Assessing the Impact of Climate Change and Variability on Wetland Maize Production and Food Security in Highlands and Central Plateaus of Rwanda

Case Study of Bahimba and Bishenyi Wetlands

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Declaration

I declare that this Dissertation contains my own work and has never been submitted to any University or any other academic institution for an award of a degree in any field.

Anatole UWIRAGIYE

Date:

Signature

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ABSTRACT

Agricultural production is highly sensitive to climate change and variability. Abnormal variability in temperature and rainfall patterns increases probability of reduction of crop yields that end up in food insecurity as a direct consequence. **This study explored the impact of climate change and variability on maize production in the northern highlands and central plateaus wetlands of Rwanda and its connection to food security for local farmers**. Data were obtained using different methods and techniques including review of existing published and unpublished reports, analysis of meteorological data, field observation, household questionnaire and semi-structured interviews.

The study revealed abnormal changes in **rainfall and temperature where mean temperature has increased by 0.85 ^{0}C in Bahimba wetland and 1.1 ^{0}C in Bishenyi wetland** for the past 30 years. Research findings show that **rainfall decreased by 30 mm in Bahimba Wetland while increased by 50 mm in Bishenyi wetland**. Consequently, due to prolonged droughts in Bishenyi wetland, **maize yields reduced by 41% per hectare in 2013 and 51% per hectare in 2014. Likewise, in Bahimba wetland, maize yield reduced by 17% per hectare in 2015.** These reductions in maize harvests have caused food insecurity among maize farmers and the entire population in the same area. It is recommended that improved adaptation measures including watersheds management, new drought resistant and early maturing maize varieties, community food reserves, savings and credits groups, improving irrigation infrastructures, diversified income sources and improved maize value chain should be taken to ensure increased maize yields and sustainable food security.

Key Words: *Climate change, climate variability, Maize Production, local Farmers, Food security, mitigation and Adaptation*

LIST OF ABBREVIATIONS AND ACRONYMS

CCS	Carbon Dioxide Capture and Storage
CCVI	Climate Change Vulnerability Index
CIP	Crop Intensification Program
COVAMABA	Cooperative de Valorization du Marais de Bahimba
DDP	District Development Plan
EICV	Enquête Intégrale de Condition de Vie
ENSO	El Nino/Southern Oscillations
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
MIDIMAR	Ministry of Disasters Management and Refugees Affairs
MINAGRI	Ministry of Agriculture and Animal Resources
MINITERE	Ministry of Lands, Environment, Forestry, Water and Mining
NISR	National Institute of Statistics of Rwanda
REMA	Rwanda Environmental Management Authority
RMA	Rwanda Meteorological Agency
RMS	Rwanda Meteorological Service
SPSS	Statistical Package for Social Science
SST	Sea Surface Temperature
TVET	Technical and Vocational Education and Training
UNDP	United Nations for Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UN-OHRLLS	UN-Office of High Representative for Least Developed Countries
WMO	World Meteorological Organization

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CHAPTER ONE: INTRODUCTION

Climate change and variability is one of the huge challenges being reversing the efforts of development worldwide. Agricultural production is the most vulnerable sector to climate change and variability especially for the developing countries including Rwanda. It is in this context that the study was conducted to assess the impacts of climate change and variability on agricultural production and food security with a focus to maize production in wetland zones. These wetlands are located in both highlands and central plateaus of the country precisely in Bahimba wetland (Rulindo District) and Bishenyi wetland (Kamonyi District) respectively. The reason is that the nature and magnitude of impacts of climate change and variability vary with geographical location.

1.1. Background Information

The global climate has been changing including precipitation patterns and rising average temperatures. Climate change brings new challenges and new risks for all human activities on the planet (Rian, 2008). Today, climate change and variability is becoming the most major challenge experienced worldwide (Bizimana, 2014). In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. According to IPCC (2014) and Bizimana (2014), climate change will amplify existing risks and create new risks unevenly distributed and generally greater for the disadvantaged people and communities in countries at all levels of development.

IPCC (2014b) defines climate change as any change in state of the climate in terms of mean and variability of its relevant quantities such as temperature, precipitation, and wind for an extended period typically 10 years or longer. It is caused by natural internal processes and external forcing like solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of atmosphere and in land use. Climate variability however refers to a shorter term variations in climate such as the fluctuations associated with El Niño or La Niña events (Bizimana, 2014). Action Aid (2015) reported that the amount of greenhouse gases already present in the atmosphere is enough to increase the average of temperature of the planet.

Consequently, the occurrence and the severity of extreme climatic events like storms, droughts, serious floods, landslides, crop failures and food insecurity will became even more common and grave than today.

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Despite several adaptation initiatives being undertaken including the implementation of National Adaptation Programs of Actions, climate change related threats, particularly severe floods, droughts and extreme temperatures, are increasingly exposing the millions of people to poverty, hunger and disease. Recent climate models reveal that more adaptation and mitigation actions are required along with added capacity building and technology transfer in order to increase resilience capacity. Developing Countries especially in Africa are predicted to be the most vulnerable to climate change as the majority of population in these countries fully depend on income from rain-fed agriculture with limited adaptive capacity to climatic shocks. The adaptation capacity in these poor countries is undermined by the limited availability of social, economic, political and technical resources available to rural communities (IPCC, 2014; UN-OHRLLS, 2009). Climate change impacts are predicted to threaten past development gains and constrain future economic progress as well as adversely affect food security and worsen malnutrition (SEI, 2009).

Agricultural production, including access to food, is projected to be severely compromised. Projected reductions in yield in some countries could be as much as 50% by 2020, and crop net revenues could fall by as much as 90% by 2100, with small-scale farmers being the most affected.
Most countries in Sub-Saharan Africa depend on rain-fed agriculture for food security and employment to keep their economies growing and viable (IPCC, 2007). In Rwanda, agriculture represents more than 43% of the Gross Domestic Product and crop production constitutes the major part of agricultural production for the majority of the Rwandese households (MIDIMAR, 2015). However, Rwanda being the one of most vulnerable developing countries, climate change and variability effects will reverse efforts to improve food security and keep rural community poor until they understand their situation and risks to prescribe more suitable innovative coping strategies. The rainfall seasons have already been unexpectedly starting late and farmers were increasingly wary of establishing new optimal times for planting their crops that has negatively impacted their livelihoods and increased vulnerability to food insecurity.

Floods also have reduced food production by a margin of 20-30% in marshlands (Mutabazi, 2010). Rwanda has already experienced a growing number of disasters in recent decades amongst these disasters are droughts, floods, landslides and windstorms especially occurred in 1988, 1989, 2000, 2005-2006, 2010, 2011 and 2014 which have caused physical, social and economic damages and losses (MIDIMAR, 2015). The average temperature has increased from 19.8 ° C in 1971 and 20.7 °C in 2007, making an increase of 0.9 °C in 27 years and the number of days of rainfall has dropped from 148 to 124 from 1971 to 2009 (REMA, 2014).

Effective decision-making to address climate change effects can be informed by a wide range analysis of existing and near future climate related risks recognizing the importance of governance and diverse perceptions and responses to risk and uncertainty. Adaptation is required in every sector to address climate change effects but their context for implementation and potential to reduce vulnerability differs across sectors and regions (IPCC, 2014). Therefore, this study intended to contribute to the body of research in the area of climate change by assessing the effects of climate change and variability on maize production in wetlands and the extent to which have impacted food security focusing on Bahimba and Bishenyi Wetlands in Rulindo and Kamonyi Districts located in highlands and plateaus respectively.

1.2. Problem Statement

The population of Rwanda is largely rural and the majority of them are fully engaged in rain-fed agriculture. This sector employs 72.7% of population and among them 82% are women smallholder farmers (NISR, 2012). Cultivating households are at 84.1% in Rulindo District and at 85% in Kamonyi District (NISR, 2012). One of the major inputs in agricultural production is land and only 52 % of the land surface area is arable, representing approximately 1,385,000 hectares. The country has 860 marshlands covering a total surface of 278,536 hectares (10.6 % of the country surface area) and 53 % are under cropping mainly used for maize and rice production (REMA, 2008).

However, the changing climatic conditions were causing poor performance of agriculture including maize production that has been worsening food security situation, nutrition and health throughout the country.

The intensity and frequency of climate hazards and their adverse effects are exacerbated by the topographical structure of Rwanda's territory mainly characterized by a very accidental relief very prone to erosion and landslides. The southern part of the country is already rainfall constrained and prone to aggravating dry spells and prolonged droughts while in Northern region, crops failure is caused by heavy rainfall and floods (MINITERE and UNEP, 2006; Rwanyiziri and Rugema, 2013).

Maize is one of the major crops which have been selected by the Government of Rwanda (GoR) to help in achieving agricultural-market oriented and food sovereignty in the country. However, maize production in wetlands has been facing with serious impacts of climate change and variability include water stress during the extended dry spells that also increases proliferation of crop pests and diseases particularly in lowlands and central plateaus of the country. In highlands, hilly terrain, deforestation and heavy rainfalls cause floods and siltation that damage crops and destroy irrigation infrastructures. According to IPCC (2014), without additional adaptation efforts beyond those in place today, climate change will lead to high and very high risk of severe, widespread and irreversible negative impacts especially on agriculture that will lead to food insecurity and hunger.

Therefore, there is a need of better understanding of the nature and magnitude of the impacts of climate change and variability in wetlands as the last options for crop production particularly while prolonged droughts. This research assessed major impacts of climate change and variability which maize farmers have been facing or are likely to be facing in the near future to contribute in the identification of suitable adaptation measures, enhance preparedness and resilience capacity hence reduce vulnerability to food insecurity among maize farmers and Rwanda's population in general.

1.3. Objectives

1.3.1. General Objective

The main objective of this study was to assess the impacts of climate change and variability on wetland agricultural production and food security in Rwanda with a focus to maize production in Bahimba (Rulindo District) and Bishenyi (Kamonyi District) wetlands.

1.3.2. Specific Objectives

To achieve the main objective, the specific objectives were as follows:

1. To evaluate the current trends of rainfall and temperature patterns in the study area;
2. To assess the impacts of climate change and variability on maize production and food security in the study area;
3. To propose suitable adaptation practices for better coping with climate change and variability impacts on maize production and food security in the study area.

1.4. Hypotheses

1. There are significant abnormal changes in rainfall and temperature over the past 30 years in the study area.
2. Changes in rainfall and temperature patterns have lowered maize yields and this has significantly contributed to food insecurity among maize farmers in the study area.
3. New drought resistant varieties and/or early maturing maize varieties are some climate change and variability adaptation strategies, among others, towards an increased maize production and improved food security in the study area.

1.5. Research Questions

The study was guided by the main research question: "to what extent maize production and food security is affected by the impacts of climate change and variability?"

This main question is further guided by the following sub-questions:

1. To what extent the rainfall and temperature have fluctuated over the past 30 years in the study area?
2. What are the impacts of climate change and variability on maize production and food security in the study area?
3. What are the possible adaptation practices to better cope with climate change and variability on maize production and food security in the study area?

1.6. Limitations of the Study

The 1994 Tutsi Genocide in Rwanda destroyed more than 80% of meteorological infrastructures and more than 90% of RMA employees were lost. Though very few meteorological stations reopened since 1998 only the station of Kigali Airport has pre- and post-genocide climate data (Mutabazi, 2010).

Although Rwanda Meteorology Agency recovered data at all local levels using merging methods (satellite and gauges), rainfall and temperature data during genocide were available as the weather stations were destroyed and due to this challenge, climate data used for the study were not 100% accurate.

In addition, the study could not obtain all seasonal maize production data over the entire period under study as the Crop Intensification Program (CIP) for maize was formally implemented in the selected wetlands since 2010 that could not allow deepening the effect of climate change/variability on maize yields over the past 30 years.

1.7. Conceptual Framework

The present study assumes that if rainfall and temperature which are the main weather parameters are abnormally changed, maize production (yields) will decrease then adversely affect food security as shown in figure below.

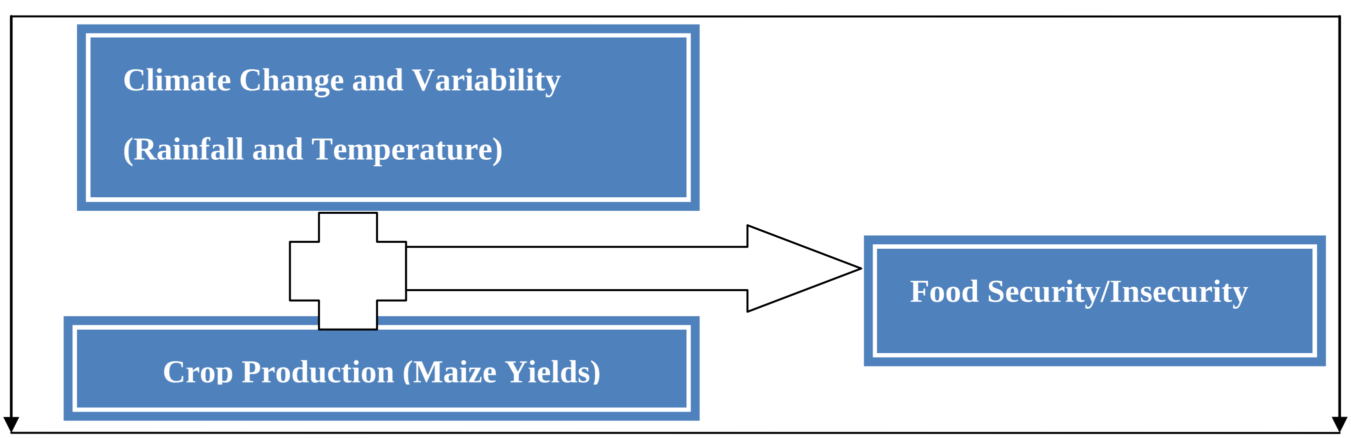

Figure 1: Conceptual Framework (adapted from Jecha Haji, 2013)

CHAPTER TWO: LITERATURE REVIEW

This chapter discusses the definitions of key concepts under climate change and variability, the review of related scientific publications on climate change and variability worldwide including Rwanda, its adverse impacts on agriculture and food security, and mitigation and adaptation options.

2.1. Definitions of Key Concepts

2.1.1. Climate

Climate in a narrow sense is usually defined as the “average weather” or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

2.1.2. Climate Variability

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) 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). The UNFCCC makes a distinction between “climate change” attributable to human activities altering the atmospheric composition, and “climate variability” attributable to natural causes.

2.1.3. Climate Change

As defined by IPCC (2014), climate change refers to a change in the state of climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. The United Nations Framework Convention on Climate Change (UNFCCC) in its article 1, defines “climate change” as: “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.”

Climate change is also caused by natural processes or external forcing such as modulation of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. Muhammad (2012) reported that climate change occurs by change in the mean, frequency or both. In addition, UNFCCC confirmed that global climate is changing, largely due to the observed increases in human produced greenhouse gases where greenhouse gases absorb heat from the sun in the atmosphere and reduce the amount of heat escaping into space. This extra heat has been found to be the primary cause of observed changes in the climate system over the 20th century.

IPCC (2014) indicated that Greenhouse gases contributed to global mean surface warming likely to be in the range of 0.5°C to 1.3°C for the period 1951 to 2010, with the contributions from other anthropogenic forcings, including the cooling effect of aerosols, likely to be in the range of −0.6°C to 0.1°C. The contribution from natural forcings is likely to be in the range of −0.1°C to 0.1°C, and from natural internal variability is likely to be in the range of −0.1°C to 0.1°C. Together these assessed contributions are consistent with the observed warming of approximately 0.6°C to 0.7°C over this period. Anthropogenic influences have affected the global water cycle since 1960 and have also contributed to observed increases in moisture content in the atmosphere (medium confidence), to global scale changes in precipitation patterns over land (medium confidence), to intensification of heavy precipitation over land regions where data are sufficient (medium confidence), and to changes in surface and sub-surface ocean salinity (very likely).

Moreover, IPCC (2014) stated that continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Changes in the global water cycle in response to the warming over the 21st century will not be uniform and the contrast in precipitation between wet and dry regions and between wet and dry seasons will increase but there may be regional exceptions.

Joseph (2013) stated that human emissions of greenhouse gases, principally carbon dioxide (CO_2), methane, and nitrous oxide, are causing a catastrophic rise in global temperatures. During the past century, human activities such as burning wood and fossil fuels and cutting down or burning forests are thought to have increased the concentration of CO_2 in the atmosphere by approximately 50 percent.

Continued burning of fossil fuels and deforestation could double the amount of CO_2 in the atmosphere during the next 100 years, assuming natural “sinks” don’t grow in pace with emissions.

Furthermore, De Laat et al. (2004) stated that clearing forests, irrigating deserts and building cities cause climate change. Cities tend to be warmer than suburbs, and suburbs warmer than rural areas, because they have greater concentrations of energy-producing machines and vehicles and large amounts of concrete, asphalt, and other building and road materials that absorb solar energy and then re-emit thermal energy leading to global warming. Also, Muhammad (2013) reported that climate has been changing largely due to the observed increases in human produced greenhouse gases that absorb heat from the sun in the atmosphere and reduce the amount of heat escaping into space. This extra heat has been found to be the primary cause of observed changes in the climate system over the 20th century.

2.1.4. Vulnerability to Climate Change and Variability

This refers to the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensibility or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014). According to MINIRENA (2013), the population of Rwanda faces multiple vulnerabilities to climate change effects because of its ecological sensitivity, and social and economic structure. In addition, Government of Rwanda (GoR) has developed a community/household climate change vulnerability index using 14 indicators which were divided into three categories namely exposure (changes in temperature, changes in rainfall patterns, drought episodes, flooding events); sensitivity (soil erosion and landslides, soil fertility, changes in natural environment, dependency level, irrigation, Livelihood sources) and adaptive capacity(awareness, information, surplus production and adoption of changed agricultural practices).

As reported by Rian (2008), climate change poses many risks to human activities especially those are specific to agricultural production include but not limited to:

- ✓ Warmer and shorter winters
- ✓ Increasing annual average temperatures
- ✓ Summer droughts affecting quality and quantity of water resource
- ✓ Increased competition for declining water supplies will increase

- ✓ Increased agricultural drought intensity
- ✓ Increasing frequency of severe weather events such as, ice storms, tornadoes, floods, droughts and heat wave
- ✓ Heavier shorter duration rainfalls resulting in increased erosion, flooding and runoff of nutrients, pesticides and other toxins from agricultural operations.
- ✓ Increasing risk of non-native (invasive) pests and diseases to crop
- ✓ Longer growing seasons, but crop yields may be impacted by increased and longer droughts.

Mark et al. (2008) highlighted some of the direct impacts of climate change on agricultural system as follows:

(a) Seasonal changes in rainfall and temperature, which could impact agro-climatic conditions, altering growing seasons, planting and harvesting calendars, water availability, pest, weed and disease populations;

(b) Alteration in evapotranspiration, photosynthesis and biomass production;

(c) Alteration in land suitability for agricultural production; some of the induced changes are expected to be abrupt, while others involve gradual shifts in temperature, vegetation cover and species distributions. As found by Matarira and *al*. (1995), even though irrigation can boost maize production, the yields are lower under climate change conditions than under normal climate.

The reduction in mean seasonal precipitation under climate change conditions implies that the water available for irrigation purposes would also be affected accordingly. This will reduce the effectiveness of irrigation as a strategy to combat the effects of climate change. Yield decreases are caused primarily by the increase in temperature, which shortens the duration of the crop growth stages particularly the grain fill period. IPCC (2007) reported potential impacts of climate change on agricultural production in different parts of the world and has predicted a decrease of up to 30% in world food production due to effects of climate change on agriculture.

A South African study undertaken by the University of Pretoria focusing at the provincial level, found significant correlation between higher historical temperatures and reduced dry lands staple production and forecast a fall in net crop revenues by as much as 90% by 2100. The study found small-scale farmers to be worst affected by the decrease.

The developing world already contends with chronic poverty and food crisis due to climate change. Khanal (2009) classified the impact of climate change on agriculture into biophysical and socio-economic impact. The biophysical impacts include: physiological effects on crop and livestock, change in land, soil and water resources, increased weed and pest challenges, shifts in spatial and temporal distribution of impacts, sea level rise and changes to ocean salinity and sea temperature rise causing fish to inhabit in different ranges. The socio-economic impacts result in decline in yield and production, reduced marginal GDP from agriculture, fluctuation in world market price, changes in geographical distribution of trade regime, increased number of people at risk of hunger and food insecurity, migration and civil unrest. He also reported that the patterns of the effects of climatic change are dependent on latitude, altitude, type of crop grown and livestock reared. When temperatures exceed the optimal level for biological process, crops often respond negatively with a steep drop in net growth and yield.

