education are more likely to pursue adaptation strategies related to climate change than are farmers with lower education levels.

Table 19: Number of education years of the household head

Variable	Observation	Mean	Std. Dev.	Min	Max
Education level_ Bugesera	67	5.626866	2.917221	1	18
Education level_ Gicumbi	53	5.188679	2.434184	1	16
Education level_ Nyabihu	65	5.815385	2.567174	1	12
Education level_ Nyamagabe	67	5.134328	1.857789	1	9
Overall	252	5.452381	2.47733	1	18

Figure 5 reveals that about 28% of the household head had no formal education, about 58% attained primary education, while about 13.14% attained secondary education. Only about 0.86% attained university education. Thus, about 72% of the household heads have at least form education. According to (Adebayo et al 2012), this could have implication for agricultural production and also for adaptation to changes in the climate. Adoption of measures that could result in climate change adaptation is also easier and faster among the educated farmers than the uneducated farmers.

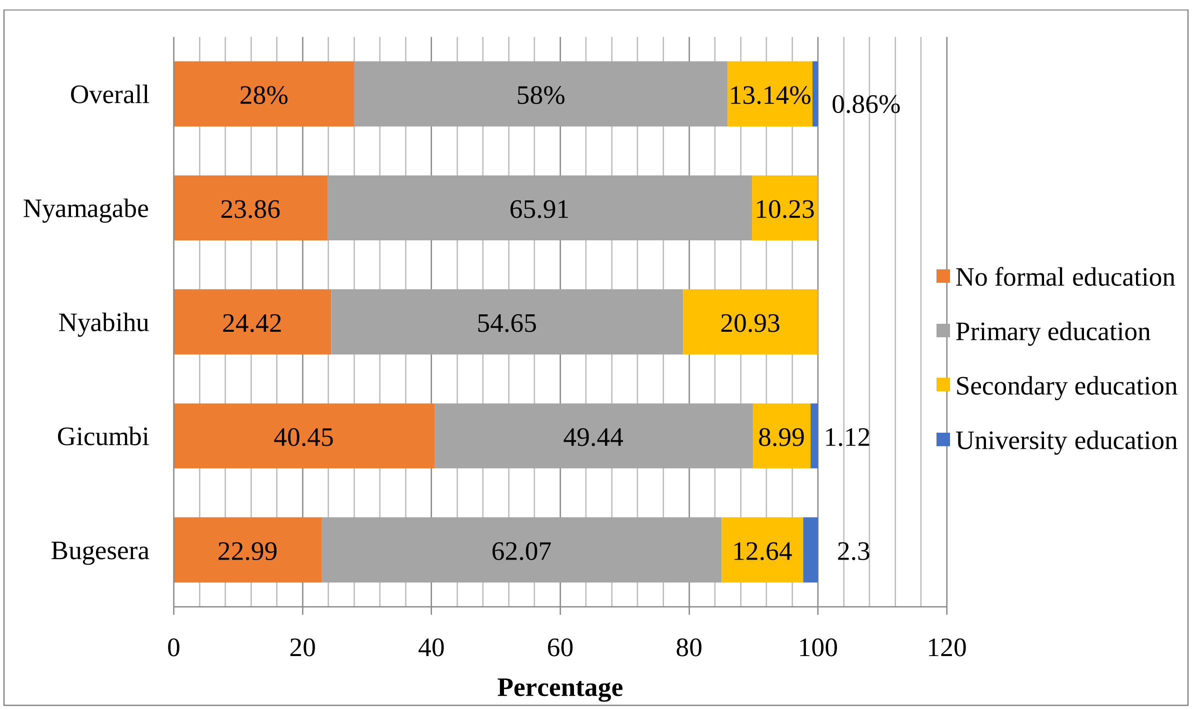


Figure 5: Education level of the household head

Employment status of the household head

(Adebayo et al. 2012) found that employment is an important factor influencing decision to adapt to climate change and off-farm jobs could increase farmers' income and could help cope with adverse change in climate. The focus of this study was on rural people who full time and part time in farming. Table 20 indicates that about 89.53% of household heads from Nyabihu district reported that they are full time in farming while about 74.71% in Bugesera district are full time. It is obviously that the proportion of full time farmers in Nyabihu is higher than other districts. This is attributed to the fact that Nyabihu farmers are more motivated to cultivate Irish potato as cash and food crop because of fertile soil (volcanic) of the area. Table 20 reveals that Gicumbi district constitutes a large proportion of part-time farmers (about 16.85%) than other districts. About 6.9% of household heads in Bugesera are formally employed. The fact that Bugesera is closer to Kigali city, some farmers (educated ones) seek permanent jobs and hire labors to cultivate their farms. The proportion of farmers (2.27%) running their small businesses to support their farming is higher in Nyamagabe district than other districts.

Table 20: Employment status of the household head per district

Employment status	**District**				
	Bugesera	Gicumbi	Nyabihu	Nyamagabe	**Overall**
Own farming	74.71	80.90	**89.53**	85.23	**82.57**
Casual labor	11.49	**16.85**	8.14	9.09	**11.43**
Own small business	1.15	0.00	0.00	**2.27**	**0.86**
Salaried work	**6.90**	2.25	0.00	1.14	**2.57**
Other	5.75	0.00	2.33	2.27	**2.57**

The figure 6 below presents the overall employment status of the household heads in sampled districts. Generally, the results indicate that about 82.57% household heads practice their own farming (full time farmers) while about 11.43% of farmers temporally employed in others farms (casual labor) and part-time in their farms. Only about 2.57% of heads of household are formally employed while 0.86% of farmers run their businesses as supplement to their main activity (agriculture). About 2.57% of household heads reported that they work off-farm employment on temporally basis like carpentry, masonry, etc.

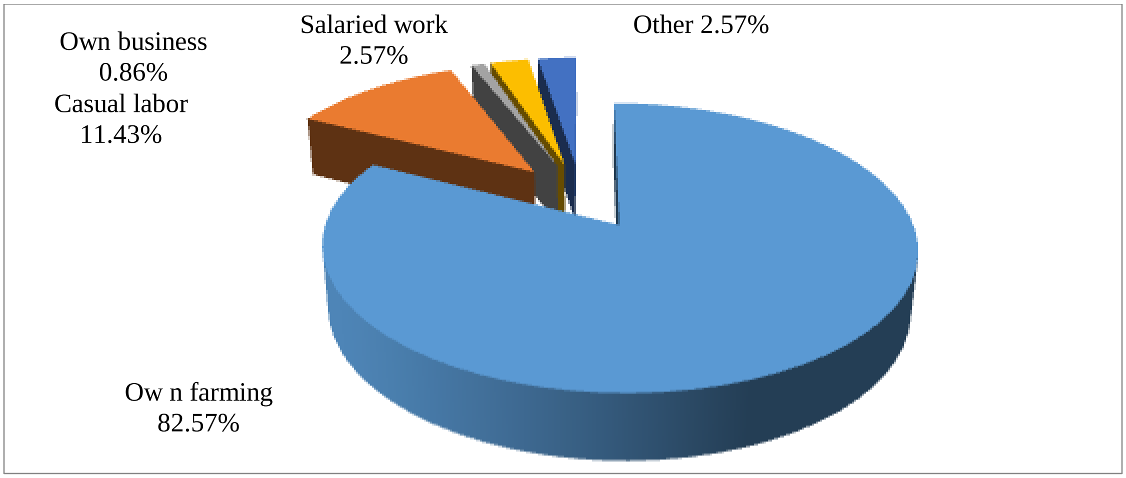


Figure 6: Overall employment status

Farming experience

(Maddison 2007) argued that educated and experienced farmers are more likely to notice climate change and more likely to respond to the climate change events using adaptation measures. Table 21 shows the average number of years in farming of farmers from sampled districts. Results indicate that Gicumbi farmers are more experienced (with about 28 years) than other districts. The farming experience of farmers is between 1 and 62 years.

Table 21: Experience of farming

Variable	Observation	Mean	Std. Dev.	Min	Max
Number of years in farming_ Bugesera	65	23.89231	13.98562	1	56
Number of years in farming_ Gicumbi	72	27.51389	13.27923	2	60
Number of years in farming_ Nyabihu	77	23.41558	14.88584	2	62
Number of years in farming_ Nyamagabe	75	24.41333	14.74842	2	62
Overall	289	24.80277	14.27869	1	62

Household income

Table 22 summarizes the average of monthly, annual on- farm and off- farm income, crop and livestock income in sampled districts. Results indicate that most of farmers earn on-farm income than off-farm income. About 310 farmers reported to earn income from both full time and part time farming, while about 122 farmers from off- farm jobs, 113 and 82 farmers earn income from selling crops and their livestock. The figures in the below table show that the maximum monthly income of Gicumbi and Bugesera farmers is too high (200,000 Rwf and 150,000 Rwf respectively) because some farmers who are formally employed. Overall, the average monthly income is 15923.43 Rwf, while annual on-farm and off-farm average income are 153026.5 Rwf and 223172.1 Rwf respectively. For crop and livestock the overall average are 39916.19 Rwf and 103097.6 Rwf.

Table 22: On- farm and Off-farm income (Rwf)[6]

	Variable	Observation	Mean	Std. Dev.	Min	Max
Bugesera	Monthly income	87	17563.22	20795.35	2000	150000
	Annual on-farm income	72	151530.6	143227.3	20000	720000
	Annual off-farm income	43	240348.8	304871.7	10000	1800000
	Crop income	36	46997.22	87149.09	1200	504000
	Livestock income	33	119766.7	160331.6	12000	912000
Gicumbi	Monthly income	89	13240.45	22488.89	2000	200000
	Annual on-farm income	82	109253.7	100066.8	12000	600000
	Annual off-farm income	21	297476.2	508912.3	15000	2400000
	Crop income	26	15898.08	16584.45	1500	70000
	Livestock income	16	69606.25	65089.58	2700	204000
Nyabihu	Monthly income	86	21393.02	15521.11	1000	66000
	Annual on-farm income	79	240243	188117	50000	792000
	Annual off-farm income	33	193454.5	137418.4	30000	600000
	Crop income	31	71799.35	76911.44	5000	340000
	Livestock income	16	128875	139409.2	10000	468000
Nyamagabe	Monthly income	88	11670.45	11053.39	1000	60000
	Annual on-farm income	77	111558.4	98606.41	12000	720000
	Annual off-farm income	25	170440	178810.9	30000	720000
	Crop income	20	8975	11041.45	1000	50000
	Livestock income	17	78000	79799.75	3000	230000
Overall	Monthly income	350	15923.43	18375.42	1000	200000
	Annual on-farm income	310	153026.5	146782.4	12000	792000
	Annual off-farm income	122	223172.1	297128.6	10000	2400000
	Crop income	113	39916.19	68134.63	1000	504000
	Livestock income	82	103097.6	128044	2700	912000

[6] Rwf: Rwandan Francs. Current exchange rate: 1 USD= 840 Rwf

In line with the above results (Table 22), farmers were asked the main source of their on-farm and off-farm income. As presented in Table 15, about 79.5% of farmers earn their income in farming activities (from sales of agricultural products and casual labor), while about 13% of farmers earn from off-farm employment. Some of the old household heads (about 4%) reported that they usually receive remittances from their children or other close relatives. Only 2.86% of farmers confirm that their main income comes from salaries and wages, while 0.86% of farmers earn income from livestock production.

Table 23: Source of income

	District				
Main source of Income	**Bugesera**	**Gicumbi**	**Nyabihu**	**Nyamagabe**	**Overall**
Farming	70.11	85.39	79.07	82.95	**79.43**
Livestock	0	2.25	1.16	0	**0.86**
Salaries and wages	9.2	1.12	0	1.14	**2.86**
Remittances	5.75	2.25	5.81	2.27	**4.00**
Off-farm income	14.94	8.99	13.95	13.64	**12.86**

4.2. Livestock production

This sub-section gives a summary of each variable that contributes to livestock production such as livestock ownership, source of livestock, number and value of livestock sold and purchased. Table 24 summarizes the average number of livestock owned by household. Results indicate that the majority of farmers own cattle, goats and poultry. The total number of farmers own cattle, goats and poultry are 132, 87 and 37 respectively. The average ownership of poultry and goats is about 3 and 2 respectively which is higher than average ownership of other livestock. The minimum ownership of all livestock is 1while the maximum ownership for pigs, goats and poultry is 10, 14 and 26 respectively. The last column of Table 24 presents ownership proportion of livestock by farmers. Out of 315 farmers reported to own livestock, about 41.9%, 27.62%, 11.75% and 10.16% own cattle, goats, poultry and pigs respectively. While only 6.98% and 1.59% own sheep and rabbits.

Table 24: Overall livestock ownership

Variable	Observation	Mean	Std. Dev.	Min	Max	**Ownership Proportion**
Number of cattle	132	1.325758	0.559392	1	4	**41.90**
Number of goats	87	2.54023	2.203615	1	14	**27.62**
Number of sheep	22	1.818182	0.795006	1	4	**6.98**
Number of pigs	32	1.53125	1.795772	1	10	**10.16**
Number of poultry	37	3.297297	4.477505	1	26	**11.75**
Number of rabbits	5	1.6	0.547723	1	2	**1.59**

In the last decade, government of Rwanda implemented socio-economic development programmes such as Girinka Program, VUP, Ubudehe, and Crop Intensification Program (CIP) to support mainly rural poor farmers to improve their livelihoods. The information in Table 25 below gives the status of livestock ownership of sampled households. Results reveal that Girinka program beneficiary are about 54 framers across sampled districts (representing 17.14% of farmers). In addition to that some proportion of farmers (about 61.9%) reported that they purchased livestock for their own. This implies that farmers are more likely to keep livestock in order to increase crop productivity through organic fertilizer application. About 10.48% of farmers acquired livestock from relief NGOs (like World Vision and Care International) while 6.67% of farmers confirmed to receive livestock from their neighbors[7]. Only 3.81% of farmers reported that they acquired livestock from other government projects other than Girinka program and civil society organizations based project.

Table 25: Source of livestock

Source of Livestock	Number of livestock owners						Proportion
	Cattle	Goats	Sheep	Pigs	Poultry	Rabbits	
Purchased	50	64	20	27	30	4	61.90
Girinka program	54						17.14
Neighbor	11	5	2	1	1	1	6.67
NGO	11	14		4	4		10.48
Other	6	4			2		3.81

[7] This is a Rwandan culture whereby a farmer with more livestock gives freely his/her neighbor who is in need to strengthen their friendship. We call it “Kugabira or kworoza” in local language

As the majority of farmers in rural depend directly or indirectly on agriculture, they do not have other source of income other than agriculture. Therefore they are more likely to sell their livestock in order to sustain their livelihood. Table 26 shows the average number of livestock sold in the past 12 months whereby, on average, farmers sold about 6 and 4 poultry and rabbits respectively. The minimum livestock sold is 1 while the maximum is 30 (for poultry).

Table 26: Average number of livestock sold

Variable	Obs.	Mean	Std. Dev.	Min	Max
Cattle	37	1.162162	0.373684	1	2
Goat	30	1.666667	1.093345	1	5
Sheep	10	1.8	1.549193	1	6
Pigs	8	1.625	1.407886	1	5
Poultry	11	6.181818	9.621	1	30
Rabbits	2	4.5	2.12132	3	6

Table 27 below summarizes the total amount spent by household by selling livestock. Results show that the high value is for cattle as its average amount is 169,000 Rwf and its maximum is 900,000 Rwf. The less minimum value is 2300 Rwf (for poultry) while the less maximum value is for rabbits (9000 Rwf).

Table 27: Average sales value (Rwf)

Variable	Observation	Mean	Std. Dev.	Min	Max
Cattle	37	169000	141831	25000	900000
Goat	30	30866.7	29494.3	8000	150000
Sheep	10	63300	116698	12000	390000
Pigs	8	43375	26864.4	7000	96000
Poultry	11	25727.3	44544.1	2300	150000
Rabbits	2	6000	4242.64	3000	9000

Despite their low household income, rural farmers purchase livestock just to improve their farming. Due to unavailability and high cost of inorganic fertilizer, most of the farmers are more likely to use organic manure to increase crop productivity. Table 28 shows that in the past 12 months about 19 farmers purchased cattle, 18, 14 and 11 farmers purchased goats, poultry and pigs respectively. Only 5 and 2 farmers reported to purchase sheep and rabbits respectively. The minimum livestock purchased is 1 while the maximum is 6.