Brussel (2009) stated that rising atmospheric CO_2 concentration, higher temperatures, changes in annual and seasonal precipitation patterns and in the frequency of extreme events will affect the volume, quality, quantity, stability of food production and the natural environment in which agriculture takes place. In extreme cases, the degradation of agricultural ecosystems could mean desertification, resulting in a total loss of the productive capacity of the land in question.

This is likely to increase the dependence on food importation and the number of people at risk of famine. Morton (2007) in his research found three different categories of climate change impact upon smallholder livelihoods namely biological processes affecting crops and animals at the levels of individual organisms or fields; Environmental and physical processes affecting production at a landscape, watershed or community level and impacts of climate change on human health and on nonagricultural livelihoods.

Uzayisenga (2014) has showed a direct impact of changes in temperature, CO_2 and precipitation on yields of both food and cash crops as well as health of livestock.

She reported that higher levels of warming will have serious negative impacts on yields of maize and wheat. Increases in temperature increase irrigation water requirements of major crops and increasing water stress. He also reported that proliferation of crop pests and diseases increase under climate change. According to her report, there was an increase in Maize Streak Virus and Cassava Mosaic Virus in areas where rainfall increases, and sorghum head smut (a fungal disease) in areas where rainfall decreases (which would be compounded by farmers switching adaptively to sorghum in areas where maize becomes marginal).

According to MINAGRI (2009), extreme climate events have adverse environmental impacts on agricultural productivity. For instance, the 2008A and 2008B harvests were both negatively affected by serious droughts that came in at the beginning of the planting season. The droughts destroyed just-planted seeds and in some instances delayed planting so that crops became vulnerable to dry spells late in the season in ways that affected overall productivity.

2.1.5. Mitigation and Adaptation

a) Mitigation is defined as the action of reducing the severity, seriousness, or painfulness of something. According to UNEP, climate change mitigation refers to efforts to reduce or prevent emission of greenhouse gases. New technologies and renewable energies can be used to making older equipment more energy efficient, or changing management practices or consumer behavior. It can be as complex as a plan for a new city or as a simple as improvements to a cook stove design. Efforts underway around the world range from high-tech subway systems to bicycling paths and walkways.

Protecting natural carbon sinks like forests and oceans, or creating new sinks through silviculture or green agriculture are also elements of mitigation. Reducing climate change involves reducing the flow of heat-trapping greenhouse gases into the atmosphere, either by reducing sources of these gases (for example, the burning of fossil fuels for electricity, heat or transport) or enhancing the “sinks” that accumulate and store these gases (such as the oceans, forests and soil).

The goal of mitigation is to avoid dangerous human interference with the climate system, and “stabilize greenhouse gas levels in a timeframe sufficient to allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner” (IPCC, 2014).

b) Adaptation involves adjusting to actual or expected future climate. The goal is to reduce vulnerability to the harmful effects of climate change (like sea-level encroachment, more intense extreme weather events or food insecurity).

It also encompasses making the most of any potential beneficial opportunities associated with climate change (for example, longer growing seasons or increased yields in some regions). Though climate change is a global issue; it is also felt on a local scale. Cities and municipalities are therefore at the frontline of adaptation. In the absence of national or international climate policy direction, cities and local communities around the world have been focusing on solving their own climate problems. They were working to build flood defenses, plan for heat waves and higher temperatures, install water-permeable pavements to better deal with floods and storm water and improve water storage and use.

In addition, IPCC (2014) defines adaptation as the process of adjustment to actual or expected climate and its effects. The report states that in human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects. Governments at various levels are also getting better at adaptation. Climate change started to be factored into a variety of development plans like how to manage the increasingly extreme disasters we are seeing and their associated risks, how to protect coastlines and deal with sea-level encroachment, how to best manage land and forests, how to deal with and plan for reduced water availability, how to develop resilient crop varieties and how to protect energy and public infrastructure.

According to IPCC (2014), carbon dioxide capture and storage (CCS) technologies could reduce the lifecycle GHG emissions of fossil fuel power plants.

It also indicates that combining bioenergy with CCS (BECCS) offers the prospect of energy supply with large-scale net negative emissions which plays an important role in many low-stabilization scenarios, while it entails challenges and risks. Regarding waste management, important options for mitigation in waste management are waste reduction, followed by re-use, recycling and energy recovery.

2.1.6. Food Security

Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2008). From this definition, four main dimensions of food security can be identified as follows:

(1) Physical availability of food: Food availability addresses the “supply side” of food security and is determined by the level of food production, stock levels and net trade;

(2) Economic and physical access to food: An adequate supply of food at the national or international level does not in itself guarantee household level food security. Concerns about insufficient food access have resulted in a greater policy focus on incomes, expenditure, markets and prices in achieving food security objectives;

(3) **Food utilization** commonly understood as the way the body makes the most of various nutrients in the food. Sufficient energy and nutrient intake by individuals is the result of good care and feeding practices, food preparation, and diversity of the diet and intra-household distribution of food. Combined with good biological utilization of food consumed, this determines the nutritional status of individuals and;

(4) **Stability of the other three dimensions overtime**: Even if your food intake is adequate today, you are still considered to be food insecure if you have inadequate access to food on a periodic basis, risking a deterioration of your nutritional status.
Adverse weather conditions, political instability, or economic factors (unemployment, rising food prices) may have an impact on your food security status.

In opposite to food security, FAO (2008) reported that there are two type of food insecurity: (1) Chronic food insecurity which occurs when people are unable to meet their minimum food requirements over a sustained period of time, and (2) Transitory food insecurity which occurs when there is a sudden drop in the ability to produce or access enough food to maintain a good nutritional status.

2.1.7. Overview of Climate Change and Variability in Rwanda

Rwanda's climate is generally equatorial, but strongly influenced by the mountainous and hill relief of the country.

It is mainly determined by the Inter-Tropical Convergence Zone (ITCZ), and additionally by subtropical anticyclones, monsoons, East waves as well as the tile connections related to the temperatures of the oceans (SST) and episodes of El Nino/Southern Oscillations (ENSO). Normally climate of Rwanda was moderate characterized by two rainy seasons from mid-September to mid- December and from mid-February to May and two dry seasons from Mid-December to Mid-February and from June to mid-September (UNDP, 2010).

Mutabazi (2010) found that temperature has increased with high frequency of warm days exceeding 30°C. He also found that the number of annual rain days decreased that is likely to negatively impact on agricultural productivity as crops requires the quantity of water within the given number of days. He mentioned that frequency of torrential rain increased with daily rainfall quantity sometimes exceeding the total monthly rainfall caused floods and soil erosion. He also noted that the number of dry spells during rainy season increased and affected poor performance of crops due to the late set of rainfall and/or early rainfall cessation during rainy season also caused poor performance of agriculture productivity. He noted that annual mean maximum temperatures range from 13 ° C to 28 ° C according to the layering of relief. The low values of 13 ° C to 20 °c; are observed in Northwest in the volcanic region. The highest values above 25 ° C are located in the east and south east of the country and that the shores of Lake Kivu. Elsewhere in the country, the maximum temperatures are viable at 20 ° C to 25 °C.

REMA (2010) reported that observations and analysis from existing data shows that over the last 30 years, some parts of Rwanda have experienced unusual irregularities in climate patterns including variability in rainfall frequencies and intensity, persistence of extremes like heavy rainfall in the northern parts and drought in the eastern and southern parts. Analysis of rainfall trends show that rainy seasons are tending to become shorter with higher intensity. This tendency has led to decreases in agricultural production and events such as droughts in dry areas; and floods or landslides in areas experiencing heavy rains. Heavy rains have been being observed especially in the northern and the western province.

These heavy rains coupled with a loss of ecosystems services resulting from deforestation and poor agricultural practices have resulted in soil erosion, rock falls, landslides and floods which destroy crops, houses and other infrastructure (roads, bridges and schools) as well as loss of human and animal lives. Heavy rainfall, in combination with natural factors like topography, is having great impact in some areas. Floods and landslides are the main disasters in the high altitude regions mainly during the rainy seasons. Indeed in light of Rwanda's topography, the potential for flash flooding in many parts of the country is ever present.

2.1.7.1. Status of Temperature in Rwanda

The analysis of the average annual temperatures from the Kigali Airport and Kamembe meteorological stations shows a consistent increase in average temperature from 1971 to 2012. For Kigali, the average temperature has increased from 19.8°C in 1971 to 21.0°C while Kamembe experienced an increase from 18.9°C to 19.7°C in 2012. The figure 2&3 below showed that the mean temperature has increased from 20.2^{0}C to 21.9^{0}C for Kigali weather station (+1.7^{0}C) and 19.1^{0}C to 21.1^{0}C (+1^{0}C) for Kamembe weather station since 1971 up to 2011.

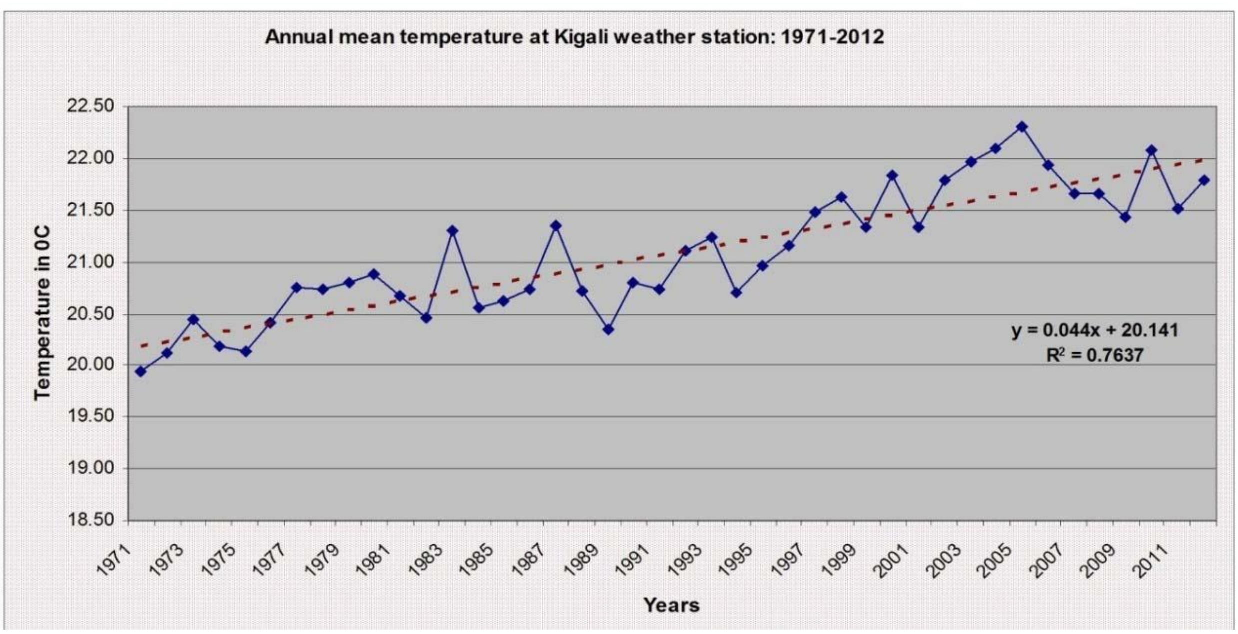

Figure 2: **Mean Annual Temperature at Kigali Weather Station** (RMA, 2014)

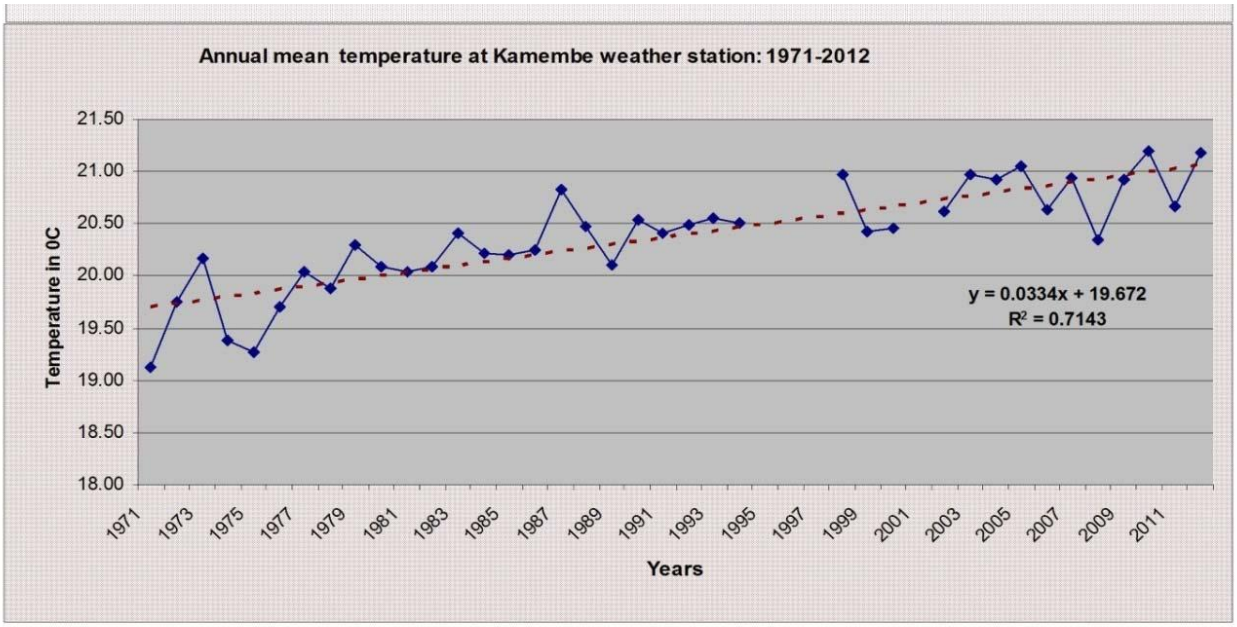

Figure 3: **Mean Annual Temperature at Kamembe Weather Station** (RMA, 2014)

Although the trends at Kigali and Kamembe stations have a gentle slope, a 1.2°C increase in 4 decades is as worrisome as it exceeds the 0.8°C reported to have been caused by global warming over a period of 150 years (Figure 3). According to Ruosteenoja et al. (2003) the temperature is expected to increase gradually in Rwanda during the 21st century.

2.1.7.2. Status of Rainfall in Rwanda

The analysis of rainfall data recorded at Kanombe Airport weather station reveals that total annual rainfall has significantly changed and more unpredictable patterns of precipitation increased. The highest rainfall was observed in the year 1998, 2001, 2010 and the lowest in 1992, 2000 and 2008. In other years the amount is fluctuated. However, between 1980 and 1992 the amount of rainfall is generally decreasing and between 1992 and 2003 there is extremely high variability. From the year 2003 to 2011, the trend shows that the rainfall is increasing. Although the overall trend shows a declining trend, there is tendency towards increased precipitation seen from 2008 onwards (RMS, 2012 cited in Rwanyiziri and Rugema, 2013).

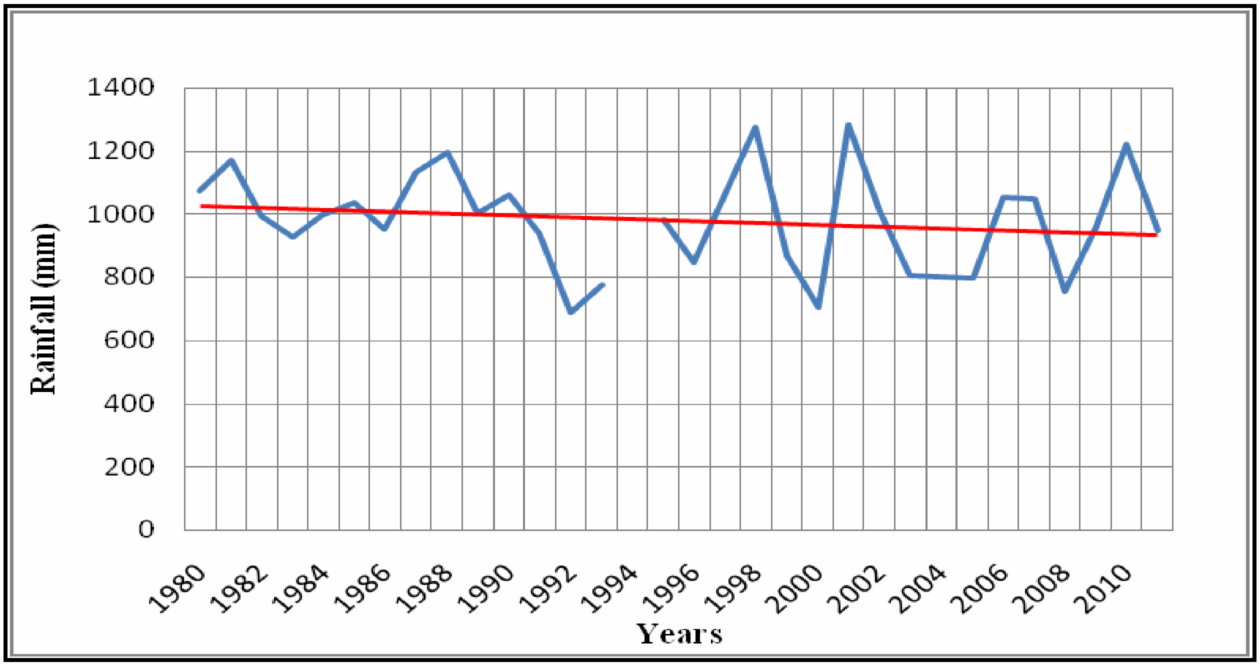

Figure 4: **Annual Mean Rainfall of Kigali Airport Meteorological Station** (Rwanyiziri & Rugema, 2013)

REMA (2010) assessment, observed rainfall at Kigali meteorological station indicated that the monthly and annual total rainfalls recorded during the six years are generally lower than the average of 1961 to 1990. More particularly, April, the month with the highest rainfalls has been recorded as having the rainfall equivalent to 27%, 48%, 88%, 70% and 52% respectively in 2000,2001,2002,2003 and 2005. Months of July, September, November and December have had higher rainfalls than normal with the percentages respectively of 1,441% (in 2001), 189% (in 2003), 165% (in 2006) and 153% (in 2006).

The comparison of 1971-1990 and 1991-2009 periods indicate that the monthly average number of rain days generally decreased for most of months including April and November, the rainiest months of year. In fact the annual average total number of rain days was 146 days for the period 1971-1990 and become 131 days for the period 1991-2009.

This indicates the poor rainfall performance in last years. This is also confirmed by the annual average rainfall totals which decreased from 1020 mm to 920 mm. In other words, during the 1991-2009 periods, there is a decrease of average rainfall of about 100 mm per year compared to 1971-1990 period. Figure 3 shows the trend of annual total number of rainfall days.

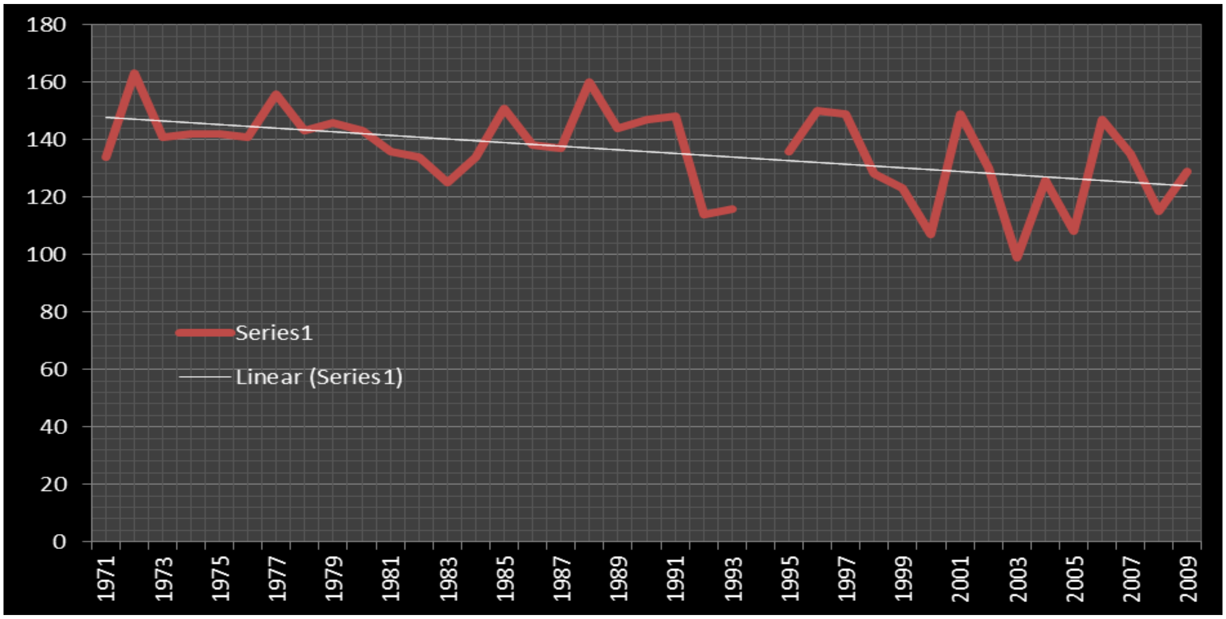

Figure 5: **Annual Number of Rain Days at Kigali Station** (Mutabazi, 2010)

2.1.8. Major Adaptation and Mitigation Strategies in Rwanda

Climate change affects all but people in the greatest danger live in the poorest countries or small island nations due to the least resources to protect their people". Climate change vulnerability in Rwanda has already been experienced in the areas of agriculture and food security; renewable energy; frequency of natural disasters and epidemics, among others (REMA, 2010).

Though Rwanda is a low-carbon economy, it's among those most vulnerable to climate change. According to REMA Strategic Plan (2010-2015), recent events such prolonged droughts characterized by crop failures, erratic and destructive rains, floods, have demonstrated that climate change is real and will affect poor countries like Rwanda and poor, natural resource dependent communities with limited safety nets like the most Rwandans. Presently, climate change management initiatives in Rwanda are limited to monitoring greenhouse gases (GHG) emissions and a few projects for mitigation and adaptation, under the Rio Multilateral Environmental Agreements (MEAs). Yet the scale and magnitude of climate change effects will be large and multi-sectorial requiring holistic, integrated, sustainable, policy-linked interventions.

Under the EDPRS and Vision 2020, REMA has designed a comprehensive national climate change policy and strategy to integrate climate change into all development policies, programs and budgets to address the following priorities:

- ❖ Generating spatial and thematic information on Rwanda's climate change vulnerability, including implications for poverty reduction and regional integration;
- ❖ Developing a policy and institutional framework for integrated climate change management;
- ❖ Capacity development for climate change management including disaster preparedness and response, climate change mitigation and adaptation, in a sustainable way;
- ❖ Public-private partnerships for sustainable financing and management of climate change issues, including international negotiations and communication

In addition, MINIRENA (2013), Government of Rwanda has been implementing large-scale afforestation projects specifically to reverse deforestation and increase the supply of forest and tree resources. In 2006, Rwanda formulated a National Adaptation Programs of Action to Climate Change (NAPA) that communicate priority activities addressing the urgent and immediate needs and concerns relating to adaptation to the adverse effects of climate change. NAPA specifically highlighted the following strategic priority responses to addressing climate change (adaptation):

1. An Integrated Water Resource Management – IWRM;

2. Setting up an information system to early warning of hydro-agro meteorological system and rapid intervention mechanisms;

3. Promotion of non-agricultural income generating activities;

4. Promotion of intensive agro-pastoral activities;

5. Introduction of species resisting to environmental conditions;

6. Development of firewood alternative sources of energy; and

7. A National Plan for Disaster Management (Emergency Plans).

Furthermore, through FONERWA (2015), GoR also has designed a metadata handbook that encompasses the government targets to fight climate change which include: cumulative volume of finance mobilized for climate and environment purposes; area (ha) forest and agro-forest cover; area (ha) of watersheds and water bodies protected; research and feasibility studies that facilitate adoption of clean and climate-resilient technologies; Number of households with improved access to off-grid clean energy; tons of CO_2 equivalent emissions avoided; number of people supported to cope with effects of climate change; national level MIS with sufficient environmental & climate change data to inform policy decisions; number of people involved in climate resilient income generation activities among others.

Changes in government policy in response to climate change would have a very significant influence on how agriculture ultimately responds. The availability of facilities, level of funding and outlook on private sector initiative can greatly influence the rate at which crop varieties, livestock breeds, agricultural technologies, and management systems adaptable to climate change can be implemented (Parry and Duinker, 1990). Efforts to manage agricultural climate risks can involve many decision-makers, conflicting values, competing objectives and methodologies, multiple options, uncertain outcomes and debatable probabilities.

According to Mizina et al. (1999); Reilly and Schimmelpfennig (1999), adaptation is an important component of any policy response to climate change. Without adaptation, climate change will be problematic for agricultural production and for agricultural economies and communities. Adaptations to climate change occur at two levels: the farm level where adaptations arise from the farmers’ perception of changed or changing conditions and the national level adaptations as reflected in government policy.

He also highlighted the forms of adaptation at farm-level include modification of resource management, purchasing crop insurance, and diversification while forms of policy level adaptations include aid for research and development, incentive strategies and infrastructure measures. Agricultural adaptation options are grouped according to four main categories that are not mutually exclusive: (1) technological developments, (2) government programs and insurance, (3) farm production practices, and (4) farm financial management. The typology is based on the scale at which adaptations are undertaken and at which the stakeholders are involved (Barry and al. (2002).

CHAPTER THREE: MATERIALS AND METHODS

This chapter discusses the methodology used in the study, describes the study areas, the population and sample size, sample selection techniques, research instruments, methods of data collection, data management and analysis.

3.1. Description of Study Area

The research was conducted in the highlands and central plateaus of Rwanda precisely in Rulindo (Highland) and Kamonyi (plateau) Districts. In Rulindo District Bahimba wetland was chosen and in Kamonyi District, Bishenyi wetland was also selected. Maize farmers using these wetlands constituted the sample population for the study.

3.1.1. Bahimba Wetland

This study focused on Bahimba Wetland located in Rulindo District in highlands of Rwanda. The District shares its borders with Gasabo and Kamonyi Districts in the South, Gakenke District in the West, Gicumbi District in the East and Burera District in the North. Rulindo District is one of the five Districts that make up the Northern Province and the majority of the district's population depends on agriculture whereby 84% of households are smallholder farmers.

The District has 17 administrative Sectors with an estimated total population of 288,452 of which 136,058 are males while 152,394 are females. The surface area is estimated at 567 km2 and population density of 509 per km2 with the average annual growth rate within the last ten years (2002-2012) being 1.4%. Rulindo District is mostly characterized by hills among which include Tare, Tumba and Cyungo with their altitude rising to 2,438 m. These hills are interspersed by valleys and swamps that also border with rivers of Nyabarongo, Muyanza and Nyabugogo. The challenges in Rulindo include Low agricultural output/yields, soil acidity, climate variability and limited research in agriculture. Compared with other districts in Northern Province, Rulindo district has the highest percentage of extreme-poor. This depicts the required efforts and need for concrete strategies to increase productive capacity of the population in order to come out of poverty (Rulindo District, 2013).

Bahimba wetland is located in two sectors namely Mbogo and Tumba. In wide sense, it covers five sectors namely Mbogo, Tumba, Bushoki and Rusiga in Rulindo District, and Base Sector in Gakenke District. Though the five sectors are all touched by Bahimba Wetland, the study focused on only two sectors which are Mbogo and Tumba within which water resources are mostly found.

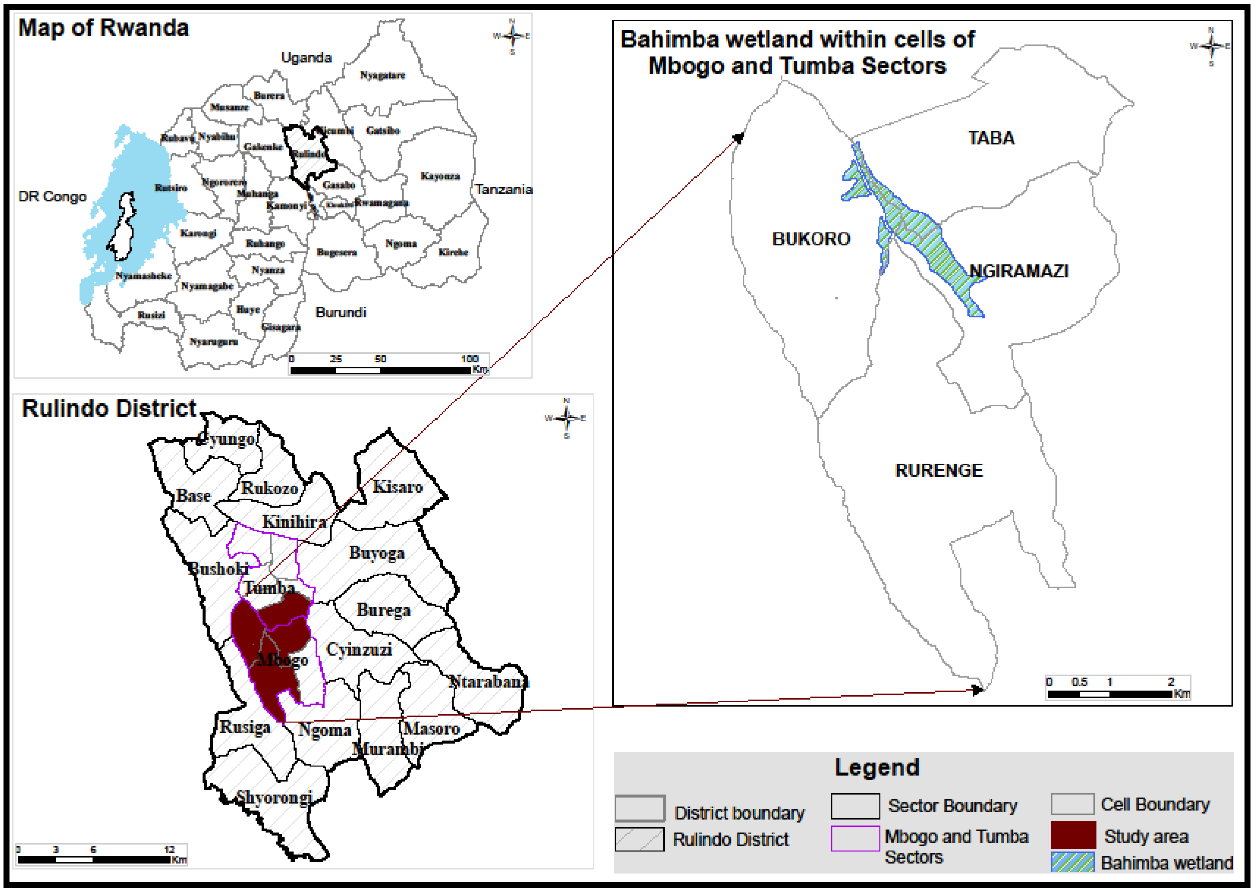

Figure 6: **Map of Bahimba Wetland in Rulindo District** (CGIS, 2016)

3.1.2 Bishenyi Wetland

Kamonyi is one of the eight Districts that make up the Southern Province and is located in the central plateaus of the country. The District shares its borders with Ruhango District in the South, Muhanga District in the West, Bugesera and Nyarugenge Districts in the East, Gakenke and Rulindo Districts in the North. It is composed of 12 Sectors with a population of 342,792 inhabitants on a total surface area of 655.5 km² and 72,000 households (NISR, 2011). Its average density is 523 inhabitants per Km^2 and 85% of households are farmers. District's economy mainly is based on agriculture and livestock.

Kamonyi District is drained by the great river of Nyabarongo along the East and North of the District and Akanyaru River which border the District in North and Eastern part. There are also a number of small water courses, such as Kayumbu, Bakokwe, Bishenyi, Mukunguri, Nyabuvomo, Bishenyi, Gatimbazi and Ruvubu. Its general relief is made of low lying plateau. The District is facing with soil erosion and overexploitation due to demographic pressure. Marshlands occupy 4183.2Ha. District Kamonyi several marshes include: Rwabashyashya, Kibuza, Bishenyi, Kayumbu, Mpomboli, Kivogo, Kavunja, Akanyaru, Mukunguli, Barama, Ruvubu and Nyabarongo and most of them are used for food crops include Maize. Compared with the national agricultural production level attained in different crops in the year 2011, the district is in low position in all those crops. This study focused on Bishenyi Wetland located in two sectors namely Runda and Rugarika (Kamonyi District, 2013).

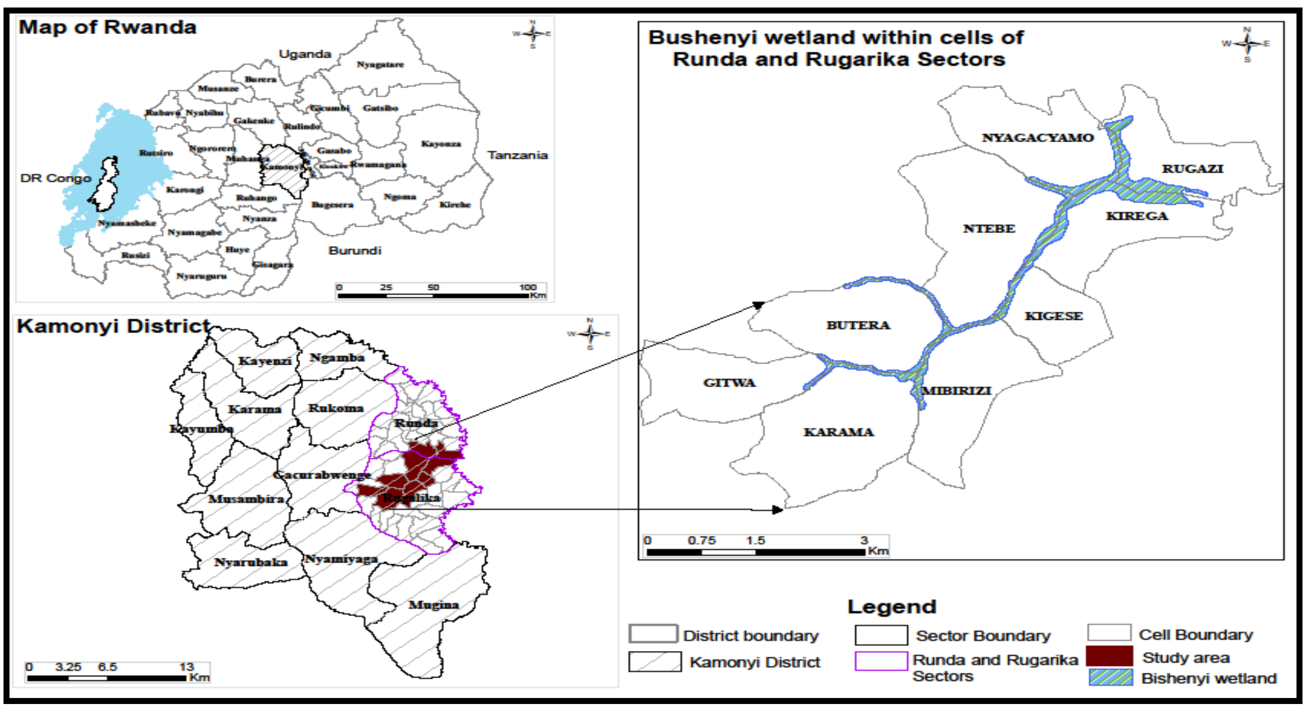

Figure 7: **Map of Bishenyi Wetland in Kamonyi District** (CGIS, 2016)

3.2. Source of Data

The study used existing rainfall and temperature data and maize yields of the last five years

3.2.1. Secondary Data

a) Existing Literature

The literature review consisted of the analysis of relevant climate-related scientific publications, UNFCCC and IPCC reports, government reports and policy documents available in libraries, ministries, local institutions, DDPs and key organizations' and institutes' archives such as University of Rwanda/Huye Campus; National Institute of Statistics (NISR), Rwanda Meteorological Agency (RMA) especially for rainfall and temperature data annually recorded over the past 30 years, Rwanda Environment Management Authority (REMA), World Meteorological Organization (WMO), Food Agriculture Organization (FAO), and United Nations Environment Programme (UNEP), Cooperative book records of seasonal maize harvests, among others.

b) Climatic Data

The current study used climate data of temperature and rainfall over the past 30 years to evaluate the fluctuation of rainfall and temperature in the areas of study hence linked the climate changes to the performance of maize crop in wetlands under study. The study used data merging method to obtain specific data for the areas of study. The Merging method involves combining point measurements from rain gauge networks and satellite estimates. Gauges provide "accurate" point measurements, but limited spatial coverage whereas satellite and reanalysis provide information on the spatial structure rainfall/temperature with excellent spatial coverage. As satellite data may not be accurate, merging data combines the strengths of the two different data sets.

Simple bias removal

This involves the extraction of rainfall estimate values at rain gauge locations, computation of the difference between satellite and rain gauge values at each station location, interpolating the differences to each grid point (same as satellite pixel centers) then adding the interpolated differences back to the satellite estimate.

Merging Rainfall

Merging rainfall data involved combining rainfall data from both weather stations (gauges) and satellite to obtain rainfall datasets for climate monitoring at small scale. The obtained rainfall dataset over past 30 years helped to analyse rainfall fluctuation at the locations of study areas.

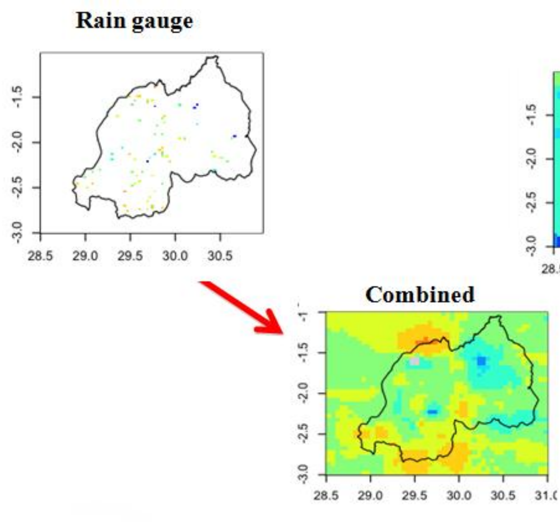

Figure 8: Merging rainfall (RMA, 2016)

Merging temperature

Merging temperature data also involved combining temperature data from weather stations and satellite/reanalysis to evaluate temperature change at sectors levels. The obtained temperature dataset helped to analysis temperature change over the past 30 years at Bahimba wetland (Tumba sector) and Bishenyi wetland (Runda sector) as follows.

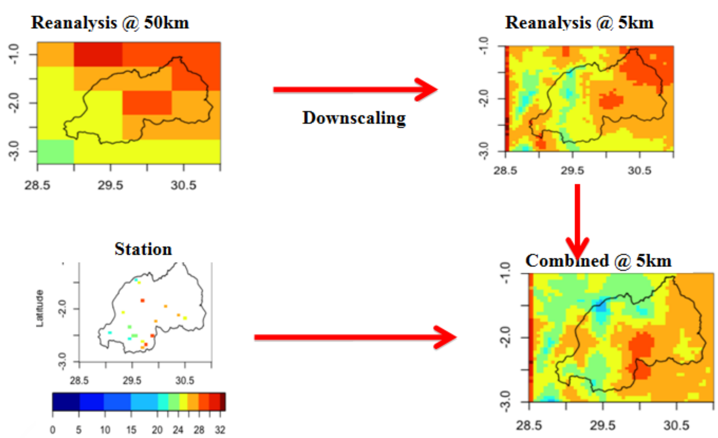

Figure 9: Merging Temperature (RMA, 2016)

Process of obtaining climatic data

In order to obtain rainfall and temperature datasets, climate data tools computer program, version2.3 was used. This software helped to get rainfall dataset and temperature dataset of the study areas over the period of past 30 years by extracting rainfall and temperature data at the locations of study areas as follows.