Table 28: Number of livestock purchased

Variable	Obs.	Mean	Std. Dev.	Min	Max
Cattle	19	1.315789	1.15723	1	6
Goat	18	1.444444	0.704792	1	3
Sheep	5	1.6	0.894427	1	3
Pigs	11	1	0	1	1
Poultry	14	1.857143	0.949262	1	4
Rabbits	2	1.5	0.707107	1	2

Table 29 gives a summary of average amount (Rwf) for purchased livestock. Results indicate that the highest average purchase value is 207368.4 Rwf (for cattle) while the lowest is 1750 Rwf (for rabbits). Also maximum purchase value for cattle is too high (420,000 Rwf) compared to the maximum value of other livestock.

Table 29: Average purchase value (Rwf)

Variable	**Observation**	**Mean**	**Std. Dev.**	**Min**	**Max**
Cattle	19	207368.4	87040.35	90000	420000
Goat	18	23277.78	11145.06	6000	42000
Sheep	5	32200	21217.92	14000	60000
Pigs	11	11454.55	5483.861	5000	25000
Poultry	14	5750	3651.923	1000	15000
Rabbits	2	1750	1767.767	500	3000

4.3. Farm characteristics and crop production

This sub-section gives some information on land characteristics such as land ownership and tenure, farm size and farm location. Some studies have shown that farm characteristics hypothesized to influence adaptation to climate change (Gbetibouo, 2009). Also this sub-section presents the results on crop production vis a vis the effects of climate variability.

4.3.1. Farm characteristics

Land ownership

Table 30 below summarizes the average total land owned by farmers in sampled districts. Results indicate that the average total land owned by Bugesera farmers (about 0.79 ha) is greater than average total land owned by framers from Gicumbi, Nyabihu and Nyamagabe (as their average is 0.30 ha, 0.33 ha, and 0.12 ha respectively). The minimum total land per household is 0.0025 ha while the maximum is 3 ha. Also the results reveal that Bugesera farmers have larger land for cultivation than other sampled districts. Some of the reasons explain this include the NISR 2012 Report (EICV3) which approved that the average arable land per household in Bugesera seems to be high if we compare with the ones for sampled districts (see Table 10). Secondly, Government of Rwanda allocated 1 hectare to each household relocated to Bugesera district[8] in the past two decades as asserted by farmers during the focus group discussions.

Table 30: Land ownership (ha)

Variable	Observation	Mean	Std. Dev.	Min	Max
Total land owned_ Bugesera	87	0.794	0.7352979	0.05	3
Total land owned_ Gicumbi	89	0.3008764	0.2889719	0.0025	1.655
Total land owned_ Nyabihu	86	0.3346488	0.3865162	0.0048	1.53
Total land owned_ Nyamagabe	88	0.1288955	0.1579693	0.0035	0.81

[8] For its low risks in terms of climate change extreme events (floods and landslides) and large space not occupied by farming, the government has relocated families from high risk zones (especially those from Northern Province) and Rwandese came from neighboring countries like Uganda and Tanzania.

Land tenure

Table 31 below presents land tenure of 3 plots considered in this study. Results reveal that 471 farmers are landowners of which 359 farmers inherited the land while 112 farmers purchased land. About 117 farmers are tenants while only 9 farmers borrowed land for cultivation purpose. Due to land shortage, farmers borrow land to their relatives or neighbors but with condition that after harvesting landowner and tenant share the harvest[9], while other farmers rent out plot to increase the level of production needed to satisfy the household size.

Table 31: Land tenure

District	Plot number	Land tenure				
		Owned	Purchased	Rented out	Borrowed	Other
Bugesera	Plot 1	31	33	9	2	12
	Plot 2	8	10	12	3	3
	Plot 3	5	2	1		1
Gicumbi	Plot 1	70	14	5		
	Plot 2	35	6	6		1
	Plot 3	11	3	9		1
Nyabihu	Plot 1	60	17	7	2	
	Plot 2	25	9	13		
	Plot 3	7	3	7	1	
Nyamagabe	Plot 1	71	9	7	1	
	Plot 2	30	2	31		
	Plot 3	6	4	10		
Overall		**359**	**112**	**117**	**9**	**18**

Farm size

Table 32 summaries also the size of the cultivated land during 2015 season B (February to June). Results indicate that all farmers visited cultivated at least 1 plot while 194 farmers cultivated 2 plots and 71 farmers 3 plots. The average cultivated land for each household is 0.21 ha, 0.13 ha and 0.09 ha respective to the three plots considered in this study. According to the results, the smallest cultivated land is 0.0018 ha while the largest is 1.2 ha. Some studies found farm size to have positive influence on farmers' perception on climate variability. For instance, Ehiakpor et al

[9] During the FGDs

(2016) noted that farmers with larger farm sizes are more likely to perceive climate variability than their counterparts with smaller farm sizes.

Table 32: Farm size (ha)

Variable	Observation	Mean	Std. Dev.	Min	Max
Plot size 1	350	0.2138552	0.2507507	0.0025	1.2
Plot size 2	194	0.1362974	0.1854755	0.0018	1
Plot size 3	71	0.0909887	0.1064218	0.0032	0.6

<u>Plot location</u>

Table 33 displays where the plots cultivated were located. Results show that most of Bugesera and Nyabihu farmers (62 and 37 farmers respectively) cultivate more the lowlands which are prone to flooding with high intensive rains (during the rainy season). Contrary, Gicumbi and Nyamagabe farmers cultivate the uplands (due to topography which is mountainous) prone to landslides during the rainy season.

Table 33: Plot location

District	Plot number	Plot location				
		Upper	Middle	Lower	Valley	Marshland
Bugesera	Plot 1	16	8	**62**	1	
	Plot 2	5	2	28	1	
	Plot 3	1		6	2	
Gicumbi	Plot 1	**38**	19	29	3	
	Plot 2	11	13	18	5	1
	Plot 3	2	6	10	3	3
Nyabihu	Plot 1	20	14	**37**	15	
	Plot 2	12	12	16	7	
	Plot 3	6	8	3	1	
Nyamagabe	Plot 1	**58**	24	5	1	
	Plot 2	27	17	9	7	3
	Plot 3	6	7	3	4	
Overall		**202**	**130**	**226**	**50**	**7**

4.3.2. Micro level effects of climate variability on crop production

Household survey questionnaire used put much emphasis on primary food crops grown by the majority of farmers during the season B of 2015 more specifically beans, maize, cassava, Irish and sweet potatoes. Table 34 presents the frequencies and proportions of farmers reported to cultivate these crops during 2015B following their suitability areas. It is clear that a large number of farmers cultivate beans and maize because of their importance in food security in Rwanda. Cassava as drought resistant crop is mostly grown in Bugesera and Nyamagabe Districts (with high temperatures), Irish potato in Northern part of the country where there is fertile and productive soil (volcanic soil). About 81.4% of Nyabihu farmers cultivated Irish potato for its high productivity and market accessibility.

Table 34: Frequency and percentage of farmers who have cultivated crops per district

Crop	Bugesera		Gicumbi		Nyabihu		Nyamagabe	
	Freq.	Percent	Freq.	Percent	Freq.	Percent	Freq.	Percent
Beans	79	88.51	84	94.38	31	36.05	74	84.09
Maize	60	66.67	13	14.61	15	17.44	7	7.95
Cassava	25	28.74	0	0	0	0	5	5.68
Irish potato	0	0	0	0	70	81.4	0	0
Sweet potato	0	0	8	8.99	0	0	44	50

Table 35 below presents the frequencies and proportions of farmers reported that their crop have been damaged by climate variability extreme events (drought and flooding) during season B 2015 (February to June 2015). The delays of rain, heavy rain which lasts for a short period and destroyed houses and damage crops, dry season which starts soon and lasts for a long period are some of the reasons stated by farmers to be the main causes of crop production reduction.

Table 35: Frequency and percentage of farmers affected by climate variability events

Crop grown	Bugesera		Gicumbi		Nyabihu		Nyamagabe	
	Freq.	Percent	Freq.	Percent	Freq.	Percent	Freq.	Percent
Beans	78	89.66	74	83.15	26	30.23	59	67.05
Maize	59	67.82	7	7.87	13	15.12	4	4.55
Cassava	10	11.49					3	3.41
Potato	1	1.15	5	5.62	52	60.47	24	27.27

Results shown in Table 36 give information on how climate variability extreme events have affected crop production at farm level. Across all sampled districts, beans and maize have been affected by drought than flood or heavy rain while Irish potatoes in Nyabihu district were damaged by heavy rain which consequently led to river overflowing and flooding of lowlands where the majority of farmers have plots (about 91.23% of Irish potatoes farmers agreed to be affected). Additionally, farmers who cultivated beans both at lowlands of Bugesera and highlands of Gicumbi and Nyamagabe districts have been affected by drought due to prolonged dry spell. In view of the above, not only climate variability extreme events reported to have the effects on crop production, but also crop disease and low use of inorganic fertilizer (including improved seeds), among other limiting factors.

Table 36: Seasonal effects of climate variability extreme events on crop production by district

Crop	Factors that affect crop production	Bugesera		Gicumbi		Nyabihu		Nyamagabe	
		Freq.	Percent	Freq.	Percent	Freq.	Percent	Freq.	Percent
Beans	Flood or heavy rain	2	2.56	13	16.88	25	92.59	3	4.23
	Drought	76	97.44	61	79.22	1	3.7	56	78.87
	Crop disease			3	3.9	1	3.7	12	16.9
Maize	Flood or heavy rain					12	85.71	1	16.67
	Drought	59	100	7	87.5	1	7.14	3	50
	Crop disease			1	12.5	1	7.14	2	33.33
Cassava	Flood or heavy rain								
	Drought	10	40					3	100
	Crop disease	15	60						
Potato (Irish and sweet)	Flood or heavy rain			1	16.67	52	91.23	3	11.11
	Drought	1	100	4	66.67			21	77.78
	Crop disease			1	16.67	5	8.77	3	11.11

Despite the occurrence of extreme weather events, some farmers managed to adapt to these events to be food secured after damages. As summarized in table 37, farmers from Bugesera District produced large quantity of beans and cassava than other districts as their average production per household is 114.83 kg and 317.5 kg respectively, those from Nyabihu District specialized in Irish potato production (with about 472.2 kg on average) while farmers from Nyamagabe produced more sweet potato than other Districts.

Table 37: Average crop production (kg) per household by district

District	Variable	Observation	Mean	Std. Dev.	Min	Max
Bugesera	Production_ Beans	77	**114.8312**	105.3588	10	500
	Production_ Maize	58	85.86207	87.84525	10	400
	Production_ Cassava	24	**317.5**	704.8296	50	3000
	Production_ S. Potato	1	100	.	100	100
Gicumbi	Production_ Beans	83	69.18072	74.18618	5	500
	Production_ Maize	13	61.15385	77.97312	10	300
	Production_ Cassava	0				
	Production_ S. Potato	7	120	94.33981	30	300
Nyabihu	Production_ Beans	28	85.78571	63.82172	10	300
	Production_ Maize	14	41.42857	53.43683	5	200
	Production_ Cassava	1	20	.	20	20
	Production_ I. Potato	57	**472.193**	685.9112	10	4000
Nyamagabe	Production_ Beans	74	24.74324	26.31009	6	225
	Production_ Maize	7	25.71429	18.35497	10	60
	Production_ Cassava	4	93.75	138.2856	10	300
	Production_ S. Potato	44	**248.7045**	211.1907	8	750

The results presented in the above table are the average production obtained per household after occurrence of climate variability extreme events while Table 38 below gives a summary of production loss per household due to the damage caused by climate variability extreme events. Results show that in all districts farmers lost between 50 and 60 percent of beans production compared to what they expected to harvest. For those who cultivated maize, the high loss proportion of production (about 73% of loss) found in Nyabihu district due to the fact that most of farmers intercropped Irish potatoes with maize in lowlands where the probability of being damaged by floods was too high. Also the results reveal that the loss of Irish potatoes is about 72% of the production that farmers were expected to obtain. In Table 36 it is clear that some of cassava growers in Bugesera district proved that the production loss was caused by crop disease while other said that the drought damaged cassava production due to the non-resistant varieties grown. The results also indicate that sweet potatoes farmers lost between 49 and 50 percent of production. The minimum loss is 10% while the maximum is 100%. This means that there are farmers who have not harvest even 1 kg due to crop disease or flooding especially.

Table 38: Average production loss (%) due to climate variability extreme events

District	Variable	Observation	Mean	Std. Dev.	Min	Max
Bugesera	Proportion of production loss_ Beans	78	56.69114	19.5882	12	90
	Proportion of production loss _ Maize	59	55.25424	18.29885	20	90
	Proportion of production loss _ Cassava	25	51.8	24.14712	10	100
	Proportion of production loss _ S. Potato	0				
Gicumbi	Proportion of production loss_ Beans	77	51.82432	18.10499	20	90
	Proportion of production loss _ Maize	8	54.375	14.98511	30	75
	Proportion of production loss _ Cassava	0				
	Proportion of production loss _ S. Potato	6	49.16667	26.53614	20	80
Nyabihu	Proportion of production loss_ Beans	27	59.40741	18.1092	30	100
	Proportion of production loss _ Maize	14	72.85714	21.54729	40	100
	Proportion of production loss _ Cassava	0				
	Proportion of production loss _ I. Potato	57	71.84211	26.40062	20	100
Nyamagabe	Proportion of production loss_ Beans	71	55.67606	15.05302	10	90
	Proportion of production loss _ Maize	6	46.66667	22.50926	10	80
	Proportion of production loss _ Cassava	3	50	20	30	70
	Proportion of production loss _ S. Potato	27	50.37037	21.02773	10	80

4.4. Macro-level impact of climate change on major food crops yield in Rwanda

4.4.1. Trend analysis

This sub-section presents trends in crop yield, area harvested, rainfall, minimum and maximum temperature as variables of interest of the study.

4.4.1.1. Trend in crop yield

The study uses the yield data for 5 major food crops: maize, beans, cassava, Irish potatoes and sweet potatoes. Time series yield data of the period of 1970 to 2015 were obtained from Food and Agriculture Organization (FAOSTAT) and MINAGRI. Figure 7 represents yield of major food crops grown by a large number of farmers. Graphical representation below has three phases: first phase shows a slight increase and a sudden decrease of crop yield in the years between 1970 and 1989. During that period cassava yield reached its highest level in 1979 (16.4 tonnes/ha). Phase II (from 1990 to 1999) was a period of civil war/ genocide against Tutsi. During this period yield reduced gradually and almost constant for some crops like maize and beans. In the beginning of 2000 government resumed and improved its activities/ programmes after resolving political, social and economic issues between citizens. Phase III (from 2000 to 2014) was a period of slight increase in yield (from 2000 to 2006) and high yield increase between the years 2007 and 2012 resulted to the adoption of agricultural policies and programs aimed at improving and transforming agriculture sector such as PSTA, CIP, land use consolidation and Girinka Program.[10]

The changes (increase or decrease) in crop yields have resulted not only to the changes observed in temperatures and precipitations since 1970, but also to other non-weather factors including area cultivated. During the period 2012, Government of Rwanda privatized subsidy program to allow private agro-dealers to distribute and purchase agricultural inputs. This has resulted in sudden decrease in crop productivity after this period (see figure 7).

[10] Girinka is one of the programs under Vision 2020 towards moving Rwanda to a middle income country by 2020. Its objectives include (1) poverty reduction through dairy cattle farming and improving livelihoods through increased milk consumption and income generation, (2) improve agricultural productivity through the use of manure as fertilizers to improve soil quality.

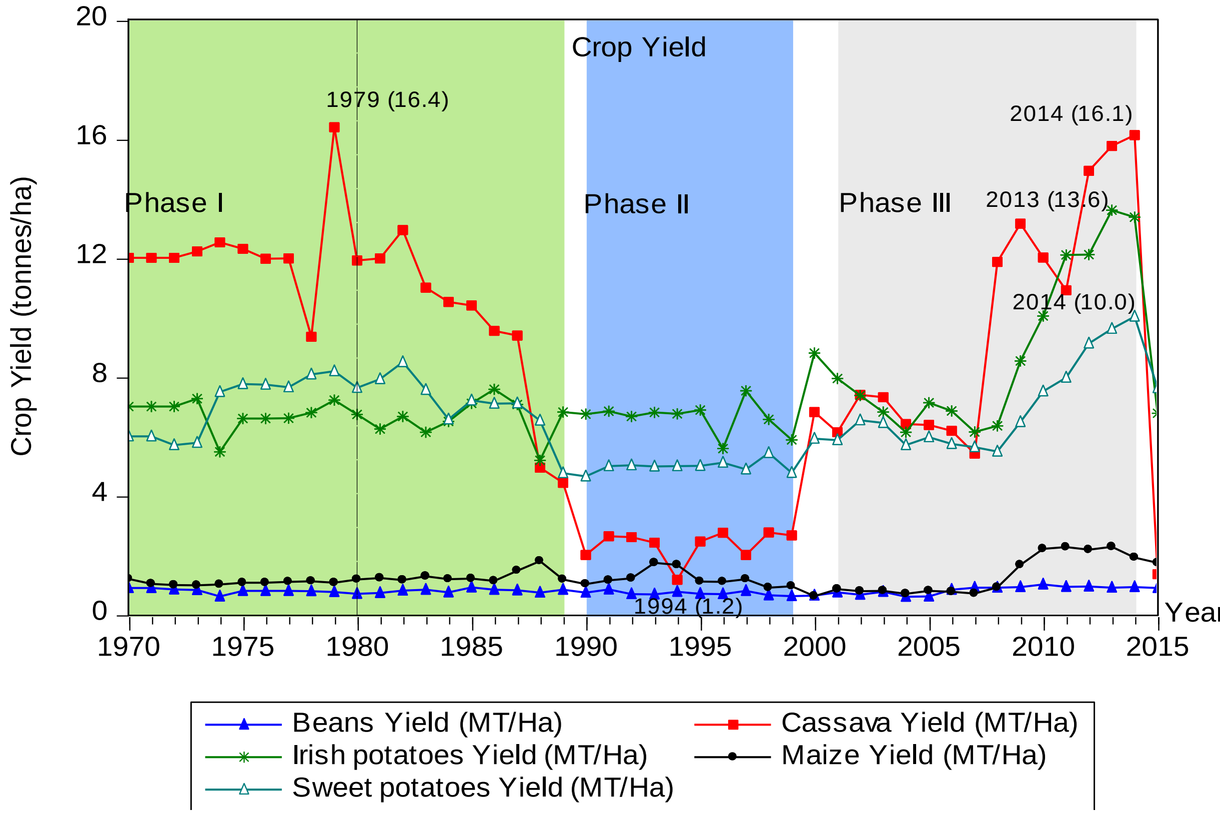


Figure 7: Graphical representation of major food crop yields (tonnes/ha) in Rwanda (1970-2015)
Source: Own computation using data from FAOSTAT (1970-1997) and MINAGRI (agricultural statistics 1998-2015)

4.4.1.2. <u>Trend in area harvested</u>

The same time series data were used to depict trend in area harvested in Rwanda since 1970. Figure 8 shows that area harvested increased slightly in the period of 1970 to 1993, and then decreased in the 1994. Area harvested for cassava and beans increased dramatically in the years 2014 and 2015 where area harvested reached their highest levels (617,000 ha and 500,000 ha respectively). Sweet potato area harvested reached its highest level (210,000 ha) in 1992 then after the area has decreased.

Graph indicates that maize and Irish potato area harvested attained their highest levels (242,000 ha, 151,000 ha) in 2015 in 2010 respectively. This increase was attributed to the CIP and LUC adopted by the government of Rwanda aimed at intensifying and improving farming system in Rwanda.

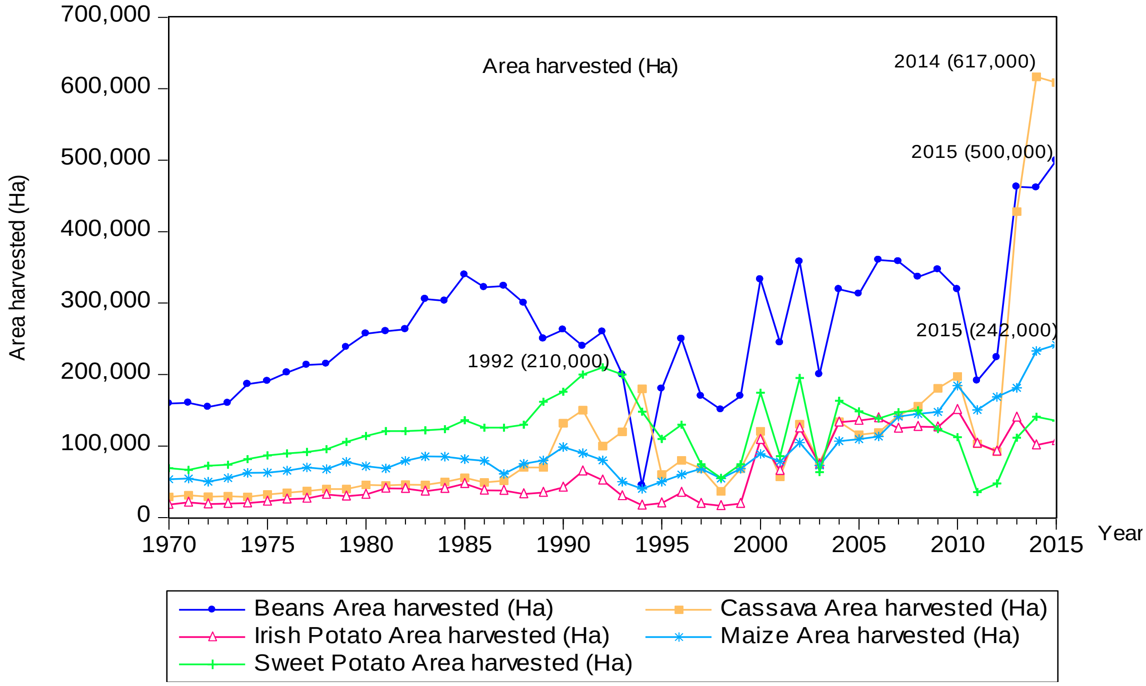


Figure 8: Graphical representation of area harvested (Ha)
Source: Own computation using data from FAOSTAT (1970-1997) and MINAGRI (1998-2015)

4.4.1.3. Trend in rainfall

Rainfall is a climate variable measured in millimeters (mm) with positive or negative influence on crop yield. This analysis used rainfall data for 16 stations obtained from Rwanda Meteorology Agency (RMA). As depicted in figure 9, graphs were depicted following climatic zones[11] in which crops under study are suitable for cultivation. In some instances, stations located where beans, Irish and sweet potatoes are grown did not record data for some years. Over the period of 1970 to 2015, average rainfall ranged between 333 mm and 1490 mm. This low level of average rainfall (333mm) in 1994 attributed to the few stations recorded rainfall information due to genocide that was taking place. High level of average rainfall (1738 mm and 1601 mm) recorded in the regions where beans and Irish potato are grown respectively. These regions comprise North-West high lands mostly suitable for beans and Irish potato production. During the period of 1990s few data were recorded, by stations where these crops are grown, due to civil war (tutsi genocide) effects. This is shown by cuttings of their respective graphs.

[11] Note that only data from stations where crops under study are mostly grown were used for these trends.

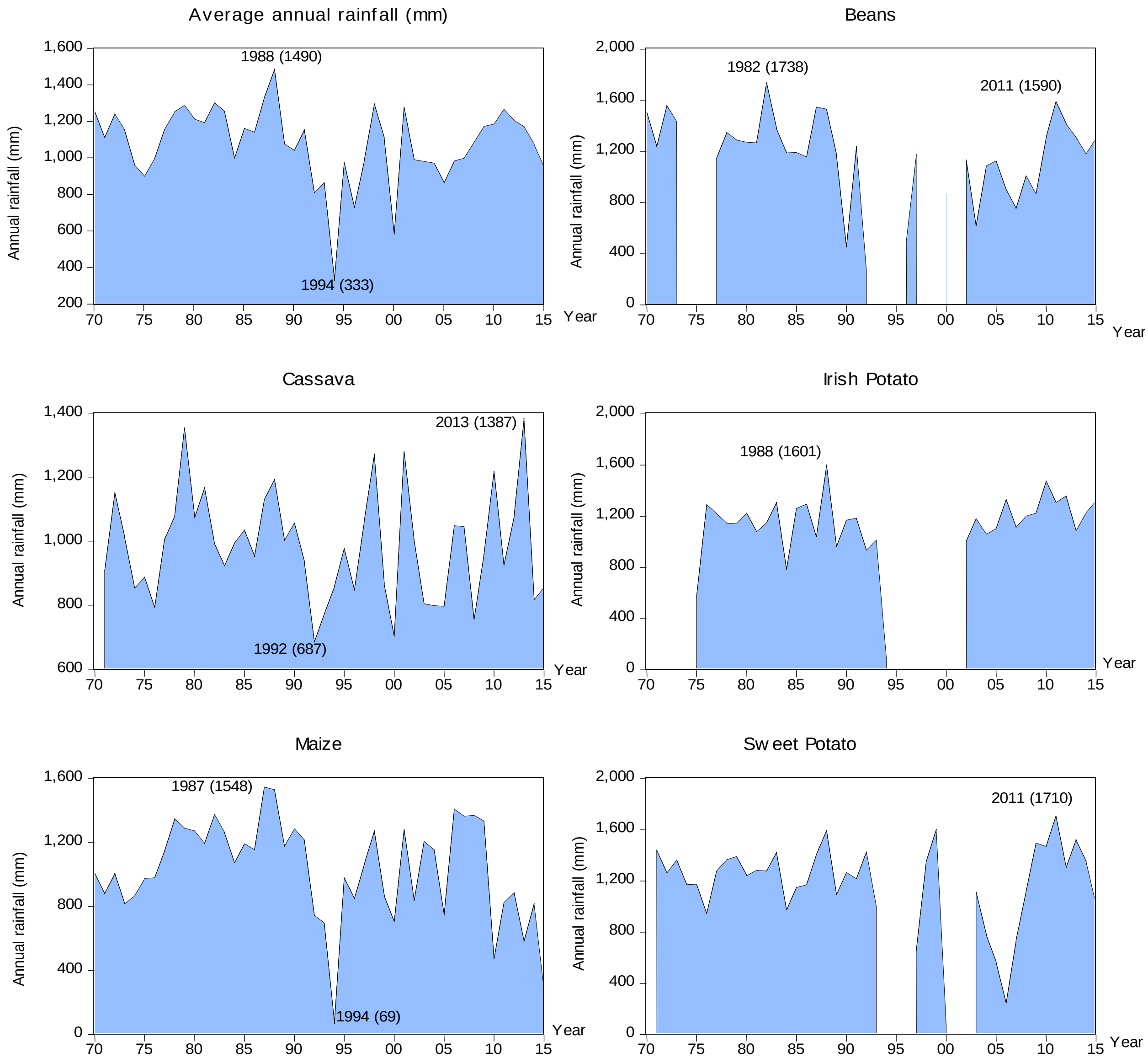


Figure 9: Graphic representation of annual rainfall (mm)

Source: Own computation using data from RMA (Rwanda Meteorology Agency), 2016

4.4.1.4. Trend in maximum temperature

Similarly, maximum temperature is another climate variable with negative effects on crop yield in case of high temperature. Figure 10 represents changes in maximum temperature over the period of 45 years. The first graph which depicts average maximum temperature in degrees (^{o}C) shows a sudden increase in average temperature between the years 1970 and 1974 with the highest level of 27.9^{o}C observed in 1974. This period followed by a period of large decrease in average maximum temperature between the years 1975 and 1992 where the lowest level of 24.0^{o}C observed in 1992. With regard to the crops under study, the highest level of average maximum temperature recorded by stations located where maize (33.5°C) and cassava (28.17°C) are mostly grown while the lowest recorded where beans and potatoes are suitable. Each graph represents temperature data recorded by one or more stations where respective crops are grown (see figure 10).

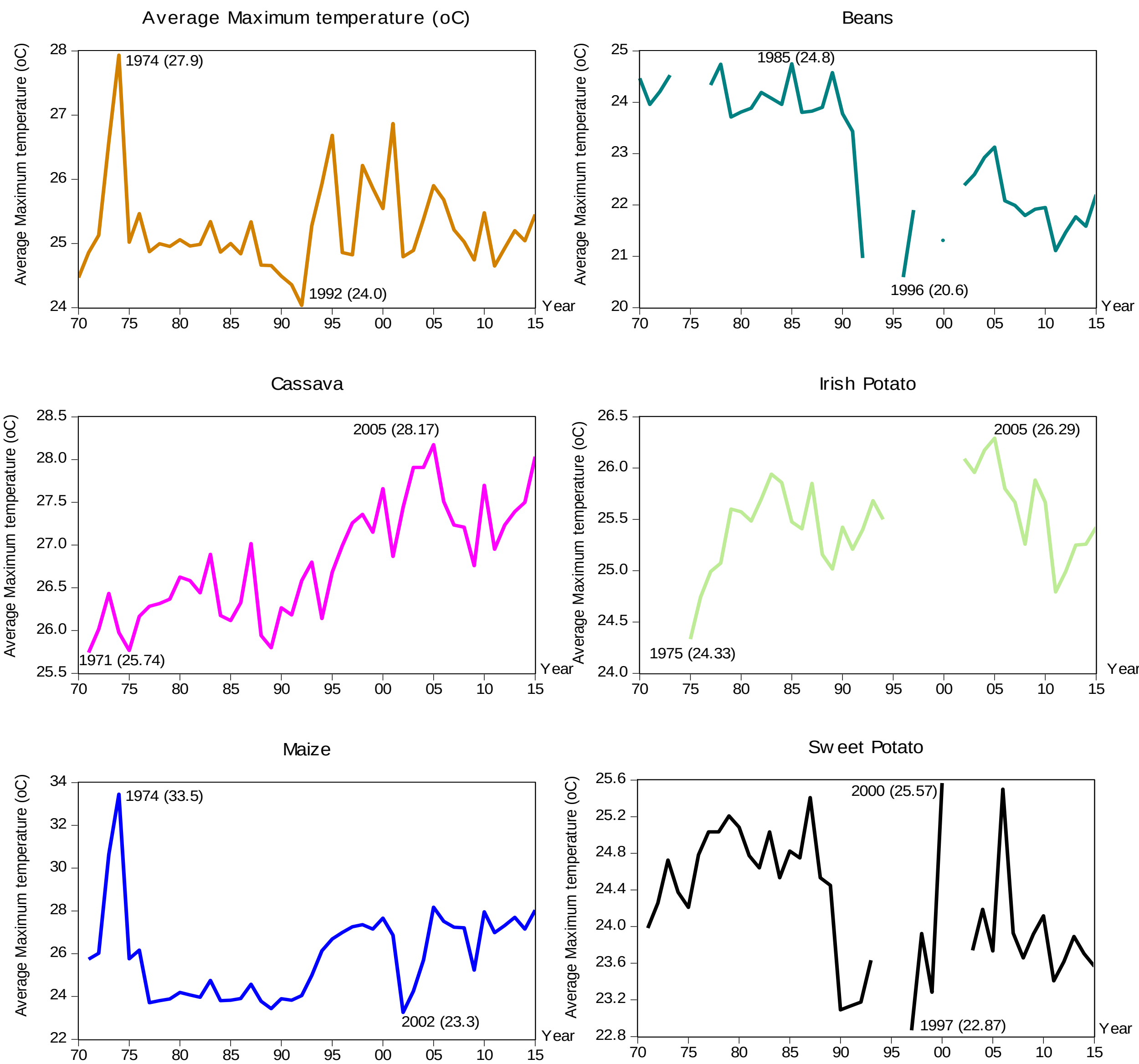


Figure 10: Graphic representation of annual average maximum temperature
Source: Own computation using data from RMA (Rwanda Meteorology Agency), 2016

4.4.1.5. Trend in minimum temperature

On average, minimum temperature recorded in all stations ranges between 13.41°C and 15.9 °C. Similarly to maximum temperature, the highest level of average minimum temperature observed in stations located where cassava (16.9 ^{o}C) and maize (16.5 ^{o}C) are grown. This corresponds to the suitability of cassava and maize in Eastern Southern Province of Rwanda.