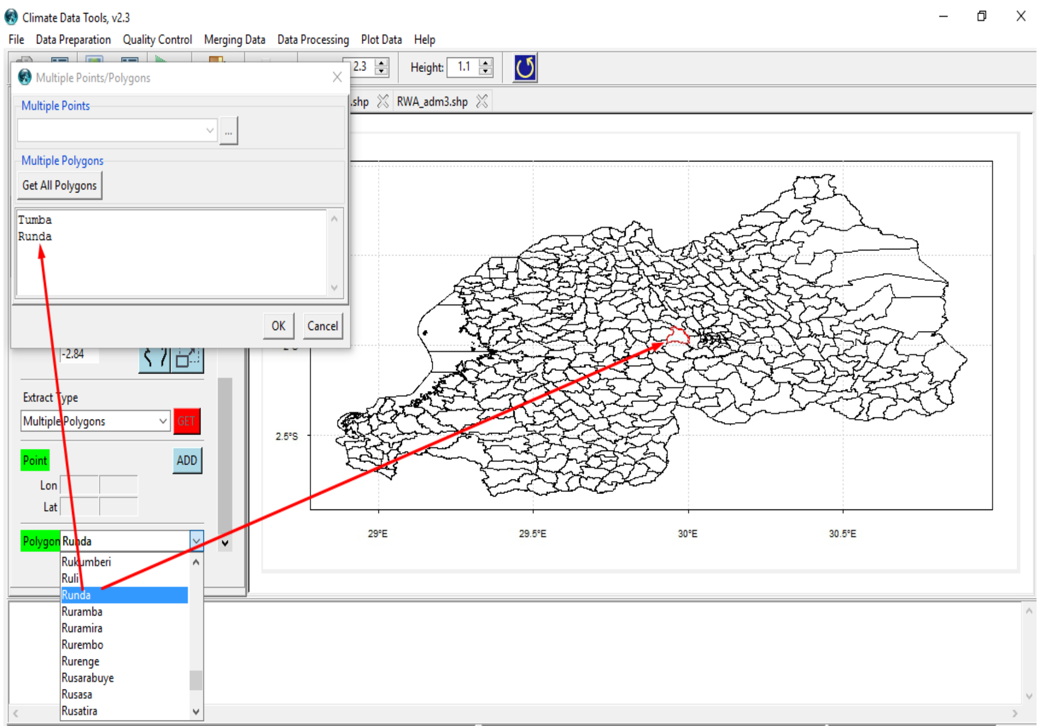

Figure 10: Extraction of rainfall datasets for the study locations (Author's construct, 2016)

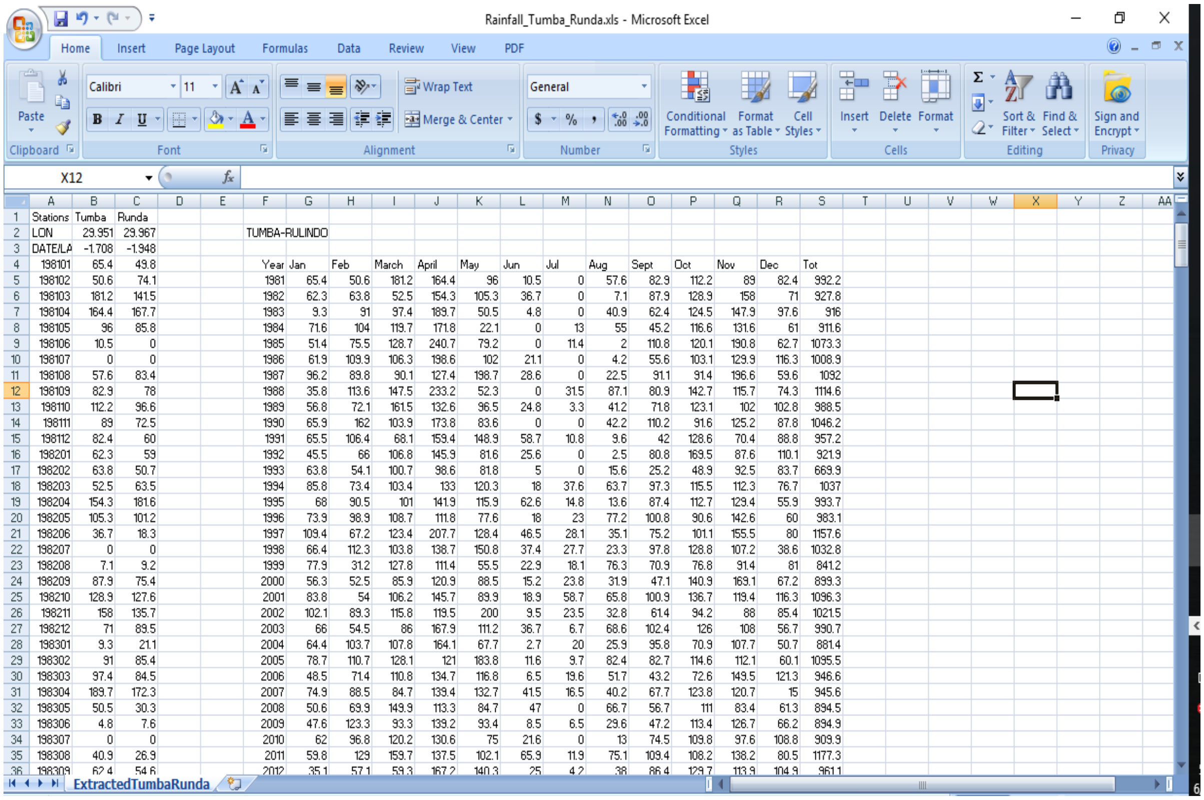

Figure 11: Imported merged rainfall dataset in Excel sheet (Author's construct, 2016)

c) Data of Maize Yields

The study used maize harvests data as recorded by maize farmers' cooperatives to evaluate the change in maize yields to help in analysis of relationship between maize yields, food security and climate conditions in terms of rainfall, temperature, droughts and floods events as well as the effects of maize pests and diseases.

3.2.2 Primary Data

Primary data focused on multi-methods approach include field observations and geospatial data were obtained using Global Positioning System (GPS); taking pictures with a digital camera; Interviews and focus group discussions (a combination of participatory and rapid assessment techniques was used) and questionnaires where a semi-structured questionnaire was used in farmers' survey involving 200 maize farmers and 7 key informants.

3.3. Data Collection Techniques

Data were obtained using a semi-structured interview and self-administered questionnaires were completed by 200 maize farmers (n=200).. Group discussions and interviews with key informants from Maize cooperative committees and local agronomists were also conducted (n=7) to obtain different ideas in relation to impact of climate changes and their effects on maize yields in the surveyed wetlands. Group discussion and interview focused on variables including the impacts of climate change and variability on maize production in the study area, existing adaptation strategies and the possible solutions for farmers to better cope with impacts of climate change and variability. Climate data over the past 30 years consisting rainfall and temperature were obtained from Rwanda Meteorological Agency.

3.3.1. Field Observation

The field observation focused of the physical status of wetlands' and landscapes' management along with photo taking with a digital camera in order to get general picture of the current situation in terms of wetland agricultural production mainly maize and management of the entire ecosystem being exploited for crop development that helped to know and understand farmers' practices towards resilience to climate change and variability.

3.3.2. Household Survey

a) Population of the Study

The research population or target groups included the maize farmers in the two wetlands (Bahimba and Bishenyi) and local government agronomists and key informants in the areas.

b) Sample Size

This thesis was conducted in two wetlands. A study population of 207 farmers was randomly selected from the maize farmers using wetlands of Bahimba and Bishenyi and key informants having roles in the exploitation of the stated wetlands. 103 people were selected in Bishenyi wetland located in Kamonyi District in the central plateaus of the country.

The other 104 respondents also were randomly selected in Bahimba wetland located in Rulindo District in the highlands of the country.

c) Administration of the Questionnaire

A semi-structured questionnaire was administrated to the random selected study population in a farmer survey involved farmers working in the selected wetlands. It was mainly focusing on exposure, sensitivity and capacity of maize growers in wetlands towards adaptation of impacts of climate change and variability and how they managed to build resilience to sustain food security when climate related threats occur in the study areas.

3.3.3. Interviews

Semi-structured interview was used to understand maize farmers' and authorities' perceptions towards climate change and variability impacts focusing on what kinds of climatic hazards and frequencies, climate-related shocks, questions related changes in rainfall, temperature, droughts and floods, coping strategies and how they can be improved. This allowed respondents to discuss and raise issues which have not considered while designing the questions for interviews. Face to face interviews with key informants was organized particularly for local government agronomists, environmental managers and cooperative committee members to capture their views, observations and experiences in relation to research problem.

3.4. Data Analysis

Several methods of data analysis were used. Responses were organized into categories based on the information affiliation. These include statistical analysis of socio-economic data (primary/secondary) by using SPSS, Microsoft Excel for climate data analysis and for visual display of information; and Geographic Information System (GIS) and ArcGIS 10.2 software for mapping the sites of study. Tables, graphs, and other quantitative information were interpreted with Microsoft excel, SPSS and other facilities. The qualitative data analysis was based on content analysis of information from structured interviews organized with agronomists and key informants in the areas of study. It helped in reclassifying concerned stakeholders. Furthermore, the analysis focused on the information flow in benefits and initiative prospects in adapting climate change and variability in wetlands where crop development is being practiced and for food security improvement and sustainability. Finally, tables, figures and photos were interpreted to help formulating conclusions and recommendations for climate change and variability adaptation and sustainable food security.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter comprises two major sections which are results and discussion.

4.1. Research Findings

This chapter comprises the analysis of data followed by a discussion of the research findings. The findings are related to the research questions and objectives that guided the study. Data were analyzed to assess and describe the impacts of Climate Change and Variability on Wetland Agricultural Production and Food Security in Rwanda: Case Study of maize production in Bahimba and Bishenyi wetlands. Data were obtained using a semi-structured interview and self-administered questionnaires was completed by 200 maize farmers (n=200) and 7 key informants as a sample size of the study. Collected data were analyzed by using SPSS version 20 (IBM statistics) and Excel for visual display of information. Specific objectives oriented the content analysis, descriptive analysis and statistical analysis. Tables and charts were used to identify frequencies and percentages of responses given to the entire questionnaire.

All respondents answered all questions thus percentages reported correspond to the total number of respondents completed the individual questionnaire. The majority of respondents (55.3%) were females while 44.7% were males. 60.5% of respondents were aged between 31 and 55 years that falls into the category of economically active age and 81.8% of respondents were married. 56% attended primary school and around 81.6% had a family size of one to five household members. The analysis results showed that agricultural sector is mainly made up of the people with lower level of formal education. During cropping season, 47.5% of interviewed maize farmers use purchased manure while 47% use their own manure from livestock. The study also found that 53.9% of surveyed farmers use inputs from MINAGRI, 30.6% from agro-dealers.

In addition, group discussion and interviews was also done by applying the method of thematic Analysis to assess different ideas from 7 persons represented two cooperatives (COVAMABA and UBUMWE).

Group discussion and interview focused on variables including the impacts of climate change and variability on maize production in the study area, adaption strategies to climate change and variability to improve maize production and sustain food security in the districts of Rulindo and Kamonyi, the constraints to the implementation of the adaptation strategies and lastly the possible solutions to enable farmers better coping with climate change and variability impacts.

4.1.1. Status of Climate Change and Variability in Bahimba and Bishenyi Wetlands

4.1.1.1. Trend of Temperature Patterns

Temperature variations in the study areas (Fig.7&8) are closely similar with temperature variations in other areas of the country. Temperature trend lines in Bahimba and Bishenyi wetlands indicate the similar increase in mean temperature since 1981 to 2014 as seen in other locations of the country. In Bahimba wetland the average maximum temperature was 18.40^{o}C whereas the minimum was 17.55^{o}C since 1981 to 2014, making an increase of 0.85^{o}C

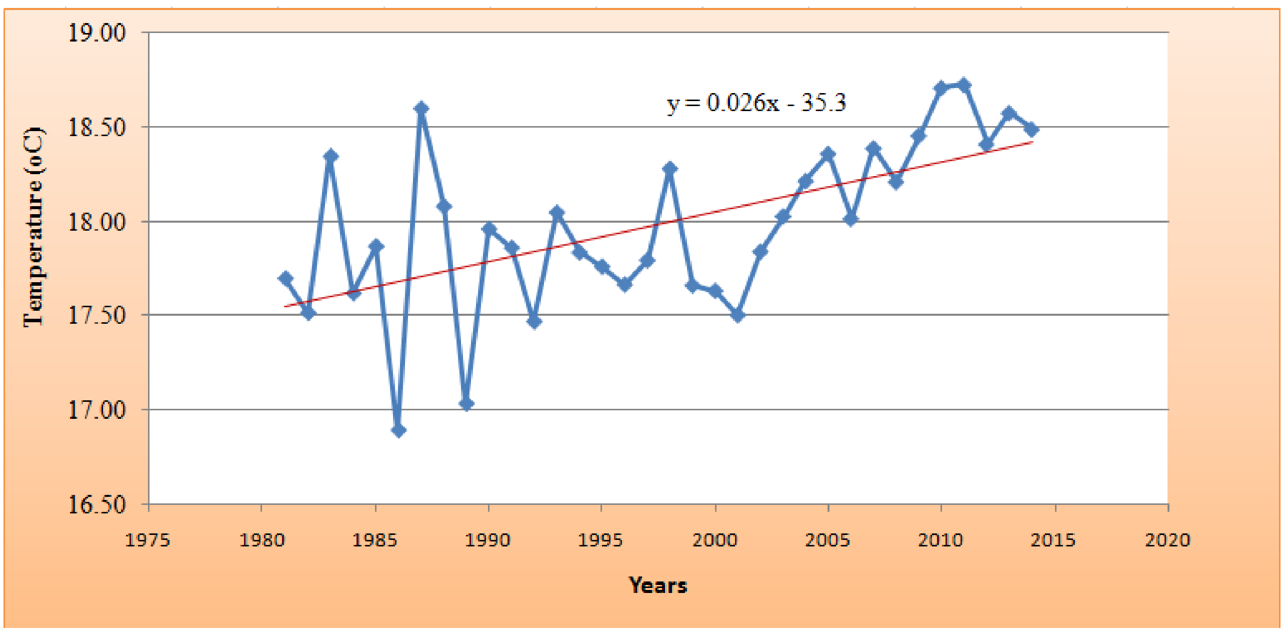

Figure 12**: Trend of Temperature for Bahimba Wetland between 1981 and 2014** (RMA, 2016)

For Bishenyi wetland the maximum average temperature was 21.08^{o}C whereas the minimum was 19.97^{o}C from 1981 to 2014 making an increase of 1.1^{0}C.

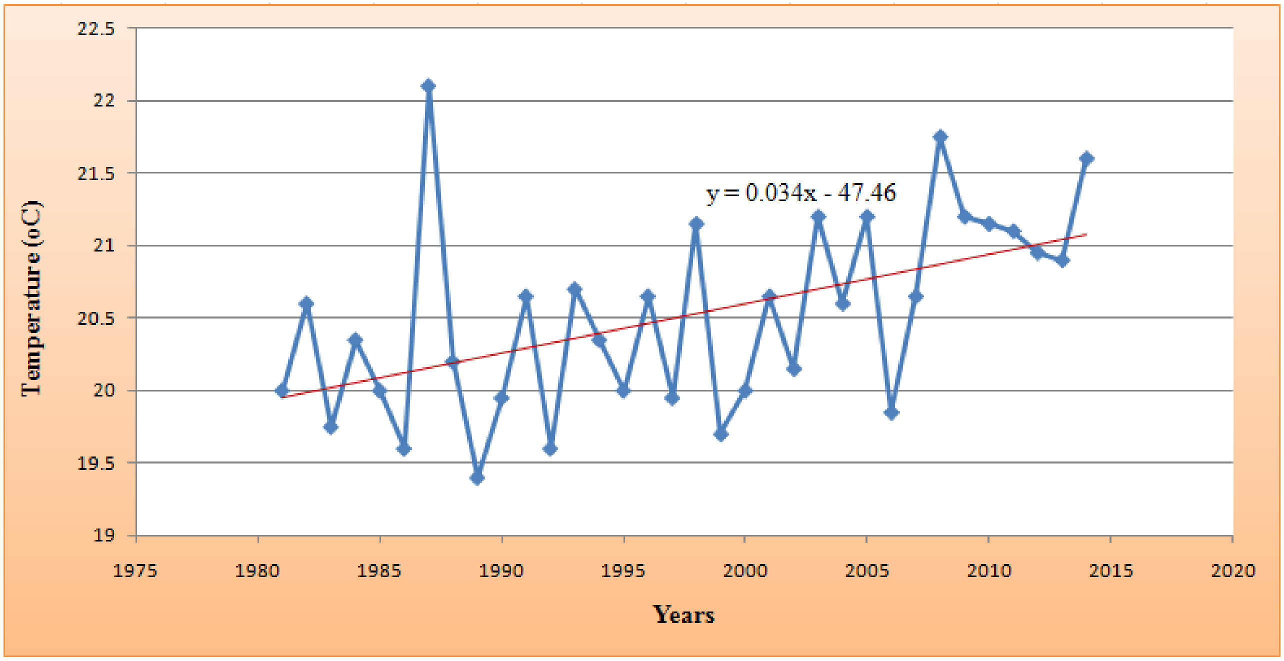

Figure 13: **Trend of Temperature for Bishenyi Wetland between 1981 and 2014** (RMA, 2016)

The increase in mean temperature in Bishenyi wetland is due to the fact that is located in central plateaus where it is hotter that in the highlands that also confirms more droughts frequencies in Central plateaus than in highlands. These mean temperature increases confirm climate change in Bahimba and Bishenyi as the Global mean temperature increase was at .85^{0}C since 1980-2012 what is thought to be an evidence of climate change that alters climate conditions worldwide. These findings also confirm the observations of maize farmers in both wetlands that maize production has been adversely affected due temperature increases.

4.1.1.2. Trend of Rainfall Patterns

The analysis results (Fig. 9 & 10) indicate abnormal rainfall fluctuations where a little decrease is found in Bahimba while a little increase was noted in Bishenyi since 1981 to 2014. For Bahimba wetland, the amount of rain decreased from 990 mm to 960mm making a decrease of -30mm since 1081 to 2014.

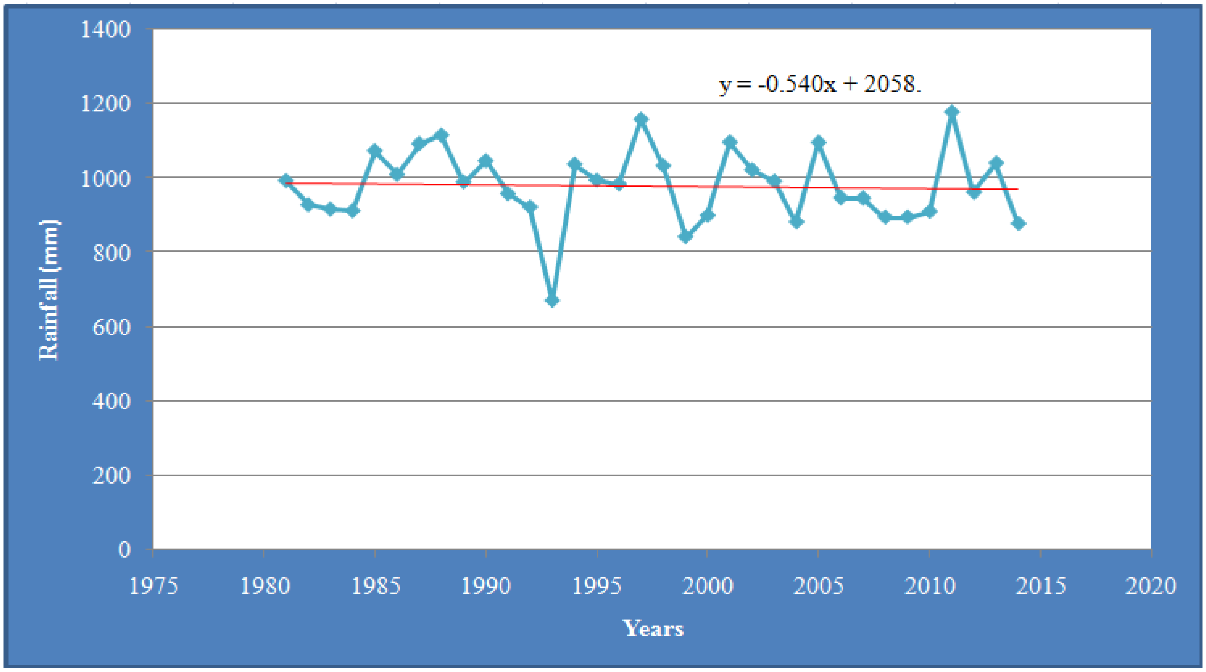

Figure 14: **Trend of Rainfall for Bahimba Wetland between 1981 and 2014** (RMA, 2016)

While for Bishenyi wetland, the amount of rain increased from 820mm to 870 mm since 1981-2014 making an increase of 50 mm.