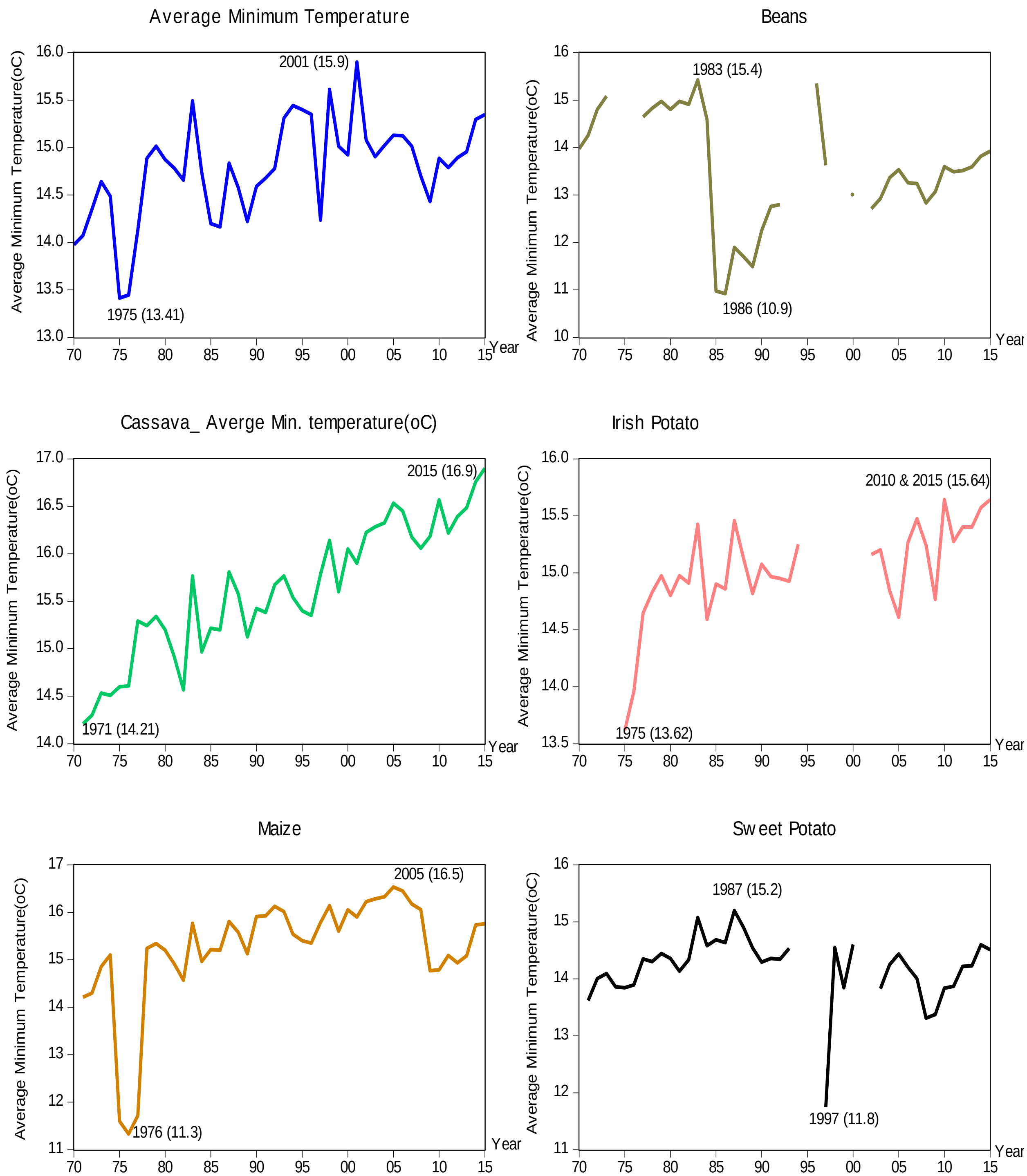


Figure 11: Graphic representation of annual average minimum temperature
Source: Own computation using data from RMA (Rwanda Meteorology Agency), 2016

4.4.2. Empirical analysis

4.4.2.1. Descriptive statistics

Table 39 reports summary statistics of weather and non-weather variables for selected food crops. This summary comprises time series data to be used in quantifying the impact of climate variables on yield of selected crops. Over the period of 1970 to 2015, some climate variables were not recorded by stations located where respective crops are grown, hence different observations of 34 to 45 years. Cassava and Irish potatoes yields were higher than yields of other crops. Beans, sweet potato and cassava growers harvested on wider areas than maize and Irish potato growers. The highest annual rainfall is observed in areas where beans, Irish and sweet potatoes are grown. The highest maximum temperature is observed in maize and cassava zones with 33.5^{o}C and 28.2^{o}C respectively. Drought events occurred in cassava and sweet potato zones (lowlands of Eastern and Southern Province) and floods in the Irish Potato and cassava areas. Further descriptive analysis of model variables is displayed in the following table.

Table 39: Summary statistics of model variables (1970-2015)

Variable	Crop	Observation	Mean	Std. Dev.	Min	Max
Yield (Tonnes/ Ha)	Beans	37	0.81	0.10	0.60	1.02
	Maize	45	1.238696	0.4304964	0.63	2.28
	Cassava	45	8.435556	4.557989	1.18	16.4
	Irish potato	34	7.561765	2.102285	5.19	13.61
	Sweet potato	40	6.7335	1.402713	4.65	10.03
Area harvested (Ha)	Beans	37	283,629.1	85,051.6	154,593	499,755
	Maize	45	93,788.27	47,305.91	40,000	241,713
	Cassava	45	113,413.6	129,078.4	28,768	616,569
	Irish potato	34	70,765.69	44,717.22	17,000	150,777.1
	Sweet potato	40	118,187	42,613.82	35,540.26	210,000
Annual rainfall (mm/year)	Beans	37	1,164.0	328.9	266.8	1,737.9
	Maize	45	1,030.598	314.6147	68.7	1,547.9
	Cassava	45	986.5844	168.1302	687.2	1,386.6
	Irish potato	34	1,130.238	265.2901	68.7	1,600.6

Variable	Crop	Observation	Mean	Std. Dev.	Min	Max
	Sweet potato	40	1,175.055	348.0379	63.6	1,709.9
Maximum Temperature (oC/year)	Beans	37	23.0	1.2	20.6	24.8
	Maize	45	25.92	2.090085	23.3	33.5
	Cassava	45	26.8	0.6657191	25.7	28.2
	Irish potato	34	25.47941	0.4422939	24.3	26.3
	Sweet potato	40	24.23	0.7161864	22.9	25.6
Minimum Temperature (oC/year)	Beans	37	13.5	1.2	10.9	15.4
	Maize	45	15.24444	1.153169	11.3	16.5
	Cassava	45	15.61556	0.703548	14.2	16.9
	Irish potato	34	15.02059	0.4311924	13.6	15.6
	Sweet potato	40	14.1925	0.564954	11.8	15.2
Flood (Dummy)	Beans	46	0.173913	0.383223	0	1
	Maize	46	0.1521739	0.3631584	0	1
	Cassava	46	0.2608696	0.4439611	0	1
	Irish potato	46	0.173913	0.383223	0	1
	Sweet potato	46	0.0652174	0.2496374	0	1
Drought (Dummy)	Beans	46	0.173913	0.383223	0	1
	Maize	46	0.173913	0.383223	0	1
	Cassava	46	0.2391304	0.431266	0	1
	Irish potato	46	0.0869565	0.2848849	0	1
	Sweet potato	46	0.2173913	0.4170288	0	1

Source: MINAGRI, FAOSTAT and RMA (2016)

4.4.2.2. Empirical Model

As the study is using time series data to assess the impact of climate change on crop yield over a period of 45 years, a test for stationarity must be verified before executing the regression.

Stationarity and Unit Root Test

To determine the stationarity of time series variables a method of Augmented Dickey Fuller (ADF) test can be performed to check the presence of unit root (Junbiao et al, 2015). The null hypothesis is that a variable contains a unit root, and the alternative is that a variable was generated by a stationary process. Results presented in Table 40 indicate that annual rainfall and yield of sweet potato yield are stationary at 1% at level while average temperature, yields of beans and Irish potato are stationary at 5% at level. Yield of maize is stationary at 5% at first difference and yield of cassava is stationary at 10% at second difference. As all variables are stationary, co-integration test shall be performed to determine the relationship between model variables.

Table 40: Results for ADF Unit Root Test

Variables	ADF- Statistics	Critical level	Order of integration
Beans yield	-3.053** (0.0302)	1% = -3.648 5% = -2.958 10% = -2.612	Stationary at level
Cassava yield	-2.591* (0.0948)	1% = -3.675 5% = -2.969 10% = -2.617	Stationary at second difference
Irish potatoes yield	-3.199** (0.0200)	1% = -3.648 5% = -2.958 10% = -2.612	Stationary at level
Maize yield	-2.906** (0.0447)	1% = -3.655 5% = -2.961 10% = -2.613	Stationary at first difference
Sweet potatoes yield	-4.642*** (0.0006)	1% = -3.615 5% = -2.941 10% = -2.609	Stationary at first difference
Average temperature	-3.153** (0.0229)	1% = -3.648 5% = -2.958 10% = -2.612	Stationary at level
Rainfall	-4.954*** (0.0000)	1% = -3.648 5% = -2.958 10% = -2.612	Stationary at level

*** And ** denote significance at 1 percent and 5 percent levels, respectively.
Figures within the parentheses are MacKinnon approximate p-value

Co-integration Tests

Co-integration test was tested using Johansen tests for co-integration and the results displayed in table 41 that on each model a number of co-integrating equations are present. This is an indication that there exist relationships between model variables. Therefore, regression model can be proceeded to indicate the impacts of climate variables on crop yields.

Table 41: Co-integration tests results

Crop	Maximum rank	Eigen value	Trace statistic	5% critical value	Maximum rank	Eigen value	Max statistic	5% critical value
Beans	0	.	66.2951	47.21	0	.	31.3139	27.07
	1	0.55198	34.9812	29.68	1	0.55198	21.6478	20.97
	2	0.42597	13.3335*	15.41	2	0.42597	7.582	14.07
	3	0.17668	5.7515	3.76	3	0.17668	5.7515	3.76
	4	0.13712			4	0.13712		
Cassava	0	.	82.1651	47.21	0	.	42.3532	27.07
	1	0.66243	39.812	29.68	1	0.66243	22.234	20.97
	2	0.43453	17.5779	15.41	2	0.43453	14.7756	14.07
	3	0.31536	2.8024*	3.76	3	0.31536	2.8024	3.76
	4	0.06933			4	0.06933		
Irish Potato	0	.	53.79	47.21	0	.	32.8568	27.07
	1	0.48278	28.7368*	29.68	1	0.56936	19.5203	20.97
	2	0.32278	13.9257	15.41	2	0.39378	10.9145	14.07
	3	0.23064	3.9623	3.76	3	0.24411	6.1229	3.76
	4	0.09902			4	0.14529		
Maize	0	.	57.7944	47.21	0	.	33.945	27.07
	1	0.54585	27.7998*	29.68	1	0.58121	23.594	20.97
	2	0.28795	14.8947	15.41	2	0.45391	12.4153	14.07
	3	0.21806	5.5478	3.76	3	0.27265	6.3718	3.76
	4	0.13584			4	0.15073		
Sweet potato	0	.	87.5972	47.21	0	.	36.1345	27.07
	1	0.70177	41.622	29.68	1	0.60407	27.4599	20.97
	2	0.54504	11.6953*	15.41	2	0.50545	14.8354	14.07
	3	0.19842	3.2908	3.76	3	0.31641	4.2234	3.76
	4	0.08296			4	0.10263		

*Indication of number of maximum ranks (or number of co-integrating equations in a model)

Regression results and discussions

A part from descriptive analysis summarized, regression results have been presented to respond to the objective 1 of the study. To assess the impacts of climate change on crop yield using time series data one need to quantify first the lagged values based on the current values of each variable (see methodological part for more details). Only calculated changes (Δ) in model variables (dependent and explanatory variables) have been used in regression model to find out the impacts of area harvested, rainfall, minimum and maximum temperatures on yield of crops of interest. Furthermore, dummy variables such as floods and droughts were included to see if historical occurrence of these events has had impacts on crop yield.

Table 42 presents regression results for the model. The findings show that an increase in area harvested has a positive and significant effect on maize, cassava and Irish potato yields (p=0.038, p=0.084 and p=0.001 respectively). This implies that a 10% increase in area leads to a 2.7% increase in maize yield increase, a 3.3% cassava increase and a 2.3% increase in Irish potato yield. With regards to rainfall distribution, the findings indicate that annual rainfall has a positive and significant effect on beans, maize and sweet potato yields. Thus, the findings are contrary to the expected a priori stating that increase in rainfall can result in increase or decrease in crop yield. Similarly, the regression results indicate that there is no any effect of floods on yield of crops under this study. Mostly, floods affect only crops cultivated on wetlands like rice.

Results also show that change in minimum temperature has a positive and significant effect on Irish potato yield and a negative and significant effect on maize yield whereas an increase in maximum temperature affect positively yield of sweet potato and has a negative effect on yields of beans, maize and Irish potato. For instance, a 1^{o}C maximum temperature increase decreases yields of beans, maize and Irish potato by 3.2%, 3.3% and 31.8% respectively and increases sweet potato yield by 1.2%. High decrease (31.8%) in Irish potato yield and increase (1.2%) in sweet potato yield is attributed to the areas with much and less precipitation under which these crops are grown respectively. These results are related to the a priori expectations that an increase in temperature results in crop yield decrease except for sweet potato. In addition, results justify that occurrence of droughts leads to a decrease in beans and maize yield by 14% and 27% respectively.

The R-Squared values indicated that 36.9% variation in beans yield, 37.42% variation in maize yield, 19.2% variation in cassava yield, 56.64% variation in Irish potato yield and 38.41% variation in sweet potato yield are explained by the area harvested, climatic variables and their respective extreme events.

Table 42: Regression results: dependent variable ΔlnY

	Beans		Maize		Cassava		Irish potato		Sweet potato	
Explanatory variables	*Robust Coef.*	*P>[t]*	*Robust Coef.*	*P>[t]*	*Robust Coef.*	*P>[t]*	*Robust Coef.*	*P>[t]*	*Robust Coef.*	*P>[t]*
ΔLnA	-0.0525	0.390	0.2718**	0.038	0.3305*	0.084	0.2278***	0.001	-0.1390	0.130
ΔR	0.0002***	0.000	0.0004**	0.025	0.0002	0.406	-0.0001	0.380	0.0002*	0.061
ΔMinT	-0.0181	0.307	-0.0659*	0.052	0.0044	0.933	0.2497***	0.001	0.0530	0.440
ΔMaxT	-0.0321**	0.033	-0.0330**	0.038	-0.0166	0.510	-0.3188***	0.000	0.01216**	0.024
Flood	-0.0307	0.625	0.0498	0.798	-0.1941	0.192	-0.1822	0.139	-0.0724	0.226
Drought	-0.1403**	0.035	-0.2763**	0.015	-0.0624	0.582	-0.0461	0.381	-0.0668	0.359
Constant	1.2139	0.239	-0.6155	0.684	-3.3301	0.096	4.0316	0.001	-0.3889	0.744
Number of observation		37		45		45		34		40
F(6, 30)		4.12		3.79		1.51		5.88		12.55
Prob > F		0.0039		0.0047		0.2028		0.0005		0.0000
R-squared		0.369		0.3742		0.192		0.5664		0.3841
Root MSE		0.11286		0.27187		0.30891		0.1675		0.17728

*, ** and *** represents the 10%, 5% and 1% level of significance respectively

4.5. Descriptive and Econometric Analysis of Farmers' Perceptions of and Adaptation Measures to Climate Change

4.5.1. Farmers' Perception of Climate Change

This sub-section presents a descriptive analysis of variables hypothesized to influence farmers' perception on climate change in the study area. A number of questions were asked to better understand what the rural farmers think about long-term changes in climate variables (rainfall and temperature). Table 43 presents the results of descriptive analysis of independent variables hypothesized to influence farmers' perception towards climate change.

Table 43: Description of model variables of the selection equation for the Heckman probit selection model

Dependent variable Description	**Farmers who perceived changes (%)**	**Farmers who do not perceived changes (%)**
Perception of climate change (dummy: takes the value of 1 if perceived and 0 otherwise)	**83.43**	**16.57**

Variable	**Variable measurement**	**Mean**	**Std. Dev.**	**Min**	**Max**
Age of the household head	Continuous	46.06	14.05	23	84
Education attained by the head of the household	Continuous	5.45	2.48	1	18
Farming experience in years	Continuous	24.8	14.28	1	62
Gender of the household Head	Dummy, takes the value of 1 if male and 0 otherwise	0.74	0.44	0	1
Crop income (Rwf)	Continuous	39916.19	68134.63	1000	504000
Livestock income (Rwf)	Continuous	103097.6	128044	2700	912000
Annual off-farm income of the household in Rwf	Continuous	223172.1	297128.6	10000	2400000
Access to climate information	Dummy, takes the value of 1 if access and 0 otherwise	0.54	0.5	0	1
Access to extension services	Dummy, takes the value of 1 if access and 0 otherwise	0.68	0.47	0	1

Source: Field Data (2016)

In all sampled districts, 83.43% of farmers interviewed had became aware and noticed a long term changes in climate phenomena while 16.57% had not. About 57.19% of farmers noted that they have been informed about climate change and variability by their own observation or experience. While about 3.08% and 39.73% of farmers have approved that they have been informed by local administration and media (television, radio, newspapers, etc) respectively.