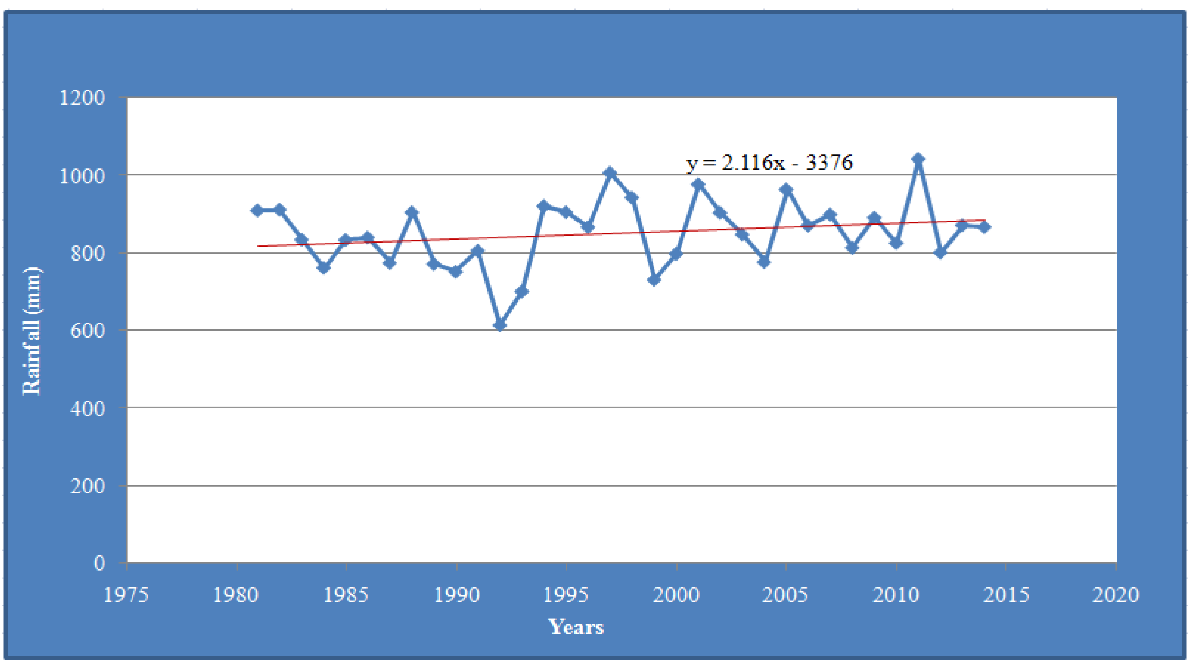

Figure 15: **Trend of Rainfall for Bishenyi Wetland between 1981 and 2014** (RMA, 2016)

This is the abnormal changes considering geographical location of Bahimba wetland where more rains were expected than in Bishenyi wetland located in central plateaus of the country. Maize farmers and agronomists from both wetlands have attributed these rainfall anomalies to poor performance of maize that also have led to food insecurity. Due to these observed rain shortage and abnormal variations, total maize yields has been reducing due to the extended dry spells especially in 2013 and 2014 for Bishenyi wetland and in 2015 for Bahimba wetland. Particularly maize farmers in Bahimba reported to have faced with maize poor germination where farmers had to replace non-germinated seeds due to early cessation of rain that led to poor growth of maize crop and hence ears per maize crop reduced from 2 to 1.

4.1.2. Perceptions of Maize Farmers on Climate Change and Variability

The survey found that 100% and 96% of maize farmers from Bahimba and Bishenyi wetlands respectively have noticed a change in climate conditions over the past 30 years. Maize producers have experienced with the late sets of rainy seasons characterized by irregular, heavy, shorter and early cessation of rainfall that has adversely affected maize crop performance. They also had felt increased warmer weathers and extended dry spells which had caused low soil moisture, poor germination and maize crop water stress and high proliferation of pest and diseases. According to maize farmers from both wetlands, this change in climate has led to maize poor harvests and food insecurity not only for maize growers but the entire communities surrounding the surveyed wetlands. Figure 12 below depicts farmers' views on climate change and variability over the past 30 years in the surveyed wetlands.

With regard to changes in temperature, 97% of the farmers in Bishenyi and 93.3% in Bahimba wetlands have been feeling the increase in temperature, for the of rainfall, the situation is worse than in Bahimba where 87 % of farmers in Bishenyi have been experiencing delayed rainy season while in Bahimba is 74% only. In addition, 90.9% of maize farmers in Bishenyi have experiencing the erratic rains while in Bahimba, was 81% of farmers. Concerning heavy rains and floods, maize farmers from Bahimba are more vulnerable than farmers from Bishenyi wetland with 92.9 and 74.2% of farmers in Bahimba while in Bishenyi are 61% and 59% of respondents. Above 70% of respondents from both wetlands have been experiencing a delayed rainy season. With regards to droughts, Bishenyi farmers are more vulnerable than Bahimba where 81% of farmers were affected with prolonged droughts while in Bahimba it was 75.5%.

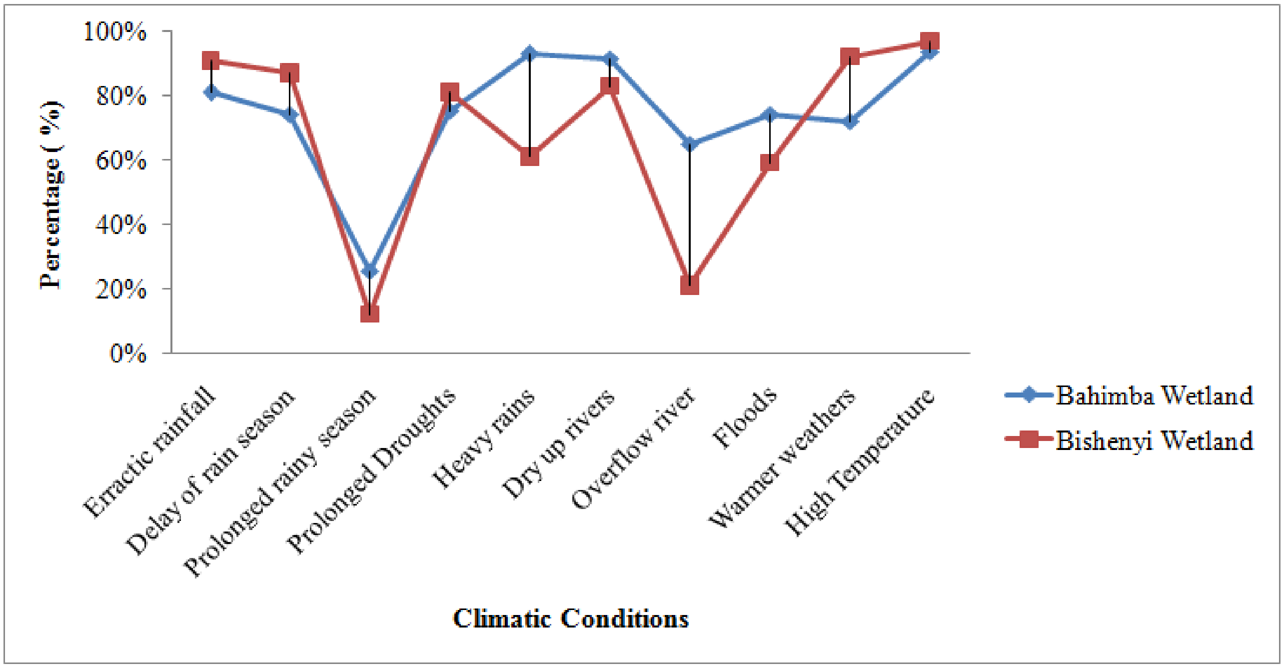

Figure 16: **Actual Climate Conditions in Bahimba and Bishenyi Wetlands** (Field Survey, March 2016)

These disparities were due to different geographical locations of the two wetlands where Bahimba is located in highlands while Bishenyi is located in central plateaus of the country. There is a need of adequate adaptation strategies to facilitate farmers improving maize production to sustain food security.

4.1.3. Impacts of Climate Change and Variability on Maize Production

This section discusses the impacts of climate changes which have caused the poor yields of maize that has led to food insecurity for maize farmers in Bahimba and Bishenyi wetlands and the communities particularly Tumba and Mbogo sectors.

4.1.3.1. Effects of Droughts on Maize Crop

Results of the assessment of effects of droughts to maize production in the two wetlands (Figure 13) revealed that between 97% and 99.5% of maize farmers faced with increase in maize diseases and pests, crop wilting, germination failure and reduced production cycle. 69% of farmers had a problem of maize premature ripening due to droughts that caused crop water stress hence affected maize crop growth.

Maize farmers reported that droughts have led to reduced maize yields, poor quality of harvest, increased production cost that also adversely has affected food security in the community.

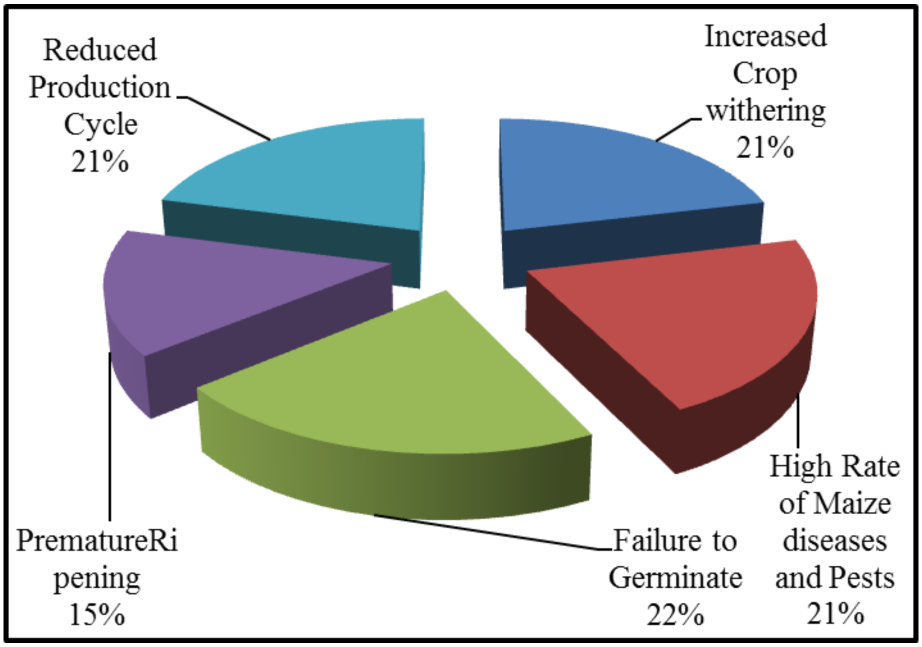

Figure 17: **Effects of Droughts on Maize Crop** (Field Survey, March 2016)

4.1.3.2. Effects of Floods on Maize Crop

The floods are more serious in Bahimba than in Bishenyi wetland due to unprotected watersheds and accidented relief that intensify run-offs during rainy seasons hence causing overflow of Bahimba wetland and floods in wetlands. Results (figure 14) showed that most of maize farmers (84%) from both wetlands reported that floods have been destroying irrigation channels with siltation and 96 % experienced crop injuries due to floods mainly in Bahimba wetlands. 94% of farmers from both wetlands faced with germination failure and 50.3% had a prolonged production cycle due to poor maize growth. 19% of farmers also have noted an increase in diseases mostly fungi like leaf spot and stalk rot due to persistent floods particularly in Bahimba wetlands.

Floods have been causing poor yields of maize as they disturb crop growth. Most corn hybrids can only survive for 24 to 48 hours under water, with smaller seedlings suffering the most damage. Flooding damages maize crop biochemically and by impairing mitochondria, it causes release of free radicals which damage cell membranes. Flooding also causes oxygen starvation and shifts the plant's metabolic processes to anaerobic fermentation.

At the minimum, flooding reduces the plant's metabolic rate, making seedlings more sensitive to disease and insects. In fact, many disease-causing fungi such as Pythium thrive in standing water.

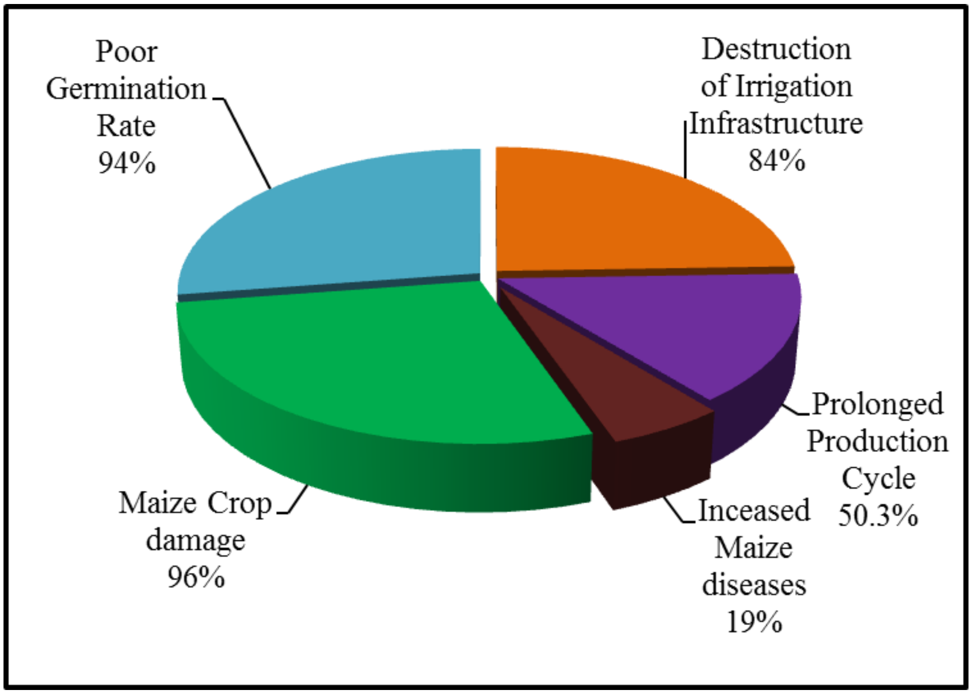

Figure 18: **Effects of Floods on Maize Crop** (Field Survey, March 2016)

The floods are more serious in Bahimba than in Bishenyi wetland due to unprotected watersheds and accidented relief that intensify run-offs during rainy seasons hence causing overflow of Bahimba wetland and floods in wetlands.

Figure 19: **A Photo Showing a Flooding Phenomenon in Bahimba Wetland** (Author, 2016)

4.1.3.3. Effects of Diseases and Pests on Maize Production

The study also assessed the effect of diseases and pests on maize production. Most of maize farmers (100%) from Bahimba wetland faced with a reduction of maize yields and 96% of Bishenyi farmers also had the same challenge. With regards to maize harvest quality, 98% of maize farmers in Bahimba and 96% of farmers in Bishenyi have been facing with poor quality of kernels. In addition, 90.9% of maize farmers from Bahimba wetland and 89% from Bishenyi wetlands have invested in purchase of pesticides to control diseases and pests. New diseases resistant varieties are needed as the observed increasing temperature in the surveyed wetlands might cause higher proliferation of pests which can end up in serious damage and postharvest losses in the near future.

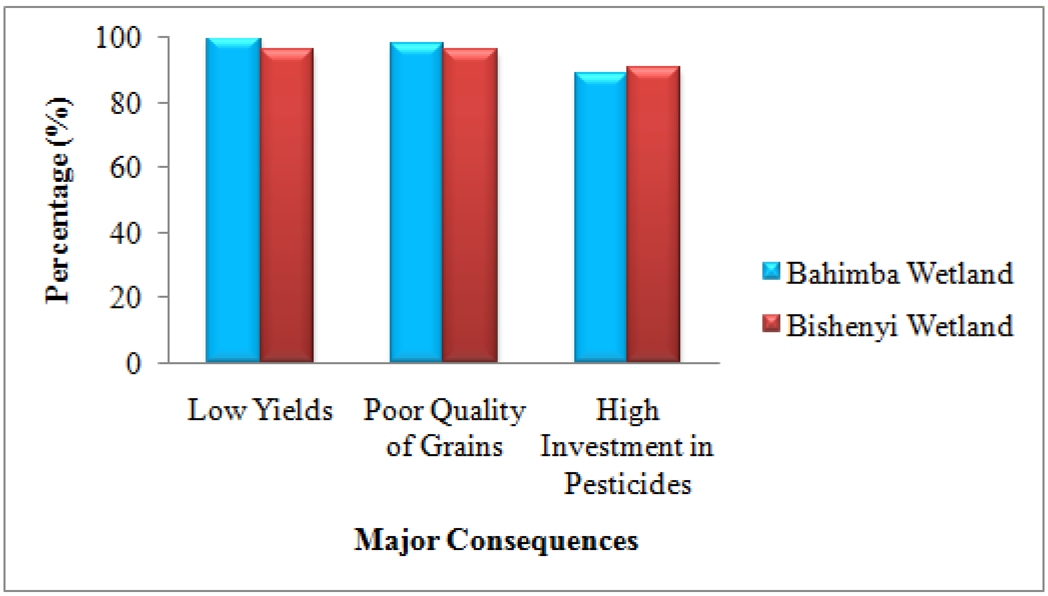

Figure 20: **Major Consequences of Diseases and Pests on Maize Production**

(Field Survey, March 2016)

Results showed that 98%, 90% and 96% of Bahimba maize farmers have been facing with maize streak virus, worms, rust and leaf blight and in Bishenyi wetland, 99% of farmers had a challenge of damage of worms, 90% faced with maize stalk borers and rust while 60.8% faced with leaf blight. Stalk rot and physiological disorders affected maize production in both wetlands. 84% of farmers from Bahimba had a problem of gray leaf spot. Maize farmers have been applying pesticides to reduce impact of diseases and pests on maize production. Table 1 below depicts major diseases and pests which threaten maize crop in the surveyed wetlands.

Table 1: Major Diseases and Pests of Maize Crop

Diseases and Pests	Bahimba Wetland	Bishenyi Wetland
Maize Streak Virus	98%	41%
Maize Stalk Borer	43%	90%
Worms	96%	99%
Rust	90%	90%
Silk Fly	11.1%	14%
Green Stinkbugs	7.1%	18%
Birds	98%	63%
Physiological Disorders	40.8%	61%
Gray Leaf Spot	84%	53.2%
Pythium Stalk Rot	45%	64.9%
Leaf Blight	96%	60.8%
Bacterial Stalk Rot	58%	54.8%

Sources: Field Survey (March 2016) and REMA (2011)

4.1.3.4. Effects of Climate Changes on Maize Yields

Apart from climate conditions, the study also has considered other factors contributing to maize production include but not limited to fertile and size of land, quantity and quality of seeds, inorganic and organic fertilizers, and disease and pest control. Analysis of maize yields data (figure 17) presents a reduction in annual maize yields per unit of hectare.

For the season A (2014/2015), farmers in Bahimba had experienced poor germination due to early cessation of rainfall at beginning of season A and had to redo seeding that had caused reduction of maize yields where the maize yield per 1 hectare had reduced by -17% in 2015 while for Bishenyi wetland, maize yield per hectare had reduced by -41 % in 2013 and -51% in 2014 due to extended dry spells. On the hand in Bishenyi wetland, the maize yields increased by 77% due to favorable climate conditions in 2012 while for Bahimba increased by 10%, 27% and 7% in 2012, 2013 and 2016 respectively. Reduction in maize yields might have been caused by the observed impacts of climate change and variability.

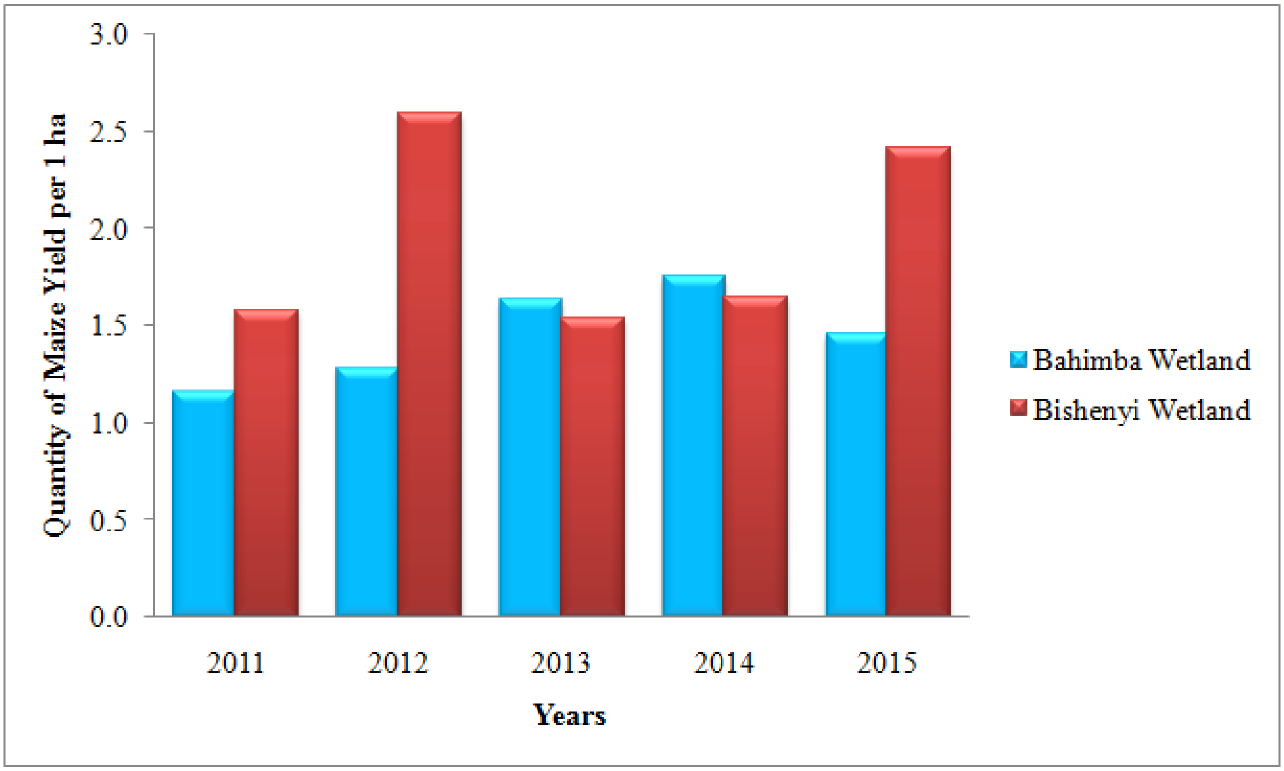

Figure 21: **Trends of Maize Yields in the Last Five Years (2011 – 2015)**

Though there was no reduction in agricultural inputs that could affect maize yields, climate changes might have been the major factor of the reduction of annual maize yields. In addition, even if maize yields were a bit better in some years, farmers showed dissatisfaction with the obtained harvests as they expected more if climate conditions cloud be more conducive. Table 2 below presents the types of farming inputs applied and the annual maize yields change.

Table 2: **Relation between agricultural Inputs and Maize Yields**

	Years	Surface Cultivated (Ha)	Quantity of Seeds (Tons)	Quantity of Manure (tons)	Quantity of DAP Applied (Tons)	Urea(Tons)	Quantity of Pesticides (liters)	Quantity of Maize Yields (Tons)	Changes in Annual Yields (%)
Bishenyi Wetland	2011	50	0.438	600	0.5	0.25	4	79	-
	2012	54	0.510	700	0.6	0.3	4	140	77.2
	2013	54	0.5	700	0.6	0.3	4	83	**-41**
	2014	54	0.5	700	0.6	0.3	4	69	**-51**
	2015	58	0.6	900	0.8	0.4	4	140	0
Bahimba Wetland	2011	320	6.5	559	9.3	4.7	100	374	-
	2012	320	6.3	532	10.3	5.1	72	411.4	10
	2013	320	5.8	514.2	14.75	7.4	75	523.6	21.3
	2014	320	5.7	575.1	17.9	7.96	120	561	7.15
	2015	320	**7.5**	562.3	14.5	5.3	82	467.5	**-17**

Source: **Field Survey** (March 2016)

4.1.4. Effects of Climate Change and Variability on Food Security

This section discusses the findings on effects of climate change and variability to food security among maize farmers from the surveyed wetlands.

4.1.4.1. Relationship between Maize Yields and Food Security

Famers' vulnerability to food insecurity has been assessed to help in identifying resilience measures that can reduce impact of climate-related threats on food security. Results revealed that when maize harvests were reduced, food security was adversely affected within households.

The majority of farmers form Bahimba wetland (95%) had a reduced number of meals per day, 97% had reduced quantity of meals par day, 80.8% had poor quality of meals, 97% faced with an increased food prices at markets and 72 % had noticed an increased rate of robbery of food and livestock in the community. For Bishenyi maize farmers, the situation food security is a bit better due to the fact that Bishenyi wetland is located nearby Kigali town where farmers can get more off-farm activities. However, 52% of Bishenyi farmers had a reduced number of meals per day, 96% had insufficient quantity of meals per day, 81% had poor quality of food, 61% noted malnutrition cases in the community and 65% faced with higher food prices at market and have also remarked an increased movement of people to towns in search of casual works. Moreover, some social conflicts were caused by food shortage due to reduced maize harvests. Table 4 below shows the indicators characterized food insecurity for maize farmers from the surveyed wetlands.

Table 3: Indicators of Food Insecurity among Maize Farmers

Effects	Bahimba Wetland	Bishenyi Wetland
Reduced Number of Meals per Day	95%	52%
Reduced Quantity of Meals	97%	96%
Poor Quality of Meals	80.8%	81%
Increased Family Conflicts due to Food Shortage	14.1%	16%
Increased Cases of Malnutrition	20%	61%
High Robbery of Food and Livestock	72%	19.2%
Rural Exodus to Green Pastures	7%	65%
High Prices of Food at Markets	97%	65%

Field Survey (March 2016)

4.1.4.2. Maize Farmers Resilience Strategies against Food Insecurity

Farmers from both wetlands started adopting resilience initiatives to reduce vulnerability to food insecurity when occurs in the community. Results (figure 19) showed that the majority of farmers 90% from Bahimba and 89% from Bishenyi have been participating in group saving initiatives, 91% from Bishenyi and 85.5% had accessed off-farm activities and casual works especially Bishenyi farmers who are closer with the City of Kigali.

At least 64% of Bahimba wetland and 59% of Bishenyi farmers have been rearing livestock and 68.7% from Bahimba and the minority in Bishenyi (44.4%) grow other crops such Irish potatoes, vegetable, banana, cassava, beans and soybeans as complement to maize production to enhance food security. Though fewer maize farmers participate in community food store (Bishenyi 31% and Bahimba 605), the majority of farmers keep food surpluses at home. In both wetlands, less maize farmers (Bahimba 43% and Bishenyi do crop mulching for upland crops. Storing food reserves at home might not be properly stored due to lack of suitable facilities and might also be more exposed to pests as well as robbery.

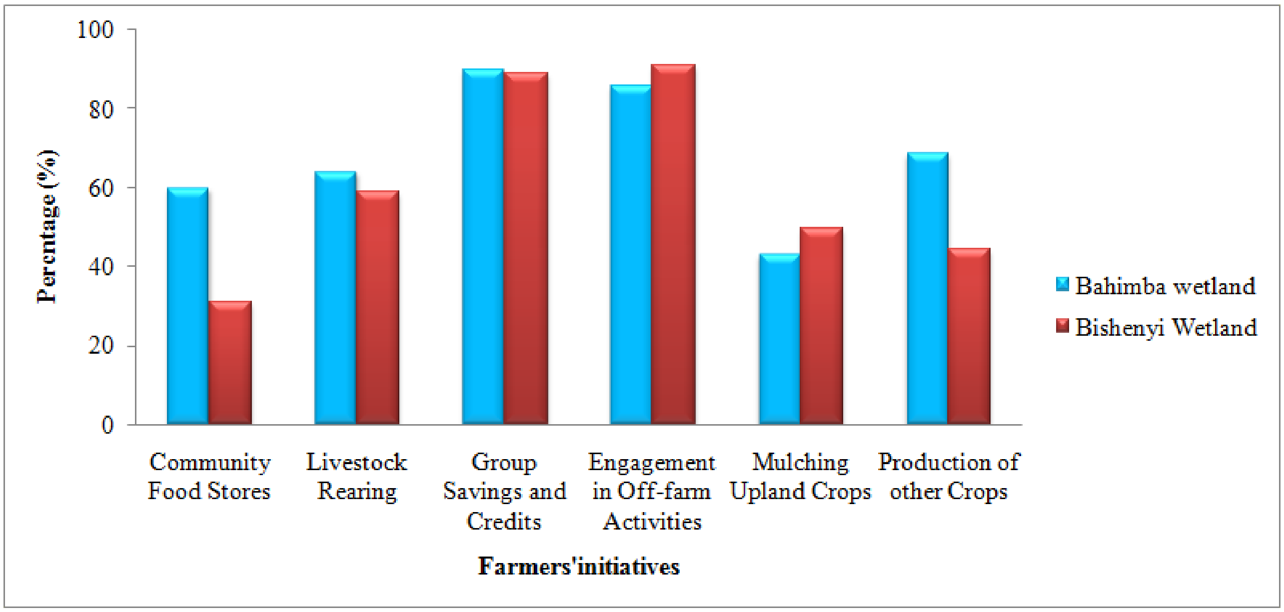

Figure 22: **Farmers' Initiatives in Reducing Vulnerability to Food Insecurity** (Field Survey, 2016)

4.1.5. Existing Adaptation Strategies among Maize Farmers

The study has investigated the adaptation practices that maize farmers have been using to reduce vulnerability to climate change and variability impacts.

4.1.5.1. Adaptation Strategies to Droughts

The study has assessed adaptation strategies that farmers were using to cope with climate change and variability effects. For case of droughts, 88% of Bishenyi and 93% of Bahimba farmers use pesticides to control insects.

In both wetlands, the minority of maize farmers, 6% in Bahimba and 41% in Bishenyi, were using animal manure and compost which could be one of the suitable adaptation strategy for droughts as the more organic matter in the soil the more moisture retention capacity of the soil. Bishenyi farmers have been having access to early maturing maize varieties where 95% of farmers reported the use of these varieties while in Bahimba was just 26.3%. Maize farmers in both wetlands use drought tolerant varieties (95% in Bahimba and 51% in Bishenyi) and the majority of farmers have been using small irrigation schemes (97% in Bishenyi and 73% in Bahimba) to adapt prolonged droughts.

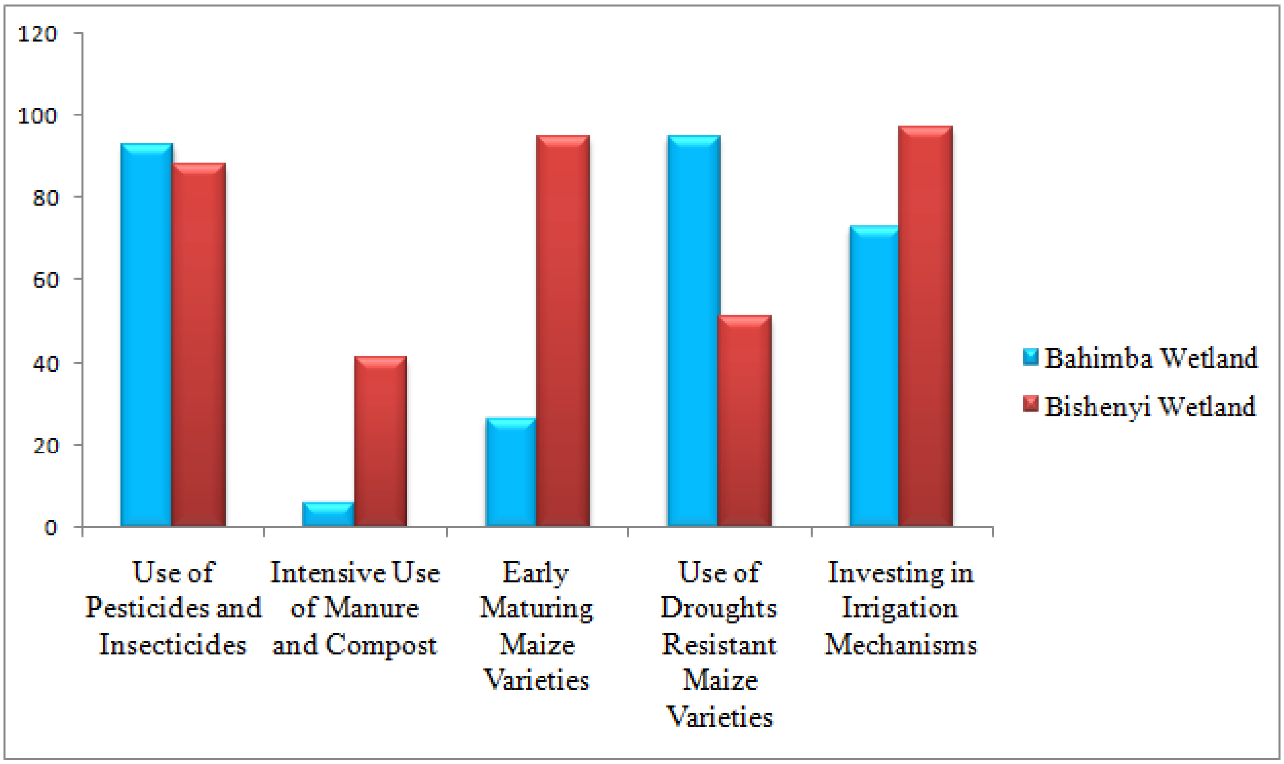

Figure 23: **Adaptation Strategies** (Field Survey, March 2016)

4.1.5.2. Adaptation Strategies to Floods

For the case of floods, 100% of maize farmers from Bahimba and above 80% from Bishenyi implemented drainage channels and river banks protection but due to unprotected watersheds for both wetlands, heavy rains have caused floods which have been destroying crops and irrigation infrastructures. There a need of both watersheds protection and improved drainage systems.

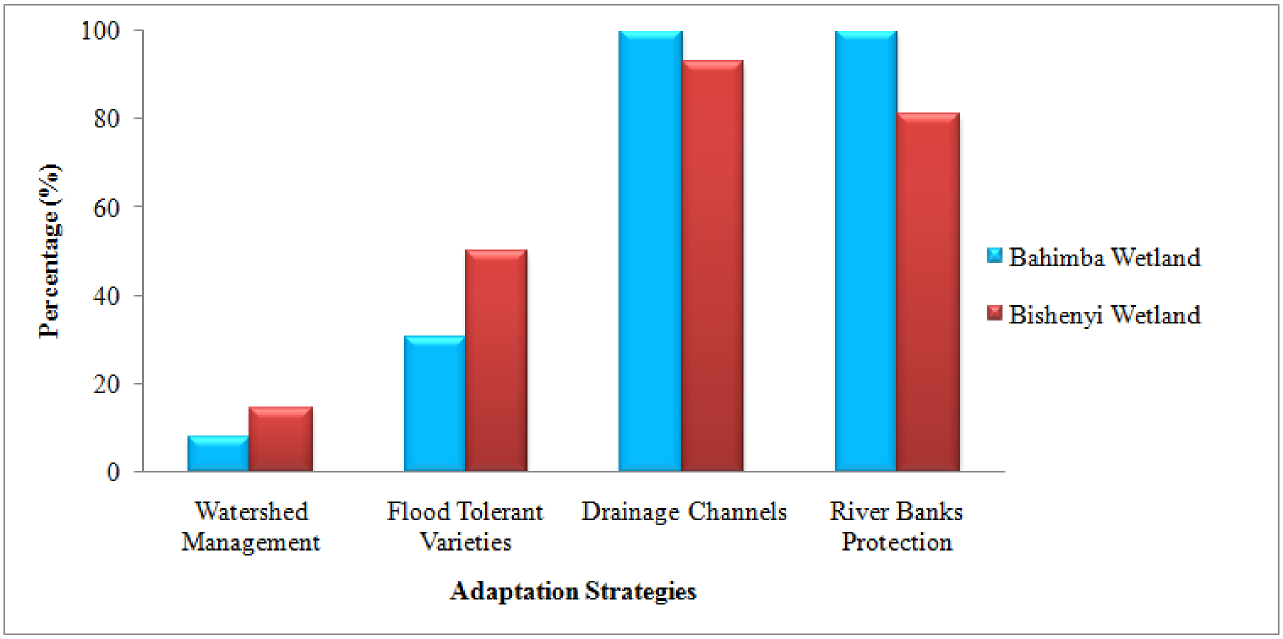

Figure 24: **Adaptation Strategies to Floods** (Field Survey, March 2016)

4.1.6. Maize Farmers Constraints in Implementing Adaptation Strategies

The study assessed maize farmer constraints which limit the implementation of coping strategies to climate change and variability. Considering the major constraints for adaptation, between 77% to 100% of both Bahimba and Bishenyi farmers had challenges of limited knowledge and skills about climate change and variability, lack of capacity to invest in irrigation infrastructures, expensive farm inputs (improved seeds, fertilizers, pesticides), lack of resistant maize varieties, poor maize value chain and limited access to banks credits. In addition, 99% of Bahimba farmers presented the need of improved maize value chain and 89.9% claimed for the lack of access to bank credits while 94% from Bishenyi farmers claimed for the insufficient subsidy of agricultural inputs.

Little percentage of farmers proposed agricultural insurance that can be helpful when climate-related threats completely damaged the whole field of crop. These constraints block farmers to improve maize production and food security. Table 5 below illustrates the maize farmers' constraints to cope with climate change and variability impacts.

Table 4: Farmers Constraints in Implementing Adaptation Strategies

Constraints	Bahimba Wetland	Bishenyi Wetland
Limited Knowledge and Skills about Climate Change Effects	100%	97%
Lack of Capacity to Invest in Irrigation Infrastructures	98%	100%
Expensive Farm Inputs (Improved Seeds, Fertilizers, Pesticides)	74.7%	98%
Lack of Resistant Maize Varieties	98%	88%
Poor Maize Value Chain	99%	59%
Lack of Loan Security for Bank Credits	89.9%	65%
Absence of Agricultural Insurance	36.4%	45%
Insufficient Subsidy for Farming Inputs	24.2%	94%

Field Survey (March 2016)

4.1.7. Proposed Adaptation Strategies to Improve Maize Production

The study assessed farmers' views on major sustainable solutions which maize farmers can implement to reduce the impact of climate change and variability. Findings in table 7 show that maize farmers between 90%-100% from the surveyed wetlands need an increased support for irrigation infrastructures, drought and disease resistant maize varieties, improved water streams management, affordable agricultural inputs, Increased extension service on climate information sharing at local level, strengthened group savings (VSLs), and increased access to off-farm activities. In addition, Farmers also proposed an improved maize value chain, increased access to farm credits, agricultural fund and crop insurance. Table 6 below presents maize farmers proposed suitable adaptation strategies to be adequately supported to increase maize yields hence reduce vulnerability to food insecurity.

Table 5: Proposed Coping Strategies to Improve Maize Production

Possible Solutions	Bahimba Wetland	Bishenyi Wetland
Increased Public Support for Irrigation Infrastructures	98%	100%
Drought Resistant Maize Varieties	100%	98%
Disease and Pest Resistant Varieties	99%	96%
River Banks Protection	100%	87%
Affordable Agricultural Inputs	100%	100%
Adequate Maize Value Chain	100%	59%
Strengthening Groups Saving and Loaning Schemes	100%	95%
Setting up a Public Agricultural Fund	44.4%	79%
Increased Access to Farm Credits	100%	79%
Improve Extension Services on Climate Change Effects	100%	90%
Affordable Farming Insurances	40.4%	65%
Creation of more Off-Farm Activities	100%	81%

Source: Field Survey (March 2016)

As came out in group discussion with agronomists and farmer cooperative committees, after any climatic chock or hazard, affected people start thinking how to deal with the threats. Focus group discussion provided views around adaptation strategies to climate change and variability so as to improve maize production and sustain food security in their communities. Key informants and agronomists presented that they have chosen to grow maize only in season A where rain is believed to more favorable and not to grow shorter crops which are more vulnerable to floods but preferred to grow these crops in the seasons B and C where small irrigation is easier than irrigation maize. The group discussion has also suggested suitable adaptation measures such as looking for resistant varieties, increased access to reliable climate information as earlier as possible including early warning, adequate irrigation infrastructures, improved processing and storage facilities, water shed management, fair market, strengthened voluntary group saving and loaning (VSLs), affordable appropriate pesticides, diversification of crops, livestock rearing and creation of more off-farms activities.

4.2. Discussion

Climatic change and variability is one the big challenges for agricultural production especially for smallholder farmers in developing countries. The overall objective of this study was to assess the impacts of climate change and variability on maize production in wetlands and food security in Rwanda focusing on Bahimba wetland in Rulindo District and Bishenyi wetland in Kamonyi District. It was found that more women (55.4%) are engaged in maize farmers than men (44.7%) as also was reported by EICV (2012) that the agriculture sector is worked mainly by women (82%) and also MINAGRI (2010) found that the majority of women farmers have lowest levels of schooling and illiteracy rate of 23.3%. This explains the limited capacity of maize farmers to combat climate change and variability effects coupled with women limited time for improved agriculture as rural women are also fully responsible for domestic work.

4.2.1. Fluctuation of Rainfall and Temperature in the Study Area

By responding the research questions, the study assessed the extent to which rainfall and mean temperature have fluctuated over the period of past 30 years both for the research areas and for other regions of the country to accurately determine the status climate change and variability in study areas and for the entire country. Serious floods have been more frequent in Bahimba wetland due the observed lack of adequate drainage infrastructures coupled with the absence watershed management. Consequently, maize harvests have been reducing and giving unsatisfied harvests that also worsened food insecurity for the maize farmers.