Table 44 below presents the percentage of farmers noted the long term changes of different climate phenomena. About 61.68% noted an increase in the levels of temperature while 51.60% observed a decrease in heavy and long period rainfall. Also the results indicate that about 67.72% of farmers approved that they noticed a change in the timing of rains. They reported that rainfall starts late and ends early. And when it ends the dry season follow and last for a long period (noted by 68.48% of farmers). This results in increase in the frequency of droughts especially in Eastern and Southern part of the country (as reported by 73.21% of farmers). Only 38.14% of farmers observed increases in heavy and long period rainfall while about 51.60% noticed a decrease. This is related to the information provided by farmers during the FGDs that heavy rainfall lasting for a short period has increased.

Table 44: Percentage of farmers noted long term changes of climate phenomena

	Direction of changes (%)		
Climate phenomena	*Decreased*	*Increased*	*Unchanged*
Unusual early rains that are not sustained to dry spell	44.62	48.31	7.08
Rainfall starts late and ends early	22.15	67.72	10.13
Delay in the beginning of rain	21.25	65.00	13.75
Long period of dry season	24.55	68.48	6.97
Rains do not come when they normally used to	32.79	41.64	25.57
Heavy and long period of rainfall	51.60	38.14	10.26
Less rainfall	30.82	59.34	9.84
High Temperature	30.66	61.68	7.66
Increase in the frequency of floods	43.67	47.16	9.17
Increase in the frequency of droughts	15.79	73.21	11.00
Land degradation/ Decreasing soil fertility	26.37	62.70	10.93
Drying up of streams	36.36	16.88	46.75
Overflowing streams/rivers	28.71	49.76	21.53

Table 45 presents a cross tabulation between some socio-economic variables and perceptions of farmers on long term changes in climate phenomena with more focus on increase in the frequency of droughts and floods. The results reveal that the large number of farmers who perceived changes in climate phenomena is found in the age group between 36 and 50 years old (33.13%) followed by those who are between 51 and 65 years (29.55%). About 27.76% and 9.55% of farmers between 21- 35 and above 65 years respectively pointed out that they noticed changes in climate phenomena. About 35.5% of farmers (36-50 years) affirmed that they noticed an increase in the levels of temperature (high temperature) while no one confirmed to observed a decrease in temperature. Also the majority of farmers observed an increase in the frequency of droughts are in the age group between 51 and 65 (33.33%) while those who noticed an increase in the frequency of floods are in the age group between 20 and 35 years (36.11%).

As the mean number of years of formal education attained by farmers is 5.45, thus the majority of farmers reported to observe the changes in climate phenomena is between 1 and 6 years (80.58%) corresponding to the primary education while those with post primary (7 years and above) accounts for 19.42% of farmers. About 85.19% of farmers with primary education observed in increase in the frequency of droughts compared to only 14.81% of farmers with post primary education. Concerning increase in the frequency of floods, about 74.03% of farmers with primary education and 25.97% with post primary perceived an increase in the frequency of floods. The results indicate that the majority (47.08%) of farmers who perceived the changes in climate phenomena are between 16 and 30 years of experience in farming compared to those who are below 16 years and above 30 years of farming experience (with proportions of 28.1% and 24.82% respectively). About 41.8% and 47.25% of farmers with 16 and 30 years of farming experience pointed out that they observed an increase in the frequency of droughts and floods respectively.

With regards to the distance to the nearest input and output market, the results reveal that about 50.93% who reside far from the nearest market (1 and above km) perceived changes in climate phenomena compared to 49.07% who are close (between 0.1 and 0.9 km) to the nearest market. About 55.1% of farmers located far from the nearest market (1 and above km) observed changes in the frequency of droughts while 54.76% of farmers resided less than a kilometer noticed changes in the frequency of floods. Concerning farmers' employment, the findings indicate that a large proportion (93.73%) of farmers who observed changes in climate phenomena are full employed in farming compared to 6.27% of those who are not fully employed in farming. About 91.5% and 96.3% of farmers fully employed in farming agreed to notice an increase in the frequency of droughts and floods respectively. While only 8.5% and 3.7% of farmers who are part time in farming perceived an increase in the frequency of droughts and floods respectively. Table 45 below continues to give further results on cross-tabulation between socio-economic variables and farmers' perception on climate change in Rwanda.

Table 45: Farmers' perception to changes in temperature and rainfall by age, education, farming experience, distance to the nearest input-output market and employment (as a % of farmers)

Farmers' perception to……	Age group				Years of education		Farming Experience			Distance to nearest market (Km)		Employment	
	20-35	36-50	51-65	>65	1-6 years	7+ years	1-15 years	16-30 years	30+ years	0.1-0.9 km	1+ km	Fulltime in farming	Part-time in farming
Changes in climate phenomena	27.76	33.13	29.55	9.55	80.58	19.42	28.1	47.08	24.82	49.07	50.93	93.73	6.27
Rainfall starts late and ends early	29.44	32.24	27.1	11.21	78.38	21.62	27.71	46.99	25.3	47.56	52.44	93.46	6.54
Long period of dry spell	26.99	34.51	30.53	7.96	80.38	19.62	29.21	46.63	24.16	44.74	55.26	93.36	6.64
High Temperature	22.49	35.5	31.36	10.65	84.68	15.32	28.57	47.14	24.29	45.28	54.72	92.9	7.1
Decreases in temperature	0	0	0	0	0	0	0	0	0	0	0	0	0
Increase in the frequency of droughts	22.88	32.68	33.33	11.11	85.19	14.81	28.69	41.8	29.51	44.9	55.1	91.5	8.5
Less/ Decreases in rainfall	25.41	33.7	30.94	9.94	86.51	13.49	28.26	46.38	25.36	49.18	50.82	93.37	6.63
Heavy rain and long period of rainfall	33.61	31.93	25.21	9.24	77.53	22.47	29.81	46.15	24.04	55.26	44.74	96.64	3.36
Increase in the frequency of floods	36.11	27.78	23.15	12.96	74.03	25.97	30.77	47.25	21.98	54.76	45.24	96.3	3.7

Source: Field Data (2016)

4.5.1.1. Farmers' perceived adaptation measures

The majority (51.43% of the farmers interviewed) reported that they perceived that soil and water conservation (SWC) practices could be a better option to cope with the adverse effects of climate change and variability. These practices include bench and progressive terraces construction, anti-erosive ditches digging up especially on steep slope areas to prevent soil degradation. About 27.43% of farmers substantiated that combine trees and crops (agro-forestry) in the same plot for different purposes is also an option to be taken into account. Moreover 20.57% of farmers perceived that increase land for cultivation is another option, by doing this the probability of huge crop production loss caused by the climatic extreme event can be reduced at household level. During the household interviews and FGDs, some of farmers (18.57%) reported that they only rely on their own climate forecasts in order to discern the right time of the first rain so that they plant early or when it delays they wait until it rains and plant later to avoid the effects associated with delays of rain. About 16.57% of the farmers visited perceived that drought resistant crops and different crop varieties as adaptation measures. The least adaptation measures perceived by farmers are making ridges, mulching and using traditional crop varieties (3.46%, 3.46% and 1.73% of farmers respectively).

Table 46: Farmers' perceived adaptation measures

Perceived adaptation measures	Number of farmers	% of farmers
Making ridges	12	3.46
Increase irrigation	40	11.43
Mulching	12	3.46
Use of wetlands/river valleys	50	14.41
Drought resistant crops and early maturing varieties	58	16.57
Different crop varieties	58	16.57
Farming to non-farming	58	16.71
Using traditional variety of crop	6	1.73
Increase of cultivated land	72	20.57
Crop rotation	23	6.57
Intercropping	24	6.92
Use of agro-forestry (Tree plantation)	96	27.43
SWC (bench and progressive terraces)	180	51.43
Early and late planting	65	18.57

4.5.1.2. Farmers' Prediction of Climate Change and Variability

This sub-section presents a number of prediction techniques mostly used by farmers without referring to the information provided by meteorological agency but to their own indigenous techniques. For this question farmers were allowed to answer more than one technique depending on their different predictions. Table 47 below indicated a list of indigenous techniques used by farmers to predict the appearance of rain season and prolonged rain season resulting to floods. Overall, the results show that the majority (97.71% and 79.43% of farmers reported that they know the exact period of rain when the sky is heavy and clouded or when the nights are very warm respectively. Likewise, some farmers (28.86%) take reference on alignment of insects to predict early the appearance of rain season while 12.29% of farmers on increase of water in the streams and rivers. In addition, during the FGDs farmers from Gicumbi districts substantiated that they usually see the increase of spring water that flows out from mountains to ensure that rain season is about to start.

Table 47: Prediction of the early appearance of rain season, prolonged rain season resulting to floods

Prediction Techniques	Bugesera	Gicumbi	Nyabihu	Nyamagabe	Overall
Heavy and clouded sky	95.4	98.88	97.67	98.86	**97.71**
Bird displacement	1.15	1.12	2.33	1.14	**1.43**
Crowing of bird	19.54	2.25	0	7.95	**7.43**
Alignment of insects	35.63	33.71	18.6	27.27	**28.86**
Increase of water	4.6	21.35	12.79	10.23	**12.29**
Warmer nights	75.86	70.79	86.05	85.23	**79.43**
Direction of earthworms	3.45	2.25	0	1.14	**1.71**
Other	9.2	4.49	11.63	15.91	**10.29**

In the same way, the Table 48 presents indigenous techniques used by farmers to make prediction about the ends of the rainy seasons and prolonged dry seasons that result to droughts. The results indicate that almost all farmers (97.43%) recognize the end of rainy season if the sky color is light while 81.14% and 20.86% of farmers reported that the end of rainy season is indicated by too much cold nights and appearance of droplets on grasses early morning respectively. Other farmers (about 17.43%) said that they follow the regular calendar of seasons (season A is between end August and end January, season B is between February and end June) and wet wind that blows from the East part of the country.

Table 48: Prediction of the early end of rainy season, prolonged dry season resulting to droughts

Prediction Techniques	Bugesera	Gicumbi	Nyabihu	Nyamagabe	Overall
Light color of the sky	95.4	97.75	97.67	98.86	**97.43**
Too much cold night	83.91	86.52	77.91	76.14	**81.14**
Convergence of earthworms	4.6	3.37		7.95	**4**
Appearance of droplets	28.74	19.1	25.58	10.23	**20.86**
Dark, black moon	6.9	1.12	2.33	6.82	**4.29**
Other	17.24	15.73	20.93	15.91	**17.43**

4.5.2. Farmers' Adaptation to Climate Change and Variability

This sub-section presents a descriptive analysis of exogenous variables to be used in the model in order to find out the variables that affect famers' choice of adaptation measures to climate variability. Table 49 below gives a summary of explanatory variables that hypothesized to affect farmers' choice of adaptation measures to the effects of climate variability experienced in season B of 2015. The results of this analysis have been computed based on the response of selected farmers about the actual adaptation they used (for those who adapted to climate change and variability only).

Table 49: Description of model variables of the outcome equation for the Heckman probit outcome model

Dependent variable Description		Farmers who adapted (%)		Farmers who do not adapted (%)	
Adaptation to climate change (dummy: takes the value of 1 if adapted and 0 otherwise)		**76.57**		**23.43**	
Independent variables	**Variable measurement**	**Mean**	**Std. Dev.**	**Min**	**Max**
Education attained by the head of the household	Continuous	5.452	2.477	1	18
Size of the household	Continuous	5.131	1.930	1	11
Gender of the household Head	Dummy, takes the value of 1 if male and 0 otherwise	0.737	0.441	0	1
Crop income (Rwf)	Continuous	39916.19	68134.63	1000	504000
Livestock income (Rwf)	Continuous	103097.6	128044	2700	912000
Annual off-farm income of the household in Rwf Livestock ownership	Continuous	223172.1	297128.6	10000	2400000
Farm size in hectares	Continuous	0.388	0.507	0.003	3
Farming experience in years	Continuous	24.803	14.279	1	62
Access to extension services	Dummy, takes the value of 1 if access and 0 otherwise	0.677	0.468	0	1
Access to agricultural credit	Dummy, takes the value of 1 if access and 0 otherwise	0.680	0.467	0	1
Access to water for irrigation	Dummy, takes the value of 1 if access and 0 otherwise	0.114	0.319	0	1
Market access		0.326	0.469	0	1
Distance to the nearest market		1.121	0.945	0.2	4

Source: Field Data (2016)

To know the exact proportion of farmers who adapted to the effects caused by climate change, sampled household heads were required to point out an adaptation option they used, among the actual adaptation measures listed in the questionnaire, in order to cope with the effects caused by the changes in temperature and rainfall. Table 62 below presents the number and percentage of farmers who agreed to use the following actual adaptation measures: irrigation, drought resistant crop, different crop varieties, agro-forestry, soil and water conservation and early and late planting. Overall, the results indicated that 76.57% of farmers had adapted to the effects of climate change and variability that affected their farming while 23.43% of farmers had not.

Table 50: Actual adaptation measures undertaken by farmers

Actual adaptation option used by farmers	Number of farmers adapted	% of farmers
Irrigation	19	5.43
Drought resistant crops and early maturing varieties	53	15.14
Different crop varieties	24	6.86
Use of agro-forestry (Tree plantation)	63	18
Soil and water conservation	94	26.86
Early and late planting	15	4.29
No adaptation	82	23.43

Number of observations= 350

In view of the above (Table 43 and 49)[12], some farmers who claimed to perceive changes in climate but failed to undertake adaptation measures in order to reduce the negative impact of climate change gave a number of reasons as constraints. Major constraints that have been reported by farmers with regard to their limited adaptive capacity include lack of money, shortage of land, high costs of inputs, inadequate knowledge to cope with climate change effects, high cost of land, poor potential for irrigation and unavailability of agricultural inputs. Mostly, these constraints are associated with poverty as 95.14% of farmers interviewed agreed that the first barrier for adapting to climate change effects is linked to financial constraints (lack of money).

Farmers in Rwanda have small land compared to their households size, and the larger the household size the more farmers cultivate their land intensively to be able to satisfy household members needs. This avoids farmers to make some practices that are associated with adaptation to climate change. High cost of inputs prevents farmers to adapt to climate change in the sense that farmers apply inorganic fertilizers during the delay of rain to make land productive while

[12] Description of model variables of the selection and outcome equation for the Heckman probit selection and outcome models (perception and adaptation)

their financial capacity is limited. About 53.71% of farmers do not have inadequate knowledge to cope with climate change effects. This is attributed to the low extension services provision to floods and droughts prone areas. Due to water shortage in rural areas and poor irrigation methods used by most of farmers, the ability to adapt to climate extreme events like drought is limited.

Table 51: Constraints faced by farmers when adapting to the effects of climate change and variability

Constraints	Number of farmers	% of farmers
Shortage of Land	214	61.14
High cost of land	100	28.57
Poor access to information source	11	3.14
Non availability of credit facilities	8	2.29
Poor potential for irrigation	95	27.14
Non availability of inputs	80	22.86
High cost of inputs	199	56.86
Inadequate knowledge to cope with climate change effects	188	53.71
Non availability of farm labor	4	1.14
High cost of farm labor	39	10.57
Lack of money	333	95.14
Other	32	9.43
Number of observations	**350**	

Table 52 below indicates the relationship between socio-economic variables and farmers' adaptations to change in temperature and rainfall in the study area. The results show that the farmers who adapted to climate are in the age groups below 65 years. Regarding the years of education of the household head, the findings reveal that 78.06% of farmers who adapted to the changes in temperature and rainfall have low educational background (1 to 6 years of education) that can be a constraint to the effectiveness of adaptation measures. Concerning farming experience, the results indicate that the majority (47.71%) of farmers who adapted to climate change had between 16 and 30 years of experience in farming. About 53.33% of farmers who adapted live closer (0.1 to 0.9 km) to the nearest input and output markets and 92.91% of them are fully engaged in farming while only 7.09% of farmers are part time. Table 46 gives further analysis on each adaptation option undertaken by farmers.

Table 52: Farmers' adaptations to changes in temperature and rainfall by age, education, farming experience, distance to the nearest input-output market and employment (as a % of respondents)

Farmers' adaptation measures	Age group				Years of education		Farming Experience			Distance to nearest market (Km)		Employment	
	20-35	36-50	51-65	>65	1-6 years	7+ years	1-15 years	16-30 years	30+ years	0.1-0.9 km	1+ km	Fulltime in farming	Part time in farming
To Changes in Climate	**27.99**	**32.46**	**31.34**	**8.21**	**78.06**	**21.94**	**27.98**	**47.71**	**24.31**	**53.33**	**46.67**	**92.91**	**7.09**
Increase Irrigation	17.5	27.5	42.5	12.5	75	25	22.58	41.94	35.48	50	50	92.5	7.5
Drought resistant Crop	22.41	29.31	32.76	15.5	85.71	14.29	28.21	35.9	35.9	52.38	47.62	84.48	15.52
Different Crop Varieties	32.76	27.59	25.86	13.8	84.21	15.79	25.58	46.51	27.91	61.54	38.46	93.1	6.9
Agro-Forestry	23.96	33.33	28.13	14.6	77.94	22.06	20	50	30	60	40	93.75	6.25
Soil and Water Conservation (SWC)	28.33	33.89	30.56	7.22	77.27	22.73	26.14	51.63	22.22	53.57	46.43	96.11	3.89
Early and Late Planting	29.23	33.85	30.77	6.15	72.92	27.08	29.31	48.28	22.41	35	65	95.38	4.62

Source: Field Data (2016)

4.5.3. Econometric Analysis of farmers' perceptions and adaptation measures

Econometric models

The study used two models notably Heckman's probit selection and outcome models and multinomial logistic regression. Heckman's probit selection and outcome models was used to analyze the farmers' perception on climate change in the first stage and farmers' adaptation to climate change in the second stage. Whilst the second model was used to determine the factors that influence farmer's choice of climate change adaptation option.