In assessing the rainfall and temperature in the study areas, data from country major weather stations of Kamembe, Kanombe, Gisenyi and Rubona were also considered to supplement the findings of rainfall and temperature changes in the areas of study. The interpretation of findings of rainfall and temperature from these weather stations indicated significant increase in temperature over the past 30 years and show the changeability in rainfall over the past 30 years similarly with the findings of rainfall and temperature in all regions of the country including the study areas.

As also found by RMA (2014), results have revealed a continuous increase in mean temperature. At Kigali Airport Weather station, the maximum average temperature was 22.2^oC while the minimum was 20.2^oC making an increase of +2^oC since 1971 to 2015(appendix 2); at Rubona station, the maximum average temperature was 19.79^oC while the minimum was 18.90^oC making an increase of +0.89^oC since 1958 to 2015(appendix2); at Kamembe station, the maximum average temperature was 20.9^oC while the minimum was 19.7^oC making an increase of +1.2^oC since 1957 to 2015(Appendix2); at Gisenyi, the maximum average temperature was 20.55^oC while the minimum as 19.95^oC and the increment was +0.6^oC since 1975 till 2015 (appendix 2). These increases in temperature putting Rwanda in alarming situation as the increase of mean temperature worldwide is +0.85°C since 1980-2012 (IPCC, 2014: page 3 of the summary report).

In complimentarily with Mutabazi (2010), rainfall analysis results (appendix3) revealed that at Kanombe station, rainfall has decreased from 1,010 mm to 950 mm since 1971 to 2015 making a decrease of -60mm. At Gisenyi station trend line (appendix 2) shows that the rainfall amount has increased from 1,150 mm to 1,240 mm since 1976 till 2015 making an increase of 90 mm (appendix 3). At Kamembe station, trend line indicates that the amount of rainfall has decreased from 1420 mm to 1360 mm since 1971 up to 2015 making a decrease of 23.1 mm (appendix 3). At Rubona station trend line indicated that the amount of rain had decreased from 1320 mm to 1040mm from 1985 to 2015 making a decrease of -240 mm (appendix 3). The rainfall variability was attributed to poor performance of agriculture and food insecurity in Rwanda (RMS, 2012).

Moreover, results showed that mean temperature has tremendously increased in the two surveyed wetlands and in other parts of the country considering analysis results found with the weather stations of Kanombe, Gisenyi, Kamembe and Rubona and rainfall has highly fluctuated with some decreases in all regions except in Gisenyi where the results show a slight increase. Particularly for the study areas, rainfall has slightly decreased in Bahimba while slight increase was found for Bishenyi Wetland. By using climate data that are specific for Tumba sector having a large part of wetland and specific climate data for Runda sector also has a larger part of Bishenyi wetland, the study found that in Bahimba there has been increase in mean temperature (+0.85^0C) and a decrease in amount of rainfall with -30mm while in Bishenyi wetland mean temperature increased by +1.1^0C with slight increase in the amount of rainfall of +50mm since 1981-2014.

The observed changes in mean temperature prove the increased warming and unreliable rains in the surveyed wetlands which caused maize yields reduction and consequently worsened food insecurity in the areas of study. Research findings are in complementarity with findings of RMA (2012) where it was found that the mean temperature in Rwanda has increased from 20.2^0C to 21.9^0C for Kigali weather station with a total increase of +2 ^{0}C and 19.1^0C to 21.1^0C with a total increase of $+1^0$C for Kamembe weather station for a period of 40 years since 1971 up to 2011 that places Rwanda in alarming case as the increase in mean temperature exceeds $+0.85^0$C at global level which has caused global warming (IPCC, 2014). The current findings also complement the findings of REMA (2010) where found that the annual average rainfall totals decreased from 1020 mm to 920 mm with a drop of number of rain days from 148 to 124 from 1971 to 2009 and 146 days between 1971-1990 to 131 days for the period of 1991-2009.

4.2.2. Impacts of Climate Change and Variability on Maize Production and Food Security

Apart from poor rainfall and increased temperature, maize farmers from both wetlands also had faced with challenges of extended dry spells and floods events especially in Bahimba wetland which had caused maize poor yields. Group discussion with key informants and agronomists converged they views on the reduction of maize yields as consequence of late sets of rainy seasons, erratic rainfall, floods, droughts, water shortage, increased warmer weathers, pest and diseases mainly maize streak virus, cornstalk borer, Leaf blight, rust and worms, among others. It was noted that food insecurity was caused by reduction of in maize production in terms of daily number, quantity and quality of meals.

Considering similarities in climate changes in both wetlands (Fig. 12), the findings revealed that 90.9% and 81% of farmers in Bishenyi and Bahimba respectively have experienced the challenge of erratic rainfall while 81% in Bishenyi and 75% in Bahimba respectively experienced prolonged dry spells. Regarding the water for irrigation, 91% of farmers in Bahimba and 83% of farmers in Bishenyi wetlands have noted the dry up rivers. In both wetlands 97% of farmers in Bishenyi and 93% from Bahimba have noticed increased temperature consider the climate before the past 30 years. The maize farmers from both Bahimba and Bishenyi wetlands have linked these climatic changes to the poor maize harvests and damage of crops both in wetland and upland crops.

These finds complement Mutabazi (2010) results where he found that temperature has increased with high frequency of warm days exceeding 30°C. He also found that the number of annual rain days decreased that negatively impacted agricultural productivity as crops requires the quantity of water within the given number of days. He also noted that the number of dry spells during rainy season increased and affected poor performance of crops due to the late set of rainfall and/or early rainfall cessation during rainy season also caused poor performance of agriculture productivity. For the case of disparities (Fig.16), analysis results showed that famers in Bishenyi are more vulnerable to erratic rainfall (90.9%) and droughts (81%) while farmers in Bahimba are more vulnerable to heavy rains (92.9%) and floods (74.2%). These disparities are due to fact that Bahimba is located in highlands part of Rwanda where heavier rainfall and floods are more frequent than in central plateaus of the country where Bishenyi wetland is located.

In addition, farmers also reported the effects of diseases and pests on maize yields (Table 1) where the majority of farmers in Bahimba wetland 98%, 96, 90%, 84 and 58% reported that maize production was also affected by maize streak virus, leaf blight, worms, rust, gray leaf sport and bacterial stalk rot respectively while in Bishenyi most of farmer 90%, 99%, 63% and 60.8% also have reported corn stalk borer, rust, worms, birds and rats and leaf blight respectively as also found by REMA (2011). Analysis of data has revealed that maize farmers from both wetlands do not adequately apply pesticides due to lack of required capacity to afford appropriate pesticides. These diseases and pests also have affected total maize harvests. Farmers' support increment with resistant varieties and appropriate pesticides at affordable prices are needed to sustain maize production and food security.

As a consequence of abnormal changes in rainfall and temperature as well as diseases and pests, maize harvests and food security were adversely affected. The results show that in Bishenyi wetland, maize harvests reduced by 41% in 2013 and 51% in 2014 while in Bahimba wetland maize yields reduced by 17% in 2015 as also found by Matarira and al. (1995) that even though irrigation can boost maize production, the yields are lower under climate change conditions than under normal climate.

Due to reduction in maize harvests, food security directly has been affected where 37.5% of respondents reported the reduced number of meals per day, 96.5% reported a reduced quantity of meals and 80.8% remarked poor quality of meals 80.9% that complement findings of Christine Uzayisenga (2014) where she found that higher temperatures reduced the yields of desirable crops and caused a higher proliferation of weeds and pests. She also noted that the changes in precipitation regime increased probability of low crop production in short and long term and threatened food security. Group discussion also came up with the key challenges in implementing adaptation strategies include lack access on reliable and timely climate information, lack of early warnings, lack of adequate irrigation infrastructures, low access to financial credits due to lack of loan security, absence of new drought and disease resistant varieties, lack of early maturing varieties insufficient animal manure and compost, poor maize value chain, absence of crop insurances as well as low ownership among farmers.

4.2.3. Sustainable Adaptation Practices to Improve Maize Production and Food Security

Concerning adaptation of climate changes, the study assessed the possible adaptation strategies to enable farmers increase resilience capacity to the observed impacts of climate change and variability essentially late set of rainy seasons, floods, droughts and diseases and pests, among others. This also was assessed by Mizina et al. (1999) and Reilly and Schimmelpfennig (1999) where they emphasized that adaptation is an important component of any policy response to climate change in agriculture. The study suggested possible adaptation and resilience strategies for maize farmers in Bahimba and Bishenyi wetlands to better cope with the observed impacts of climate change and variability to improve maize production as well as sustain food security in their communities. They also indicated that agricultural adaptation options are grouped in four main categories that include technological developments, government programs and insurance, farm production practices, and farm financial management.

Moreover, group discussion participants believed that if these strategies are implemented and adequately supported by all concerned stakeholders the maize production will be increased hence improve and sustain food security for the entire community as also had been suggested by Gepts (2014) where he indicated that adaptation strategies should be short and long-term changes to human activities in response to the impacts of climate changes.

He also mentioned that agricultural adaptation requires cost-effective investments in water infrastructure, emergency preparation for and response to extreme weather events, development of resilient crop varieties that tolerate temperature and precipitation stresses, and improved land use and management practices. Thus, there are numerous opportunities to realize climate change adaptation as without adaptation, climate change and variability is problematic for agricultural production, agricultural economies and communities but with adaptation in practice, vulnerability to climate change and variability impacts can be reduced at all levels. Also, study has found that adequate investment in new resistant maize varieties, early maturing varieties, access to reliable climate information including early warnings, watershed management especially for Bahimba, suitable irrigation infrastructures specifically for Bishenyi, improved maize value chain, livestock rearing as well as strengthened group saving and loans initiatives (Ibimina), were highlighted as the major solutions to impacts of the observed changing climate.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

This chapter presents conclusions derived from the study and subsequent recommendations. It also highlights each specific objective and its findings. The study has concerned with the impacts of climate change and variability on maize in wetlands agricultural production and its effect on food security in Rwanda precisely in wetlands located in highlands and central plateaus of Rwanda. The study was based on field observation, primary data collected from 200 maize farmers and 7 key informants from two wetlands of Bahimba and Bishenyi and secondary from Rwanda Meteorological Agency and numerous related scientific publications. The main objective of this research was to assess the impacts of climate change and variability on maize production in wetlands and it connection to food security precisely in Bahimba wetland located in Rulindo District and Bishenyi wetland located in Kamonyi District. Specific objectives of the study were to evaluate the current patterns and trends of rainfall and temperature in the study areas; assess the impacts of climate change and variability on maize production and food security in the study areas, and identify sustainable adaptation practices for better coping with climate change and variability impacts on maize production in wetlands and food security in the study areas.

5.1. Hypotheses Verification

Firstly, going through the findings to verify the hypotheses, it is clear that there has been a remarkable change in annual rainfall and annual mean temperature within a period of the past 30 years in the areas of study. Since 1981 to 2015, mean temperature in Bahimba increased by +0.85 ^{0}C while in Bishenyi Wetland increased by +1.1 ^{0}C which indicates climate change in the research areas. Considering the situation in other parts of the country, also increases in mean temperature were significantly remarked that confirms climate change in Rwanda. Regarding variability in average temperature in the study areas, temperature chart line indicates that some months have higher mean temperatures and other months with lower mean temperatures that shows climate variability in research areas and even in the whole country.

Concerning the changes in the amount of rainfall, rainfall trend line indicates that the amount of rain increased by 50mm while for Bahimba decreased by -30mm. It has also noted that in other regions of Rwanda, rainfalls significantly fluctuated either increasing or decreasing that proves climate change and variability in the Rwanda. This implies that maize production and food security were adversely affected in Bahimba and Bishenyi wetlands as result of climate change and variability.

Secondly, abnormal changes in rainfall and mean temperature patterns have led to poor performance of maize in the study areas and this has significantly contributed to food insecurity among local farmers. The analysis revealed that the majority of respondents above 90% have been facing with climatic hazards include droughts, floods, water stress, germination failure, wilting, increased diseases and pests that caused reduction of maize yields per hectare at 41% and 51% in 2013 and 2014 respectively for Bishenyi wetland and 17% reduction per hectare in 2015 for Bahimba wetland that has worsened food insecurity among maize farmers and communities.

Thirdly findings for food security (table 4) revealed there has been a reduction in number of meals per day (73.5%) and reduction in quantity of meals (96.5%) and 80.9% reported a poor quality of meals as a consequence of reduced maize harvests due to impacts of climate change and variability. In addition, results showed that 81% of maize farmers have experienced the increase in prices of food at markets. Food insecurity have caused social problems include the increased family conflicts, cases of malnutrition, rural exodus towards green pastures/urban areas, high robbery of food and livestock and higher prices of food at markets. Lastly, new resistant varieties of maize associated with adaptation strategies lead to improved maize yields and sustainable food security for maize growers where 99% of study population reported the need of new droughts tolerant and early maturing maize varieties.

Findings showed that between 77% and 99% of maize farmers have limited knowledge and skills about climate change and variability, low capacity to invest in irrigation infrastructures, insufficient manure and compost, unprotected watersheds particularly for Bahimba wetland, lack of resistant maize varieties, poor maize value chain and limited access to banks credits.

5.2. Conclusion

Based on the study findings, Rwanda's farmers, who are highly dependent on the rain-fed agriculture, need early, reliable and adequate information on changing climate that is affecting their crop harvests as well as food security. Analysis of rainfall and temperature in Rwanda and in the areas of this study, have showed the abnormal fluctuations which farmers attribute to observed poor performance of maize in the wetlands. Since 1975 to 2014, evaluation of temperature using merged station satellite data revealed a steady increase in mean temperature for both Bahimba and Bishenyi wetlands and the rainfall evaluation showed a steady decline in the amount of rainfall for Bahimba wetland while a slight increase in rainfall has been noted for Bishenyi wetland. As located in the central plateaus, Bishenyi wetland has been found to be warmer that Bahimba wetland which is located in highlands. As consequence, Bishenyi wetland is more vulnerable to droughts than Bahimba. While Bishenyi farmers use early maturing varieties to cope with droughts, Bahimba farmers are threatened by floods due to hilly relief without watershed management and poor drainage infrastructures in the wetland.

The fluctuations in rainfall and temperature patterns have been also noticed by the maize farmers. They already noted a decline in maize production due to the changes in rainfall and temperature patterns. Rainfall is key factor for the good performance of maize as poor rainfall can lead to crop failure unless crops are under adequate irrigation with high control. Even though other factors such as adequate fertilizer, improved seeds, timely planting and weeding, and pesticides can be equally dependable for a good harvest, it has been found that adequate rainfall is a key factor and in absence of it, no other inputs for maize will be of much value. The study has found that maize farmers in Bahimba and Bishenyi wetland apply necessary fertilizers and other required inputs but observed impacts of climate change and variability has caused reduction in maize harvests and this has ended up in food insecurity in these areas of study.

On the other hand, unpredictable heavy rainfall coupled with hilly terrain without watersheds management in Bahimba has been a major source of flooding which destroys major crops grown in wetlands. As consequence, maize harvests have been reducing in both wetlands but the situation is worse in Bishenyi than Bahimba due to persistent shortage of water and diseases/pests damage.

Though some coping strategies are adopted by the maize farmers, farmers have limited capacity to invest in adequate adaptation and resilience practices such irrigation infrastructure, new early maturing and resistant varieties, food processing and storage, fair market prices, strengthening group saving and investing in livestock among others. It can be concluded from the study and observation that the decline in maize production in Bishenyi and Bahimba wetlands could be highly linked to the fluctuated rainfall or higher temperatures. Variation in rainfall patterns has been reversing the time for planting, germination and crop growth until ripening. High temperatures could be the favorable condition to cause higher proliferation of diseases and pests. Anticipatory measures as mentioned above can enhance the adaptability and resilience capacity. Therefore, increased support on adaptation and resilience strategies will be vital for sustainable maize production and for improved food security.

5.3. Recommendations

Although agriculture is very sensitive to climate change and variability impacts, it may be among the most flexible of the societal systems sensitive to climate change. Based on findings and observations at field, the study could suggest the following strategies to each stakeholder to ensure increased farmers' resilience capacity which include but not limited to:

a) Maize farmers organizations

Farmers may switch to different crop types or change to more drought- and disease-tolerant crops associated with consistent crop scouting. Livestock and dairy production can be the other good alternative to invest in to complement crops. Also, farmers may introduce irrigation systems in areas where high temperatures and rates of evapo-transpiration lead to reduced levels of soil moisture. Associate monoculture approach with diversified agricultural production systems to better cope with adverse changes in climatic conditions as monoculture system is more vulnerable to climate change and variability effects include prolonged droughts, floods, pests and diseases.

b) Ministries and Government Agencies

- ✓ The government could support maize farmers with warehouse service, processing, and affordable preservation facilities in overcoming postharvest losses and enable maize farmers getting more profits from maize harvests.
- ✓ There is a need for government to establish and strengthen existing financial institutions that are geared toward extending credit to small-scale farming cooperatives and facilitate cost-effective marketing of their produce.
- ✓ Install advanced weather stations at sector levels in each district to help in monitoring and research the climate at local level and develop early warning systems that provide reliable weather predictions and seasonal forecasts
- ✓ Develop new maize crop varieties to increase the tolerance and suitability of plants to temperature, water stresses, diseases and pests, and other relevant climatic conditions.
- ✓ Develop water management innovations including irrigation to address the risk of moisture deficiencies and increasing frequency of droughts associated with climate change.
- ✓ Promote affordable farming insurance products and increased subsidy programs for many crops to influence farm-level risk management strategies

c) Local Government Entities

- ✓ Adaptation measures to climate change such as watersheds management, erosion control, agroforestry, climate resilient sustainable agriculture methods, inter-cropping, biodiversity and collection of rainwater for agricultural should sufficiently be promoted and funded.
- ✓ Sensitize and support maize farmers to diversify source of household income in order to address the risks of climate-related income loss.

d) Academic Institutions

- ✓ There is a need of periodic research on crops and livestock that are more tolerant to pest/disease and drought conditions. Research on short-season high-yielding crop varieties and livestock breeds will be of paramount importance to adaptation.
- ✓ Carry out research on crop pest and diseases, both those currently affecting the agricultural production and those that may come about due to climate change, among others.

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APPENDICES

Appendix 1: Questionnaire for Maize Farmers in Wetlands: Bahimba and Kamonyi

Maize Farmers Survey Questionnaire

I. Identification

- Questionnaire number:
- Sector:
- Name of Cooperative:
- Name of Wetland:

1. Age	1=18-30;	2=31-55;	3=56 and above	**…...**
2. Gender	1= Male	2= Female		……
3. Marital Status	1= Single	2= Married	3= widowed	…….
	4= divorced	5= Separated	6=other	
4. Education Level	1= None	2= Primary	3= Secondary	……..
	4=University	5= TVT	6= Other:	
5. Family Size	1= 1-5	2= 6-10	3=More than 10	…….
6. Occupation	1= Agriculture	2= Business/ small	3=Salaried	…….
	4= Casual jobs	5= Other…………….DATA.......		

II. QUESTIONS

Section A: Questions related to Socio-economic Aspects

1. Land acquisition (*How did you acquire your land?)* 1= Inheritance 2= Purchased land 3= Rented	….
2. How many plots (or fields) do you have/ cultivate currently?	…….
3. What is the location (topographical) of your plots/ fields 1= Wetland 2= Upland 3=both sides	…..
4. Beyond maize in wetland, what are other most types of crops do you grow?	