4.5.3.1. Results of the Heckman probit selection and outcome model

In this model, two dependents variables were regressed on a set of explanatory variables such as household and farm characteristics, infrastructure and institutional factors that influence farmers' perception of and adaptation to the climate change. In the adaptation or outcome model the dependent variable is a dummy variable indicates whether or not farmers have adapted using different measures to cope with the changes in climate and in the perception or selection model the dependent variable is also a binary showing whether or not farmers perceived changes in climate. Table 53 presents the results of Heckman probit selection model of farmers' perception of and adaptation to climate change in Bugesera, Gicumbi, Nyabihu and Nyamagabe Districts. As the study emphasizes only on 6 major actual adaptation measures, the regression results also are specifically displayed to each and every adaptation option as indicated in Table 53.

According to the regression results, the adaptation model indicates that farm size influence farmers to increase irrigation in order to adapt to the changes in temperature and precipitation. The farm size is positive and statistically significant at 1% (p=0.001), meaning that farm size influence the choice of increasing irrigation by farmers. The implication is that the more land a farmer own, the more he/she is likely to irrigate it in order to produce more not only for consumption but also for marketing. Farm size is also positively and significantly related to the use of drought resistant crops as adaptation measures. This positive relationship between farm size and use of drought resistant crops could be due to the fact that most of farmers reported to use these crops are from Bugesera district (Eastern province) where farmers have large farms for cultivation and cattle keeping compared to other districts. But the results indicate that farm size is negatively and significantly related to agro-forestry and soil and water conservation adaptation measures (p=0.079 and p=0.020 respectively). This negative relationship between farm size and these two adaptation measures reflects that each farmer, either with large or small farm size, is concerned.

In the analysis, the adaptation model indicates that increasing in household size influence increase irrigation in order to adapt to the changes in temperature and precipitation. Household size found to be significant at 5% (p=0.036). It means that the larger the number of household members the more they are likely to irrigate their plots. Sometimes, irrigation involve costs, but the fact that a given household has a high number of labor for this activity, the choice of this adaptation option can be easily undertaken by household with large number of members than household with few members. The results from the adaptation model indicate that farming experience is positively and significantly related to the use of drought resistant crops and different varieties crops as adaptation measures (p=0.070 and p=0.015 respectively) while the relationship between farming experience and SWC found to be negative regardless their significance (p=0.004). The positive relationship implies that more experienced farmers are more likely to use drought resistant crops and different varieties crops to adapt to climate change than the lower experienced farmers. Since more experienced farmers have experience in farming techniques and information on long term changes in climate, they are able to cope with climate change effects than less experienced farmers. While the negative relationship between farming experience and SWC could be the fact that this adaptation option is actually undertaken by all farmers not only experienced farmers.

The results from the selection model reveal that farming experience had higher probability of influencing farmers to perceive and to adapt to the long changes in climate. This implies that the more experienced farmers are more likely to be aware of long term changes in climate based on their own experience and observation than their counterparts with less experience in farming. Moreover, the results indicate that accessibility to climate change information influence the perception of farmers. The farmers with access to climate change information are more likely to perceive climate change than farmers without access to information. Although the same farmers are not likely to adapt to climate change, this reflects their limited adaptive capacity due to financial constraints.

Regarding livestock income, results from adaptation model indicate that is positively and significantly related to the use drought resistant crops as adaptation option. This implies that farmers who earn money from selling livestock are more likely to use drought resistant crops especially in dry land area than farmers without income from livestock sales. In the same way, livestock ownership is positively and significantly related to the use of different crop varieties as adaptation option. This indicates that livestock owners are more likely to use different crop varieties than farmers without livestock. The possible reason for this positive relationship could be the fact that livestock owners can make money (either from selling from milk products or livestock) anytime as long as they own livestock. Then, this money earned can be used for purchasing different crop varieties. Contrary, livestock ownership is inversely related to agro-forestry as an adaptation option to be used. This reflects that livestock owners are less likely to combine trees and crop in their field than farmers without livestock. The reason for this inverse relationship is that every farmer (either livestock owners or farmers without livestock) is able to buy seedlings at cheaper price as a result of government policies which promotes agro-forestry countrywide.

Concerning access to agricultural credit, the results from adaptation model reveal access to agricultural credit is negatively and significantly (p=0.060) related to the use of drought resistant crop as adaptation option. This means that farmers with access to agricultural credit are less likely to adapt to changes in climate using drought resistant crop than farmers without access to agricultural credit. This could be the fact that the use of drought resistant crop may possibly require household income. Furthermore, the results from the adaptation model indicate that access to agricultural credit has a significant and positive influence on the use of different crop varieties as adaptation option. It means that farmers with access to agricultural income are more likely to use different crop varieties in farming than farmers without access to agricultural credit. This reflects that most of the farmers with access to agricultural allocate the credit for purchasing of different crop varieties.

With regard to education status of the household head, the results from adaptation model indicate that there is a positive and significant influence of education on adaptation to climate change (early and late planting). This implies that the educated farmers are more likely to make decision on planting time (early or late) than uneducated farmers. The more the farmers are educated the more they have skills and much understanding on climate change than illiterate farmers.

The results from adaptation model indicate that access to input/output market is negatively and significantly related to the decision taken by farmers about planting time (early or late) as adaptation option. This means that farmers with access to input/output market are less likely to decide planting time than farmers without market access. This implies that the majority of farmers interviewed in this study produce for consumption not for commercialization purpose. Also the results from the adaptation model distance to the nearest input/output market is negatively and significantly related to the agro-forestry as an adaptation option undertaken by farmers. This means that farmers who located far away from the nearest input/output market are less likely to combine trees and crop in the same field (agro-forestry) than farmers who located near the input/output market. In addition, distance to the nearest input/output market is positively and significantly related to the planting time as an adaptation option. This implies that farmers living closely to the nearest input/output market are more likely to plant their crop early or late than farmers who located far away from the nearest input/output market. This reflects that farmers that are closer to the nearest input/output market have more intention of producing more in order to sell to the market without transportation costs than farmers who residing longer to the nearest input/output market.

Table 53: Results of the Heckman's Probit Model of Farmers' Perception of and Adaptation to climate change in Bugesera, Gicumbi, Nyabihu and Nyamagabe Districts

	Increase irrigation				**Drought resistant crop**				**Different crop varieties**			
	Adaptation model		*Perception model*		*Adaptation model*		*Perception model*		*Adaptation model*		*Perception model*	
Explanatory variables	Coef.	P-values	Coef.	P-values	Coef.	P-values	Coef.	P-values	Coef.	P-values	Coef.	P-values
Education	0.368	0.275	-0.020	0.942	-0.511	0.104	0.060	0.830	0.109	0.784	0.069	0.815
Farming experience	0.001	0.118	0.002***	0.008	0.001*	0.070	0.002**	0.012	0.001**	0.015	0.002***	0.003
Gender of the household head	0.163	0.584	-0.089	0.661	-0.092	0.672	-0.154	0.431	0.124	0.684	-0.113	0.610
Crop income	3E-08	0.991			-3E-06	0.208			3E-06	0.475		
Livestock income	-1E-07	0.916			2E-06*	0.058			-2E-06	0.384		
Annual off-farm income	9E-08	0.823			6E-08	0.870			-2E-06	0.116		
Access to agricultural credit	0.504	0.143			-0.350*	0.060			0.670**	0.036		
Access to water for irrigation	0.159	0.653			0.077	0.779			-0.256	0.527		
Livestock ownership	0.158	0.524			0.263	0.205			0.876***	0.006		
Household size	0.105**	0.036			-0.027	0.605			-0.073	0.264		
Farm size	0.646***	0.001			0.463**	0.004			-0.421	0.236		
Market access	0.082	0.792			-0.108	0.671			0.078	0.819		
Distance to the nearest market	0.045	0.901			-0.046	0.877			-0.189	0.638		
Age of the household head			0.078	0.222			0.058	0.394			0.077	0.166
Access to information on climate change			1.431***	0.000			1.509***	0.000			1.483***	0.000
Access to extension services			-0.244	0.246			-0.284	0.218			-0.232	0.246
Local agro-ecological			-0.222	0.353			-0.064	0.746			-0.132	0.495
Constant	-2.943	0.000	-0.159	0.899	-0.514	0.195	0.219	0.872	-1.651	0.002	-0.228	0.849
Number of observation	350				350				350			
Censored observation	58				58				58			
Uncensored observation	292				292				292			
Wald chi2(14)	24.79				27.84				20.85			
Prob > chi2	0.0367				0.015				0.1055			

Explanatory variables	Agro-forestry				Soil and water conservation				Early and late planting			
	Adaptation model		*Perception model*		*Adaptation model*		*Perception model*		*Adaptation model*		*Perception model*	
	Coef.	P-values	Coef.	P-values	Coef.	P-values	Coef.	P-values	Coef.	P-values	Coef.	P-values
Education	-0.020	0.944	0.049	0.869	0.301	0.197	0.106	0.725	0.643*	0.058	0.042	0.879
Farming experience	0.000	0.615	0.002***	0.003	-0.001***	0.004	0.002***	0.002	-0.002	0.204	0.002**	0.011
Gender of the household head	0.103	0.644	-0.155	0.486	-0.129	0.517	-0.175	0.429	0.521	0.191	-0.138	0.495
Crop income	4E-06	0.143			-1E-06	0.708			3E-07	0.915		
Livestock income	-4E-07	0.785			-5E-07	0.712			-8E-07	0.628		
Annual off-farm income	2E-07	0.746			5E-07	0.223			-7E-07	0.158		
Access to agricultural credit	0.193	0.356			0.028	0.875			0.185	0.609		
Access to water for irrigation	-0.316	0.369			0.263	0.306			0.056	0.919		
Livestock ownership	-0.504**	0.011			0.017	0.922			-0.112	0.741		
Household size	-0.035	0.466			0.033	0.437			-0.039	0.601		
Farm size	-0.402*	0.079			-0.461**	0.020			0.395	0.220		
Market access	0.186	0.461			0.330	0.146			-5.359***	0.000		
Distance to the nearest market	-0.818**	0.018			-0.144	0.587			5.426***	0.000		
Age of the household head			0.067	0.225			0.076	0.172			0.067	0.294
Access to information on climate change			1.500***	0.000			1.521***	0.000			1.499***	0.000
Access to extension services			-0.241	0.231			-0.247	0.213			-0.223	0.297
Local agro-ecological			-0.092	0.638			0.002	0.994			-0.067	0.726
Constant	-0.814	0.036	0.033	0.978	-1.085	0.003	-0.187	0.874	-2.046	0.000	-0.028	0.982
Number of observation	350				350				350			
Censored observation	58				58				58			
Uncensored observation	292				292				292			
Wald chi2(14)	22.09				20.91				6.46			
Prob > chi2	0.0767				0.1041				0.9537			

***, ** and * denote significance at 1%, 5% and 10% levels respectively

4.5.3.2. Results of the multinomial logistic regression model

This model has been used in order to determine the factors that influence farmers' choice in relation to the adaptation to climate change. The dependent variable is a multinomial variable with 7 categories including the reference category which is "No adaptation".

Table 54 below presents the results of multinomial logistic regression model adaptation measures categorized into 6 adaptation measures discussed in the previous sub-section. The results indicate that education status of the household head has a positive and significant ($p<0.01$) influence on farmers' choice of adapting to climate change using irrigation, soil and water conservation and planting time (early or late). This implies that being educated increase the probability of adapting to climate change using irrigation, soil and water conservation and planting time (early or late). With regard to the farm size, the results reveal that farm size is positively and significantly influence the choice of adaptation measures such as increase irrigation, use of drought resistant crops and planting time (early or late). This implies that farmers with large farm size are more likely to choose irrigation, use drought resistant crop and planting time as adaptation measures to climate change than farmers with small farm size. In other words, having a large farm size increase the probability using irrigation, use drought resistant crop and planting time as adaptation measures.

Crop income, which represents the amount of money earned by household from selling crop production, is inversely and significantly influences the choice of not adapting to climate change using drought resistant crops. This implies that farmers who earn income from selling agricultural products are less likely to use drought resistant crops as adaptation option than farmers without crop income. The reason for this negative influence is that most of farmers especially from dry land area reported that the current problem with drought resistant crops (cassava) is only disease. This discourages farmers to not invest their income in drought resistant crops cultivation. Regarding off-farm income, the results show that off-farm income is inversely and significantly influences the choice of not adapting to climate change based on farmers planting time (early or late). This means that farmers who are part employed in farming and earned income in other sector than agriculture are less likely to planting early or late as adaptation option than farmers who do not earn off-farm income.

Livestock ownership is positively and significantly related to agro-forestry as an adaptation option but inversely related to the use different crop varieties. This means that ownership of livestock significantly influence the choice of adapting to climate change using agro-forestry and at the same time ownership significantly influence the choice of not adapting to climate change using different crop varieties. The results also indicate that access to extension services is negatively and significantly influence the choice of different crop varieties as an adaptation option. This implies that famers with access to extension services are less likely to use different crop varieties than farmers without access to extension services. This could be the fact that farmers who have access to extension services mostly provided by sector agronomist and extension services providers at sector level are few.

Table 54: Multinomial logistic regression estimates for the choice of adaptation strategies

Explanatory variables	Increase in irrigation			Drought resistant crop			Different crop varieties		
	Coef. (β)	Exp. (β)	P-value	Coef. (β)	Exp. (β)	P-value	Coef. (β)	Exp. (β)	P-value
β_0	-6.786 (2.348)		0.004	-1.165 (1.396)		0.404	0.442 (1.753)		0.801
Household size	0.097 (0.189)	1.102	0.607	0.006 (0.123)	1.006	0.962	-0.065 (0.151)	0.938	0.668
Age of the household head	0.075 (0.049)	1.077	0.13	0.005 (0.036)	1.005	0.892	-0.069 (0.054)	0.934	0.206
Education	0.255* (0.131)	1.291	0.052	-0.037 (0.088)	0.963	0.671	0.108 (0.114)	1.114	0.344
Farm size	1.915*** (0.595)	6.788	0.001	1.529*** (0.458)	4.612	0.001	-0.385 (1.004)	0.681	0.702
Farming experience	-0.012 (0.045)	0.988	0.793	0.004 (0.036)	1.004	0.919	0.068 (0.057)	1.071	0.229
Crop income	-0.002 (0.002)	0.998	0.353	-0.003* (0.001)	0.997	0.087	-0.001 (0.002)	0.999	0.568
Off- farm income	0.002 (0.002)	1.002	0.405	0.002 (0.002)	1.002	0.389	0.000 (0.003)	0.999	0.758
Gender of the household head	-1.429 (1.175)	0.24	0.224	-0.338 (0.565)	0.713	0.549	0.219 (0.703)	1.245	0.756
Livestock ownership	0.344 (0.773)	1.41	0.656	-0.296 (0.512)	0.744	0.563	-1.257* (0.709)	0.284	0.076
Access to extension services	-0.705 (2.827)	0.494	0.803	-2.283 (1.641)	0.102	0.164	-3.783** (1.815)	0.023	0.037
Access to agricultural credit	-0.777 (2.893)	0.46	0.788	1.968 (1.642)	7.158	0.231	2.292 (1.693)	9.899	0.176
Access to water for Irrigation	-0.437 (1.226)	0.646	0.722	0.030 (0.774)	1.03	0.969	0.486 (0.965)	1.625	0.615

The reference category is: No adaptation

Explanatory variables	Agro-forestry			Soil and water conservation			Early and Late Planting		
	Coef. (β)	Exp. (β)	P-value	Coef. (β)	Exp. (β)	P-value	Coef. (β)	Exp. (β)	P-value
β_0	1.160 (1.023)		0.312	1.153 (1.012)		0.254	-16.081 (2.052)		0.000
Household	0.102 (0.344)	0.942	0.558	0.093 (0.089)	1.097	0.297	-0.013 (0.183)	0.987	0.943
Age of the household head	0.034 (0.000)	1	0.99	-0.042 (0.031)	0.959	0.177	-0.089 (0.060)	0.915	0.137
Education	0.075 (0.324)	1.044	0.569	0.110 * (0.066)	1.116	0.097	0.226* (0.123)	1.253	0.067
Farm size	0.578 (0.380)	0.7	0.538	0.089 (0.473)	1.093	0.851	1.809** (0.675)	6.107	0.007
Farming experience	0.035 (0.479)	1.024	0.489	0.032 (0.031)	1.033	0.304	0.028 (0.060)	1.029	0.637
Crop income	0.001 (1.142)	1.001	0.285	-0.001 (0.001)	0.999	0.341	-0.004 (0.003)	0.996	0.166
Off- farm income	0.002 (1.468)	1.002	0.226	0.002 (0.002)	1.002	0.229	-0.010* (0.006)	0.99	0.094
Gender of the household head	-0.096 (0.463)	0.909	0.836	0.292 (0.420)	1.339	0.487	-0.445 (0.947)	0.641	0.639
Livestock ownership	1.131*** (0.398)	3.098	0.004	-0.033 (0.351)	0.968	0.926	-1.210 (0.887)	0.298	0.172
Access to extension services	-0.406 (1.261)	0.666	0.748	-0.157 (1.116)	0.855	0.888	-1.588 (3.991)	0.204	0.691
Access to agricultural credit	-0.438 (1.296)	0.645	0.735	-0.348 (1.134)	0.706	0.759	1.725 (4.010)	5.612	0.667
Access to water for Irrigation	-0.092 (0.654)	0.912	0.888	-0.718 (0.525)	0.488	0.171	17.193 (0.000)	2.93E+07	.

The reference category is: No adaptation

4.6. Conclusion

The chapter assesses the impacts of climatic variables (annual rainfall, minimum and maximum temperatures and area harvested on yields of major food crops in Rwanda. it has been noticed that farmers are aware of long-term climate phenomena (perceptions), but the main factors found to have positive influence of their perceptions included farming experience and access to information on climate change. Due to limited adaptive capacity to climate change the majority of farmers reported to be more vulnerable to climate change (as shown by the production loss due to extreme weather events). The actual adaptation mostly undertaken by farmers were categorized into seven categories including no adaptation, increasing irrigation, drought resistant crop, different crop varieties, agro-forestry, soil and water conservation and plating time (early and late). As results from analysis revealed that about 76.57% of sampled farmers had effectively adapted to climate change, there is possibility of having good outcomes such as food security, poverty reduction, increase in crop yield, infrastructure development (irrigation, water harvesting), etc, mostly resulted to effective use of adaptation measures by smallholder farmers. The determinants shown to be positively and significantly related to the choice of adaptation measures by smallholder farmers in sampled districts included farm size, education and livestock ownership.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

There is an emerging concern of impacts of climate change on rain-fed agriculture which mainly contribute to a decreasing crop yields mostly in developing countries. Rain-fed agriculture is the most susceptible to the impacts of climate change than other sectors of economy and smallholder farmers are the most vulnerable group. In Rwanda, about 72% of population depends on agriculture for their livelihoods. Therefore, an impact of climate change on this sector could lead to food insecurity. Due to poverty, there is inadequate capacity of coping with the unpredicted impacts of climate change among smallholder farmers. This section provides a summary and conclusion of the study results and the proposed policy recommendations needed to tackle the impacts associated with climate change in Rwanda. Sub-section of summary and conclusions summarizes the findings of socio-economic characteristics that play a prominent role in influencing either farmers' perceptions of or adaptation measures to climate change in sampled districts. Moreover, results related to objectives of the study are also presented.

5.2. Summary of results and Conclusions

The main objective of the research is to assess climate change impacts on crop yields and analyze the actual perceived adaptation measures in Rwanda. The study is interested in five aforementioned crops represented by different characteristics following their respective agro-ecological zones. To assess the impacts, crop yield was regressed on a number of explanatory variables, such as area harvested, rainfall, minimum and maximum temperatures, floods and droughts. Results from regression model illustrated that an increase in area harvested has a positive and significant on maize, cassava and Irish potato yields. Annual rainfall distribution found to have a positive and significant effect on beans, maize and sweet potato yields. But results from the model demonstrated that dummy variables (floods and droughts) had no impacts on crop yield. Change in minimum temperature had a positive and significant effect on Irish potato yield and a negative and significant impact on maize yield while a change in maximum temperature affected positively yield of sweet potato and had a negative effect on yields of beans, maize and Irish potato. However, results from the analysis, the first hypothesis stating that there is a significant impact of area harvested, rainfall, temperatures, floods and droughts on crop yields, climatic extreme events such as floods and droughts had no impacts on crop yields.

To address the second objective of the study, analyzing the factors that influenced farmers' perceptions of and adaptation to climate change and variability in sampled districts, heckman probit selection and outcome models were employed. Initially, results from description of model variables substantiated that 83.43% of farmers perceived the long term changes (increase, decrease and unchanged) in climate phenomena. Results from perception model illustrated that farming experience (mainly based on farmers own observation) and access to information on climate change through media found to have a positive and significant influence on farmers' perceptions of climate change in sampled districts. Likewise, adaptation model results revealed that household size, farm size, farming experience, access to agricultural credit, livestock ownership, education, market access and distance to the nearest market had influence on farmers' adaptation to climate change. Furthermore, the findings from the study show that almost all the smallholder farmers use indigenous techniques to predict the changes in climatic phenomena without relying on information provided by meteorological agency.

The third objective was to determine the factors that influence the choice of adaptation measures by smallholder farmers in sampled districts. A number of actual adaptation measures identified for the sake of this study included measures mostly practiced by many farmers across sampled areas. Findings obtained using multinomial logistic regression model demonstrated that education, farm size are positively and significantly influence the choice of adaptation measures while livestock ownership, access to extension services, off-farm income found to be negatively and significantly influence the choice of adaptation measures. Since some of socio-economic characteristics, agricultural characteristics and institutional factors influence the choice of adaptation measures, it signifies that the analysis of this objective responded to the hypothesis tested.

Furthermore, the study attempted to assess the impact of climate change on crop yield, understand farmers' perceptions and adaptation measures to climate change in Rwanda. Results provided evidence for increasing in temperature and droughts in sampled districts over the last 45 years. This increase has undermined gradually smallholder agriculture and made smallholder farmers more vulnerable to climate change. An increase in rainfall, not translated into floods, has resulted in crop yield increase, and change the livelihood of smallholder farmers. However, these climatic variables had impacted crop yield over the last four decades, there exist other factors that contributed to the changes and improvement of crop productivity, notably good agricultural practices under CIP, LUC and PSTA programs and strategies among others. Despite limited knowledge about climate change and adaptive capacity of smallholder and vulnerable farmers, government institutions and development partners put in place a number of measures to increase aim at increasing farmers' awareness of climate change and improving their adaptive capacity in case of extreme weather events occurrence, by providing them with dam sheets, inorganic fertilizers, irrigation equipments and storage facilities.

5.3. Recommendations

This sub-section provides a way forward on how to deal with the impact of climate change on crop yield and to increase smallholder farmers' awareness of climate change and adaptive capacity to climate change. The following recommendations could be helpful:

(1) As the majority of farmers predict climate change using indigenous techniques and perceive based on the own observation and farming experience and sometimes fail to plant on time, there is need to increase farmers' awareness of climate change through media (radio) and extension services at local levels to easy predict the occurrence of climate change events;

(2) More investment in irrigation and construction of terraces (both radical and progressive terraces) is needed to prevent and weaken the adverse effects that can be caused by climate change extreme events on lowlands (floods) and highlands (erosion and landslides) respectively;

(3) A large number of vulnerable rural farmers are poor and their adaptive capacity is limited. There is need to create more employment opportunities that enable them to raise their income and to provide relief services for them to be able to adapt to the impacts of climate change;

(4) More investment by the government need to be oriented not only in establishing adaptation measures but making these owned and maintained by farmers through their different mechanisms such as farmer cooperatives and other social capital mechanisms;

5.4. Areas for Further Research

The aim of this study was to assess the impact of climate change on major food crop yields. There is need for searching further the impacts of climate change on agriculture sector including agricultural and livestock production. To inform government on how to adapt to climate change in the upcoming years, there is need to carry out another study that emphasizes much on prediction of climate change impacts on agricultural productivity as global mean temperature and population keep increasing.

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Appendix 1: Household Survey Questionnaire

Purpose:

The intention of this household survey is to collect data on climate change and variability at household level based on sample districts. Household head or his spouse is allowed to be the interviewee during household interview. Information to be collected includes socio-economic characteristics of household head, land and agriculture characteristics, effects of climate variability on crop productivity of staple crops, farmer's perceptions of climate change and variability, actual adaptation measures likely to be chosen by farmers and the effectiveness of adaptation measures to ensure sustainability recovering to climate events.

HOUSEHOLD IDENTIFICATION

Household code ⎣___⎦ ⎣___⎦ ⎣___⎦ Date of interview ____/____/ 2016
Name of enumerator ____
Name of the Head of HH ____________________________________
Name of the respondent _____________________________________

Province: [1] Eastern [2] Western [3] Northern [4] Southern ⎣___⎦
District: [1] Bugesera [2] Nyabihu [3] Gicumbi [4] Nyamagabe ⎣___⎦
Sector:__________________________ **Cell:**________________________ **Village**__________________

Homestead position: [1] Upper [2] Middle [3] Lower [4] Valley ⎣___⎦

SECTION 1: SOCIO-ECONOMIC CHARACTERISTICS

Tick the appropriate code and fill the ticked code in the box below each variable

Marital status codes of the household head: [1] Single [2] Married [3] Divorced [4] Separated [5] Widowed

Relationship codes to the household head: [1] Household head [2]Spouse of HH head [3] Son/Daughter of HHH [4] Parent of HH head [5] Sibling of HH head [6] Other relative (specify)__________________________

Employment codes of the household head:
[1] Work on own farm [2] Casual labor
[3] Working in own business
[4] Working in someone else's business
[5] Salaried work
[6] Other (specify)________________________

Q.1_01 Age of the household head (years)	**Q.1_02** Gender of the household head 1= Male 0= Female	**Q.1_03** Number of Household members	**Q.1_04**Marital status of the household head	**Q.1_05** Number of years in formal education of the household head	**Q.1_06** Employment status of the household head. *If [1] since when? (year)*
⎣___⎦	⎣___⎦	⎣___⎦	⎣___⎦	⎣___⎦	⎣___⎦

Q.1_07 What is the estimated income (farm and off-farm) of your household per month (Rwf)? └──────┘	
Sources of HH income codes: 1= Farming 2= Livestock 3= Salaries and wages 4= Remittances 5= Off-farm income 6= Other (specify)________________________________	
Q.1_08 What are the main sources of household (HH) income (Rwf)?	└───┘
Q.1_09 What is the estimated annual agricultural income (in Rwf[13])?	└───┘
Q.1_10 What is the estimated annual Off-farm income (in Rwf)?	└───┘

Livestock ownership over the past 12 months								
	[Units/ codes]	**Cattle**	**Goats**	**Sheep**	**Pigs**	**Poultry**	**Rabbits**	**Other (specify)**
Q.1.11. How many owned by your HH currently	*Number*	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘
Q.1.12. How did you acquire? [1] Purchased [2] Girinka program [3] Neighbor [4] NGO………… [5]Other (Specify)………………		└───┘	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘
Q.1.13. How many sold last 12 months?	*Number*	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘
Q.1.14. Sales value (total)	*Rwf*	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘
Q.1.15. How many purchased last 12 months?		└───┘	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘
Q.1.16. Purchase value (total)	*Rwf*	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘

SECTION 2: INSTITUTIONAL FACTORS

Q.2_01. Are you a member of any farmer's group or cooperative?	**Q.2_02. Do you have access to early warning information on Climate variability?**	**Q.2_03. Do you have access extension services**	**Q.2_04. How many times per season do you receive extension services?**	**Q.2_05. Did you have access to agricultural credit?**	**Q.2_06. Do you hold crop insurance pertinently to climate shocks?**	**Q.2_07. Do you have access to market price information?**
[1] Yes [0] No	[1] Yes [0] No	[1] Yes [0] No		[1] Yes [0] No	[1] Yes [0] No	[1] Yes [0] No
└───┘	└───┘	└───┘	└───┘	└───┘	└───┘	└───┘

[13] Rwandan Francs. Current exchange rate: 1 USD= 835Rwf

SECTION 3: LAND CHARACTERISTICS AND CROP PRODUCTION

[Unit of measurement]: Square meters	Past 12 months	2 years ago	5 years ago	10 years ago
Q.3_01. What is the total land owned by your household currently?				
Q.3_02. What was the total land owned by household?				
Q.3_03. What was the total area used by household?				
Q.3_04. Total area rented out				
Q.3_05. Land leased				
Q.3_06. Land purchased				
Q.3_07. Land sold				

Q.3_08. Plot characteristics

Plots N⁰ (Only two first main plots)	**1. Plot size (m^2)**	**2. How did you acquire this plot (land tenure)?** [1] Owned [2] Purchased [3] Rented out [4] Borrowed [5] Other (specify)….	**3. Plot location** [1] Upper [2] Middle [3] Lower [4] Valley [5]Marshland	**4. Which crop did you grow last season (2016A)?** [1] Beans [2] Maize [3] Cassava [4] Irish potato [5] Sorghum	**5. What is the soil type of this plot?** *Codes* [14]	**6. Did your HH irrigate during 2016 Season A?** [1] Yes [0] No	**7. What was the proportion of the irrigated area?** [1] 1/4% or less [2] About 1/2 % [3] About 3/4% [4] 100%	**8. What is the method of irrigation used?** [1] Watering can [2] Sprinkler [3] Drip [4] Surface [5] Other (specify) ………………….
Plot 1								
Plot 2								
Plot 3								

Plots N⁰ (Only two first main plots)	**9. Did this plot terrace during 2016 Season A?** [1] Yes [0] No	**10. What was the proportion of the terraced area?** [1] 1/4% or less [2] About 1/2 % [3] About 3/4% [4] 100%	**11. What was the type of terraces did your HH used?** [1] Bench [2] Progressive [3] Both	**12. If YES in Q.3_ 03. Who terraced this plot?** [1] Myself [2] Labor [3] Community services (VUP) [4] NGO……………………… [5] Other (specify)……………	**13. When did this plot terrace?** *(Year)*
Plot 1					
Plot 2					
Plot 3					

[14] *Soil type codes:* [1] Nitosols [2] Ferralsols [3] Arenosols [4] Lixisols [5] Luvisols/ Acrisols [6] Cambisols [7] Alisols/ Acrisols [8] Ferralsol/ Alisols. *Source: FAO soil classification by IUSS Working Group (2006)*

Q.3_09. Crop production and marketing (Season B 2015): *From September 2015 to February 2016*											
Crop	**1. Did your HH grow this [crop]?** [1] Yes [2] No	**2. Which plot did you cultivate** [1] Plot 1 [2] Plot 2	**3. On what proportion of plot did you grow the crop?** [1] 1/4% or less [2] About 1/2 % [3] About 3/4% [4] 100%	**4. Did your HH apply any input?** [1] Yes [2] No	**5. If [1] in (4), which type of input did you use?** *(At least 2) Codes*	**6. How much inputs did your HH applied?** *[Kg or liters]*	**7. What was the source of input used?**	**8. How much of them did your HH purchased at local market?** *(Quantity) in Kg or liters*	**9. What was the market price per unit (kg or liter) during 2016 season A** *(Rwf)*	**10. How much in total did your HH spend on [INPUT] applied on this crop? (Rwf)**	**11. How did the HH pay for [INPUT]?** [1] Savings [2] Loans [3] Harvest sales [4] Other………...
Beans											
Maize											
Cassava											
Irish potato											
Sweet potato											

Codes for inputs:[1] Compost [2] Organic manure [3] NPK [4] DAP [5] UREA [5] Pesticides [6] Improved seeds [7] Other (specify)………………………………

Source of inputs: [1] Local government [2] NGO [3] Agro-dealer [4] Cooperative [5] Ordinary market [6] Other(specify)…………………………….

Q.3_09. Crop production and marketing (Season B 2015): *From September 2015 to February 2016*								
Crop	**12. What is the most used labor in this plot?** *[1] Own [2] Hired [3] Both*	**13. How many farm labors did your HH used during 2016 season A** *[Numbers]*	**14. How many days did labors allocate to this plot during 2016 season A** *[Human days]*	**15. What was the wage rate for each labor** *(Rwf)*	**16. How much production of [CROP] did your HH harvested?** *(Quantity) in Kg*	**17. How much of [CROP] produced have you sold at local market or elsewhere?** *(Quantity) in Kg*	**18. What was the market price for a unit (kilogram) of output produced?** *(Rwf)*	**19. How much did your HH receive in total from selling this [CROP] at market or elsewhere?** *(Rwf)*
Beans								
Maize								
Cassava								
Irish potato								
Sweet potato								

Q.3_09. Crop production and marketing (Season B 2015): *From September 2015 to February 2016*						
Crop	**20. What was the main location of sale for this [CROP]** [1] Village market [2] District market [3] Farm gate [4] Wholesale market [5] Cooperative [6]Other (specify)……	**21. How far is the market for input and output of this [CROP]?** **Units:** *Kilometers or meters*		**22. Which transport means did you use to reach the market place?** [1] Walking [2] Bicycle [3] Motorcycle [4] Vehicle [5] Other (specify)	**23. How many minutes did it take you to reach the main location of sale for the [CROP]?** *(Minutes)*	**24. How much did it cost you to reach the main location for sale, round trip?** *(Rwf)*
		Input	**Output**			
Beans						
Maize						
Cassava						
Irish potato						
Sorghum						

Q.3_10. Crop production and climate variability (Season B 2015): *From September 2015 to February 2016*						
Crop	**1. Was climate variability affected mostly this [CROP]?** [1] Yes [2] No	**2. Which climate extreme event that affected [CROP] yields?** [1] Flood [2] Drought [3] Crop disease	**3How much yield did you lose due to climate variability extreme events? (percent)**	**4. Due to rainfall or temperature variability, have you planted less of this [CROP] than it was five years ago?** [1] Yes [2] No *If [1], Why? Explain*		**5. What did the household do to cope with reduced yield?** [1] Sold land[2] Sold livestock [3]Borrowed from neighbors/family [4] Food aid: subsidized or free [5] Used savings [6] Migrated for wage work [7] Migrated for farm work [8] Other (specify)………………
Beans						
Maize						
Cassava						
Irish potato						
Sweet potato						

SECTION 4: PERCEPTIONS OF CLIMATE CHANGE AND VARIABILITY

Q.4_ 01. Have you heard (awareness) about climate change and variability in your district? [1] Yes [2] No *If [2] skip to Q.4_03*	
Q.4_ 02. If Yes, since when? *(Year)*	
Q.4_03. By which means have you been informed about climate change and variability? [1] Own observation, experience [2] Local administration [3] Media (TV, Radio, Newspapers, etc [4] Other (specify)……………………………..	

Q.4_03. Have you observed/ noticed any long term changes in climatic phenomena over the last 30 years in this district? *[1] Yes [2] No*			
Climatic phenomena	What is their direction of change? [1] Decreased [2] Increased [3] Unchanged	In which period did you start noticing the stated phenomena? [1] Past 2 years [2] Past 5 yrs [3] Past 10 yrs [4] Past 20 yrs	What is the impact of this phenomenon on crop productivity? [1] No impact [2] Low impact [3] Medium impact [4] High impact
Unusual early rains that are not sustained to dry season			
Rainfall starts late and ends early			
Delay in the beginning of rain			
Long period of dry season			
Rains do not come when they normally used to			
Heavy and long period of rainfall			
Less rainfall			
High Temperature			
Floods			
Drought			
Land degradation/ Decreasing soil fertility			
Drying up of streams			
Overflowing streams/rivers			

Prediction of climate change and variability	
Q.4_04. Since you have lived here, is it more difficult to predict when the rainy seasons will begin and end? [1] Yes [2] No	

Q.4_05. What are the most techniques do you use to predict early appearance of rain season, prolonged rain season or floods?

Tick on the most appropriate technique

[1] Heavy and clouded sky
[2] Birds displacement
[3] Crowing of birds
[4] A long alignment of insects
[5] Increase of water in the streams and rivers
[6] Warmer nights during the dry season
[7] Direction of earthworms from the top or hillside to marshlands
[8] Other (specify)…………………………………..

Q.4_06. What are the techniques do you use to predict the early end of rain season, prolonged dry season or drought?

Tick on the most appropriate technique

[1] Light color of the sky
[2] Too much cold nights during the dry season
[3] Convergence of earthworms towards the hilltop from marshlands
[4] Appearance of droplets on grasses in the morning
[5] Dark, black and cloud moon in the morning
[6] Other (specify)………………………………………………..

SECTION 5: CLIMATE VARIABILITY & ADAPTATION MEASURES

Q.5_01. In the past three decades, did you experience changes (increase and decrease) in rainfall in this region? *[1]Yes [2]No*

Q.5_02. What are the potential impacts of rainfall variability[15] (increase or decrease) on crop yield in your district?

Tick on the most appropriate technique

1] Yes [2] No

[1] Reduced crop yield
[2] Increased crop yield
[3] Land degradation/ Decreasing soil fertility
[4] Reduced household income
[5] Increased household income
[6] Destruction of flora and fauna
[7] Streams/rivers overflowing
[8] Loss of pastureland and vegetation
[9] Deduction in farm size
[10] Other (specify)………………………………………………………

Q.5_03. In the past three decades, did you experience changes in temperature (increase and decrease) in this region? *[1] Yes [2] No*

[15]Generally, the effect of rainfall variability on crop production varies with types of crops cultivated, types and properties of soils and climatic conditions of a given area.

Q.5_04. What are the potential impacts of temperature variability (increase or decrease) on crop yield in your district?

Tick on the most appropriate technique

[1] Yes [2] No

[1] Reduced crop yield	
[2] Increased crop yield	
[3] Land degradation/ Decreasing soil fertility	
[4] Reduced household income	
[5] Increased household income	
[6] Destruction of flora and fauna	
[7]Streams/rivers drying up	
[8] Loss of pastureland and vegetation	
[9] Deduction in farm size	
[10] Other (specify)……………………………………………………	

Q.5_05. Have you adapted to the impacts caused by the changes of temperature and rainfall?
[1] Yes [2] No

What are the adaptation measures have you perceived?	**Have you perceive this [OPTION] to cope with the effects of climate variability** **[1] Yes** **[2] No**
Making ridges	
Increase irrigation	
Mulching	
Use of wetlands/river valleys	
Drought resistant crops and early maturing varieties	
Different crop varieties	
Farming to non-farming	
Using traditional variety of crop	
Increase of cultivated land	
Crop rotation	
Intercropping	
Use of agro-forestry (Tree plantation)	
Soil and water conservation (SWC) [16]	
Early and late planting	

[16] Here SWC include any farming practices that maintain soil fertility such as construction of bench and progressive terraces, use of inorganic fertilizers like NPK, DAP and UREA.

Q.5_ 06. What is the adaptation option that your household used to cope with climate change in this district?		
		How much did you invest in the last season? *(Rwf)*
[1] Increase irrigation		
[2] Drought resistant crops and early maturing varieties		
[3] Different crop varieties		
[4] Use of agro-forestry (Tree plantation)		
[5] SWC (bench and progressive terraces)		
[6] Early and late planting		
[7] No adaptation		

Q.5_07. Has your household faced with the following constraints/barriers since you have started to use the mentioned adaptation measures?	
	[1] Yes [2] No
Shortage of land	
High cost of farm land	
Poor access to information sources	
Non-availability of credit facilities	
Poor potential for irrigation	
Non-availability of farm inputs (improved seeds, fertilizers, pesticides)	
High cost of inputs (improved seed varieties, fertilizers, pesticides)	
Inadequate knowledge of how to cope with climate change effects	
Non-availability of farm labor	
High cost of farm labor	
Lack of money	
Other (specify)……………………………..	

Appendix 2: Check List for the Focus Group Discussions (FGDs)

Date of interview ____/____/ 2016

District ___________________________

Sector ____________________________

A. Socio-economic characteristics

1) Do income generating activities avail to the majority of farmers in this sector? If you agree, what are the most activities done by farmers and average income per month.
2) How female headed household differ from male headed households in terms of agricultural production, vulnerability and adaptive capacity to climate change and variability?
3) Do farmers with different level of income affected in a different way by the effects of climate change and variability?

B. Institutional factors

1) Do government institutions or other local NGO facilitate rural farmers to have access on climate variability information?
2) How farmers receive weather forecasting information in this region? What are their own predictions techniques mostly used since they noticed the long term changes in weather?
3) Does government intervene in case of adverse occurrence of climate change event? If you agree, in which ways government intervenes in this area? Please explain.

C. Land characteristics and crop production

1) How do the majority of farmers acquire land used for farming practices in this area?
2) Are farmers aware of government policies such as Crop Intensification Program (CIP) which promotes the use of inputs (organic and inorganic fertilizers)?
3) Do farmers adopt fertilizer use needed to increase crop yield; if yes, what are the main crops they apply for?
4) Did crop production, mainly for staple crops (at district level) changed (increasing, decreasing or no change) since farmers adopted fertilizer application, explain your answer

5) Did crop production vary according to plot location or agricultural practices? If yes, please explain your answer
6) Do farmers have access to input and output market and market price information of their agricultural products in this area?
7) Did crop and soil productivity changed (increasing, decreasing or no change) due to the occurrence of floods and droughts? If yes, explain your opinion

D. Perceptions of climate change and variability

1) How do you perceive the precipitation and temperature variability? Explain your views
2) Have you observed/ noticed any long term changes in climatic phenomena over the last 30 years in this district?
3) Since when have you started to notice the effects of climate change and variability in this region/ district?
4) What are the most indigenous techniques do you use to predict early appearance of rain season, prolonged rain season or floods?
5) . What are the most indigenous techniques do you use to predict the early end of rain season, prolonged dry spell or drought?

E. Adaptation measures on climate variability

1) What have been major concerns, related to soil conservation and control, do farmers face in their farming practices; mention them
2) What are the main agricultural techniques (adaptation measures) did farmers adopted to cope with the adverse effects of climate change and variability, describe them (physical, bio-physical, political, economic, etc)
3) To what extent (effort) did farmers adapt to climate variability vis a vis to crop production expectation?
4) Based on climate forecasting, how farmers intend to increase the level of crop production in this area
5) How climate variability affects crop production; what is the average level of production and portion of land that can be affected at household level?

Appendix 3: Check List for the Key Informants Interviews (KIIs)

Date of interview ____/____/ 2016

Interviewer's name: ____________________________

Position: _____________________________________

Organization: _________________________________

List of organization visited

MINIRENA	Ministry of Natural Resource and Environment
MIDIMAR	Ministry of Disaster Management and Refugees
MINAGRI	Ministry of Agriculture and Animal Resources
REMA	Rwanda Environment Management Authority
RMA	Rwanda Meteorological Agency
RAB	Rwanda Agricultural Board
CIAT	International Center for Tropical Agriculture_ Rwanda

A. Crop production and climate change

1) Describe briefly the current level of agricultural production in Rwanda. Then compare the situation with the one for the past three decades.
2) What do you see as the foremost factors that involve in shifting (increase, decrease or no shift) of agricultural productivity in rural areas?
3) How do you describe matching between agricultural inputs application and increase in crop yield mainly for staple crops?
4) Are farmers aware of government policies such as Crop Intensification Program (CIP) which promotes the use of inputs (organic and inorganic fertilizers)?
5) Did farmers adopt fertilizer use needed to increase crop yield; if yes, what are the main crops they apply for?
6) Did crop production, mainly for staple crops (at district level) changed (increasing, decreasing or no change) since farmers adopted fertilizer application, explain your answer
7) Do farmers have access to input and output market and market price information of their agricultural products in this area?
8) Are there existing infrastructure such as; feeder roads that facilitate input and output market in rural areas?

9) What government institutions and NGOs do to cope with the effects of climate change and variability in urban and rural areas?
10) Did crop and soil productivity changed (increasing, decreasing or no change) due to the occurrence of floods and droughts? If yes, explain your opinion
11) Does this organization intervene in case of occurrence of climate change event? If you agree, in which ways your organization intervenes? Please explain.

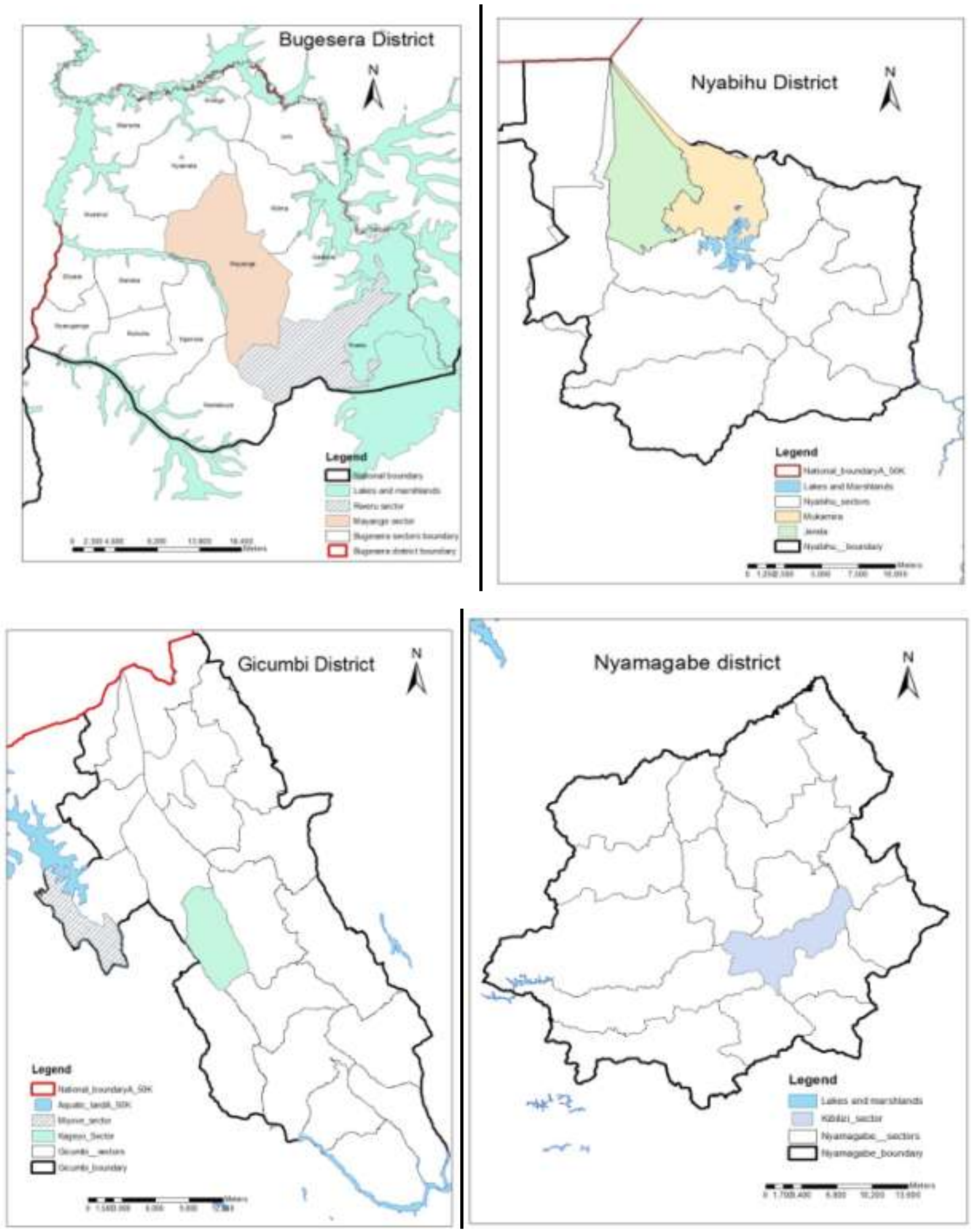
B. Farmers' Perceptions of climate change and variability

1) What are the indigenous techniques mostly used by farmers to predict the long term changes in climatic phenomena and the occurrence of heavy rain, which results in flooding, and prolonged dry spell?
2) Since when agricultural sector has been affected by the rainfall and temperature variability? Explain your answer.

C. Adaptation options on climate variability

1) What have been major concerns, related to soil conservation and control, do farmers face in their farming practices; mention them
2) What are the main agricultural techniques (adaptation measures) did farmers adopted to cope with the adverse effects of climate change and variability, describe them (physical, bio-physical, political, economic, etc)
3) To what extent (effort) did farmers adapt to climate variability vis a vis to crop production expectation?
6) Based on climate forecasting, how farmers intend to increase the level of crop production in rural areas?
7) How climate variability affects crop production; what is the average level of production and portion of land that can be affected at household level?
8) Do government institutions and NGOs help poor farmers to increase and improve their adaptive capacity? If yes, what are the options mostly adopted by these institutions in the sample districts?

Appendix 4: Map of the study area (shaded in colors)



Source: Own design using ArcMap GIS.