1= Beans 2=Sorghum 3= Potatoes 4=Vegetables 5=Soybeans 6= Cassava 7=Other (specify)……………	……..
5. Where do you get manure?	
1=My livestock 2=Compost 3=Both livestock and compost 4= Purchase 4=Other (specify)……………………………….	
6. Do you have access to agricultural inputs?	
1=Yes 2= No	………
7. If yes, what are the major agricultural inputs do you use?	
1=Improved seeds; 2=Fertilizer; 3=Pesticides; 4=Planting materials; 5= Other (specify)……………………	……..
8. What is the source of inputs?	
1= Input suppliers; 2= MINAGRI; 3= Market	

9. How much of inputs do you use for maize crop?

Quantity of Agricultural Inputs and Maize Harvests over the Five Years								
Crop	**Year/Season**	**Size of cultivated area (m^2)**	**Quantity of seeds of maize planted**	**Organic manure applied**	**Quantity of DAP applied**	**UREA applied**	**Quantity of Pesticides used(liter)**	**Maize harvests in tons**
Maize	**2011**							
	2012							
	2013							
	2014							
	2015							
10. What is the source of labor?								
1= Family members 2= Hired 3=Community work 4=Other (specify)………………								………

Section B: Questions related to Climate Change/Variability and its Impacts on Maize Production

1. What are the actual climatic conditions of this area in terms of temperature and rainfall compared to the past 30 years? (Fill in the box with **X)**

- *There is a change* ☐ *There is no change* ☐

2. If there is a change or variability, which is that change over the past 30 years?			
Phenomena	**1. Increasing**	**2. Decreasing**	**3. No change**
1=Unusual early rains			
2=Erratic rainfall			
3=Delay of rainfall season			
5=Prolonged dry season			
6=Heavy rains			
7=Shorter rains			
8=Dry up rivers			
9=Overflow rivers			
10=Low soil moisture			
12=Flooding			
14=Warmer weathers			
15=High Temperature			

3. Have you ever faced with any climatic hazard induced shock in your lifetime?

1= Yes ☐ *2=No* ☐

4. If yes, what type of climatic hazard?

1. Droughts ☐

2. Floods ☐

5. For the case of drought, how many times did this hazard occur over the past 30 years?

1=1-5 times ☐

2=6-10 times ☐

3=More than 10 times ☐

6. For the case of floods, how many times did this hazard occur over the past 30 years?

1=1-5 times ☐

2=6-10 times ☐

3=More than 10 times ☐

7. ***For the case of drought*, what happens to local farmers in the wetland agricultural zones?** Fill the box with **<u>Yes or No</u>**

1= Water shortage or water stress	/………../
2=Crops withering	……………
3=Increased diseases and pests	……………
4=Other (specify): ………………………………………………………………………………	

8. *For the case of flood*, what happens to local farmers in the wetland agricultural zones? Fill the box with **<u>Yes or No</u>**

1=Destruction of irrigation infrastructure	
2=Crops damage	
3= Increased diseases and pests	
4= Other (specify): ………………………………………………………………………………………	

9. In both cases of droughts and floods, who are more vulnerable groups among local farmers to the impact? *(Yes or No)*

1= Maize Farmers	**/…./**
2=Vegetable growers	**/…./**
3=Beans and soybeans growers	**/…./**

10. **For the case of maize farmers in this area, what happens to the maize crop when there is a prolonged drought?**

Possible Answers	**Yes**
1= Failure to germinate	
2=Premature ripening	
3=Reduced production cycle	
4=High rate of maize diseases and pests	
5=Increased crop withering	
6=Other (specify): …………………………………………………………………………………….	

11. For the case of maize farmers in this area, what happens to the maize crop when there is a flood?

Possible Answers	**Yes**
1=Maize crop damage	
2=Poor germination rate	
3=Increased maize diseases	
4=Prolonged production cycle	
5=Other (specify): ……………………………………………………………………………………….	

12. ***In the case of drought,*** **what are the major diseases and pests?** Respond with <u>Yes or No</u>

1=Common smut	
2=Corn stunt	
3=Maize bushy stunt	
4=Maize streak Virus	
5=Cornstalk borer	
6= Worms, stem weevil, loopers, beetles	
7=Rust	
8= Bacterial blight	
9=Leaf tiers	
10= Leaf Blight	
11=Aphids	
12=Green stinkbugs	
13=Spider mites	
14=Birds and rats	
15=Physiological disorders	
16=Other (please specify): ………………………………………………………………………………	

13. ***In the case of flood*****, what are the major diseases and pests?** Respond with <u>Yes or No</u>

1= Nematodes	
2=Gray leaf spot	
3=Systemic Fusarium infection	
4=Pythium stalk Rot	
5=Yellow leaf blight	

6=Purple leaf sheath	
7=Crazy top	
8=Bacterial stalk rot	
9=Holcus spot	
10= Worms, stem weevil, loopers, beetles	
11=Corn Stalk borers	
12=Birds	
12=Other (specify): …………………………………………………………………………………………..	

14. At what extent diseases and pests have affected the maize production? Respond with Yes or No

1=Reduced maize yields	
2=Poor quality of maize grains	
5=High investment in pesticides	
6=Other (specify): ……………………………………………………………………………………………..	

Section C: Questions related to the Effects of Climate Change on Food Security

1. Do you see any relationship between maize production and food security in this area?

1= Yes	*2=No*	*/………………/*

2. If yes, what are the major consequences when the maize production has decreased?

Possible Answers	**Yes or No**
1= Reduced number of meals per day	
3= Reduced quantity of meals	
4=Poor quality of meals	
5= Increased family conflicts due to food shortage	
6=Increased cases of malnutrition	
7= High robbery of food and livestock	
8= Rural exodus towards green pastures/urban areas	
9= High prices of food at markets	
10=Others (Please specify): ……………………………	

3. What are the climate resilience practices are you engaged in to reduce vulnerability to food insecurity when maize production has decreased?

Possible Answers	Yes or No
1=Community food store/reserves	
2=Domestic animals rearing	
3=Participation in group saving and loans	
4=Engagement in off-farm activities	
5. Crop mulching in uplands	
6=Intercropping practices in uplands	
7=Production of other crops (cassava, Irish potatoes, vegetables, etc.)	
8. Other (specify)…………………………	

Section D: Questions related to Climate Change Adaptation Strategies

1. In case of prolonged drought, which adaptation measures do you use in growing maize?

Possible Answers	Yes or No
1=Investing in irrigation mechanisms	
2=Use of drought resistant maize varieties	
3=Early maturing maize varieties	
4=Intensive use of manure and compost	
5=Diseases and pests resistant maize varieties	
6=Use of pesticides and insecticides	
7. Other (specify)………………………………	

2. In case of floods, which adaptation measures do you use in growing maize?

Possible answers	Yes or No
1=River banks protection	
2= Investing in drainage systems	
3=Growing water-logging resistant crop varieties	
4=Other (specify)…………………………………………………………………………………………	

3. What are the major constraints in implementing some adaptation initiatives?

Possible Answers	Yes or No
1=Limited knowledge and skills about climate change effects	

2=Lack of capacity to invest in irrigation infrastructures	
3=Expensive farm inputs (improved seeds, fertilizers, pesticides)	
4= Lack of resistant maize varieties	
5= Poor maize value chain	
6=Lack of loan security for bank credits	
7=Absence of agricultural insurance	
8= Insufficient government subsidy for farming inputs	
9=Others (specify): …………………………………	

4. In both cases of droughts and floods, what are the major sustainable solutions to reduce the vulnerability to climate change/variability effects?

Possible Answers	**Yes or No**
1= Increased public support for irrigation infrastructures	
2= Availing drought resistant maize varieties	
3=Availing disease and pest resistant varieties	
4= Protect river banks with suitable shrubs	
5=Affordable agricultural inputs	
6= Adequate maize value chain	
9= Strengthening groups saving and loaning schemes	
11=Set up a public agricultural fund	
12=Increased access to farm credits	
14=Improve extension service s on climate change effects	
15=Availing farming insurances	
16=Creation of more off-farm activities	

Interview Guide/authorities

I. Personal Identification

- Names (optional): ………………………………………………………………

- Position: ………………… ……………………………………….. …………

- District:

II. Questions

1. What are the impacts of climate change and variability on maize production in this area?

 ……………………………………………………………………………………………………

2. What are the best adaptation strategies to climate change and variability to improve maize production and sustain food security in the district?

……………………………………………………………………………………………………

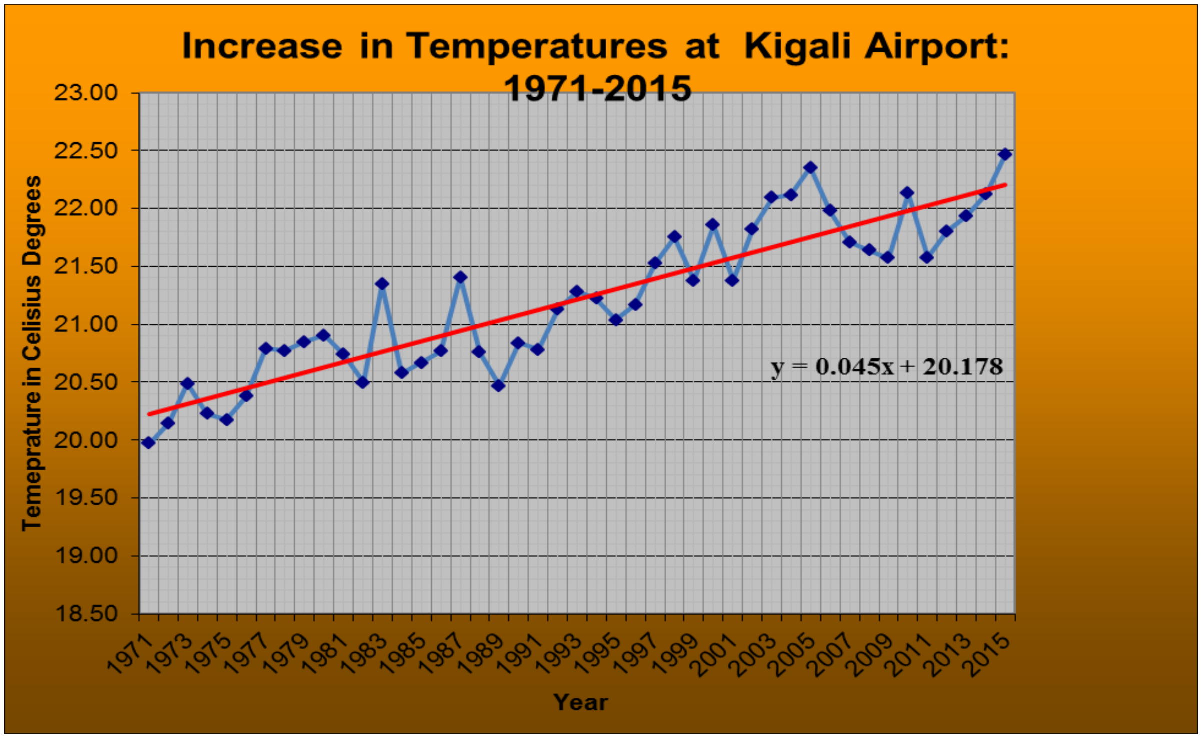
3. What may be the constraints to the implementation of these strategies?

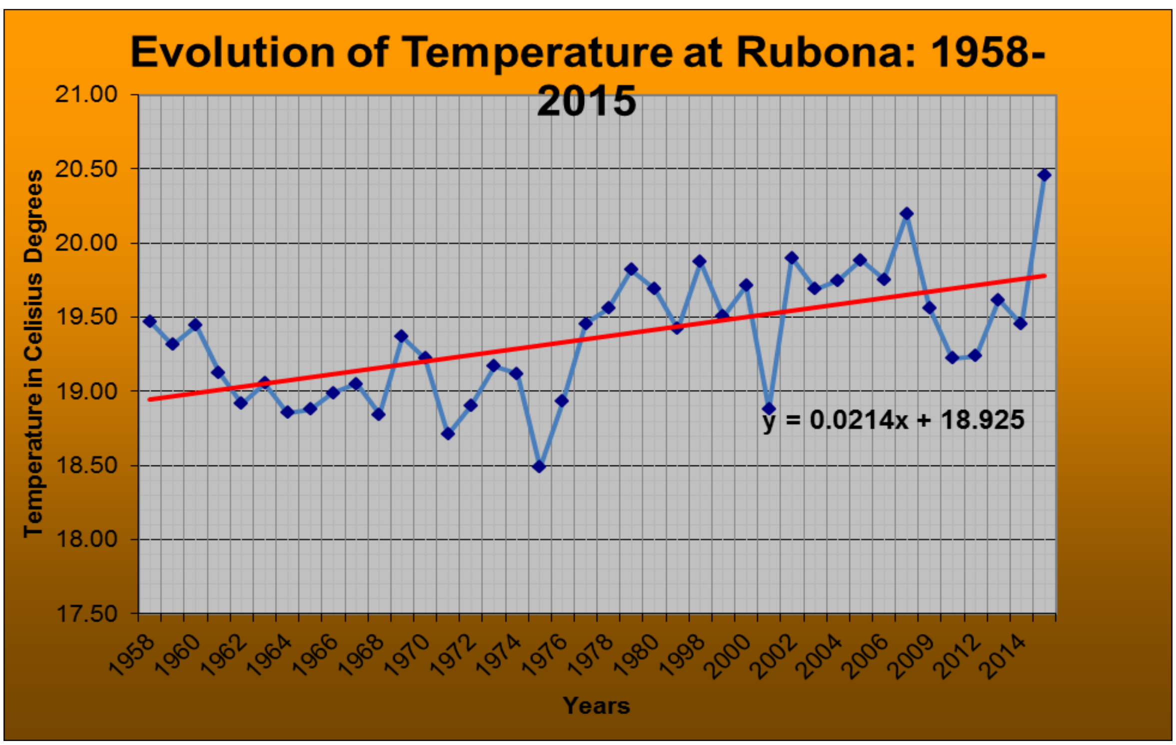
……………………………………………………………………………………………………

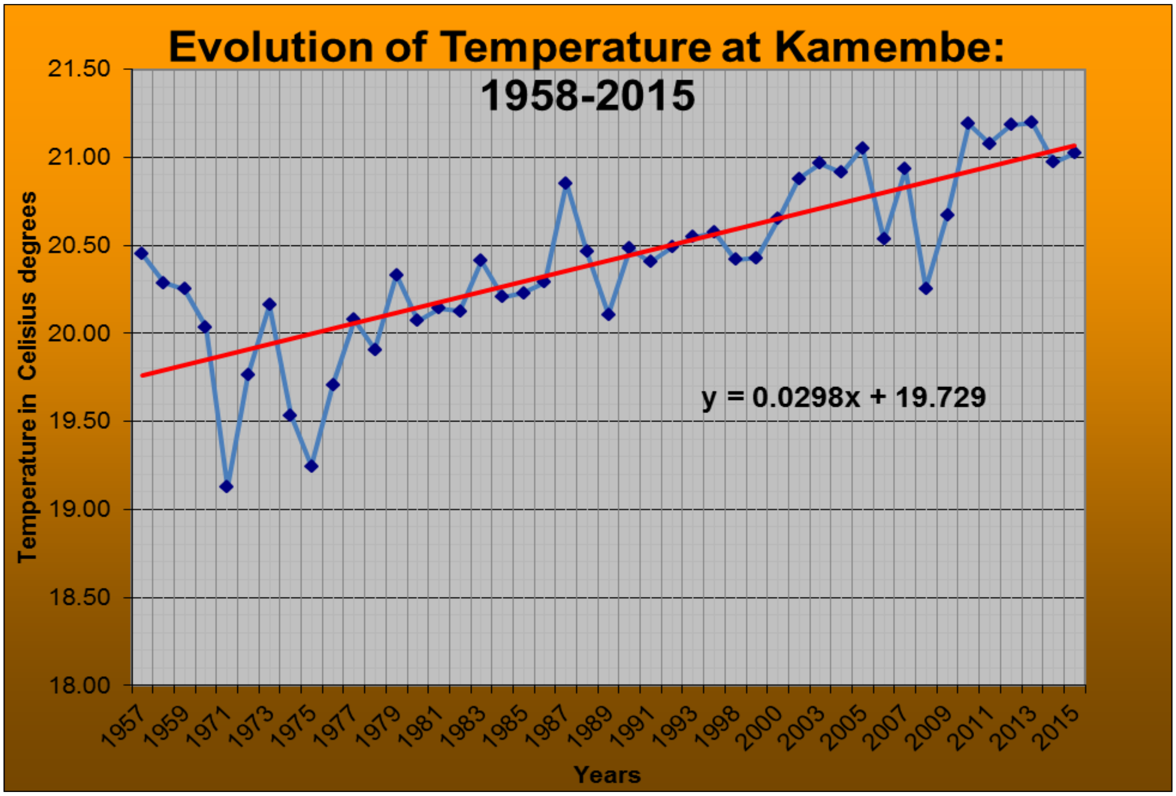
4. What are the other possible solutions to enable farmers better coping with climate change effects?
   ……………………………………………………………………………………………………

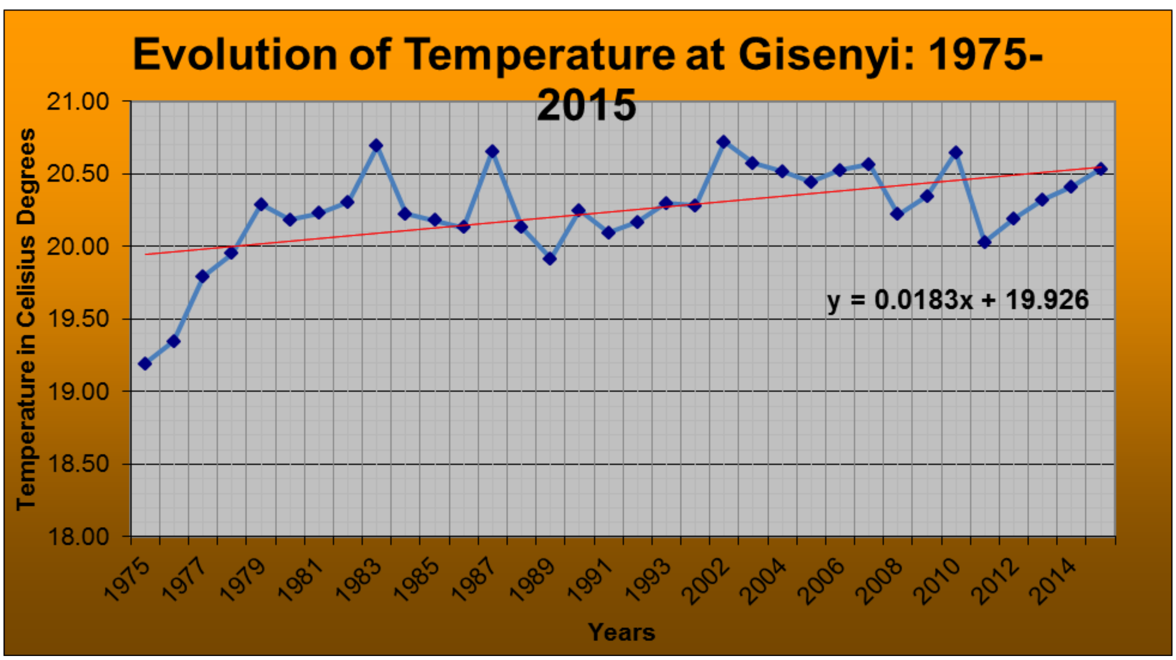
Thank you!

Appendix 2: The Representation of trends of temperature at Kanombe, Kamembe, Gisenyi and Rubona stations

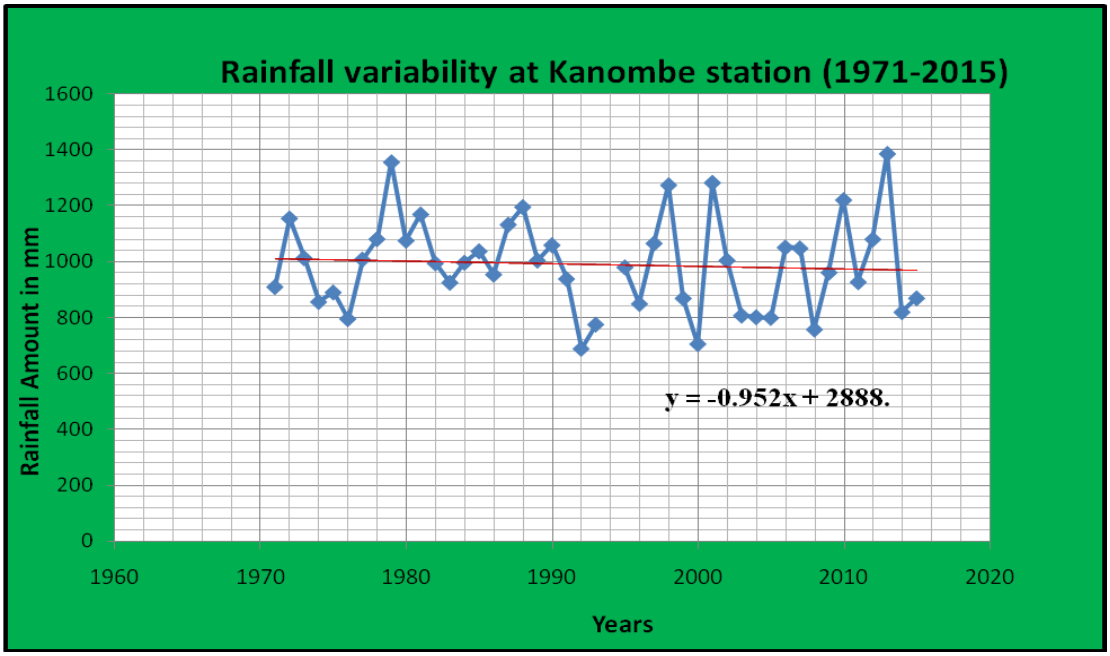


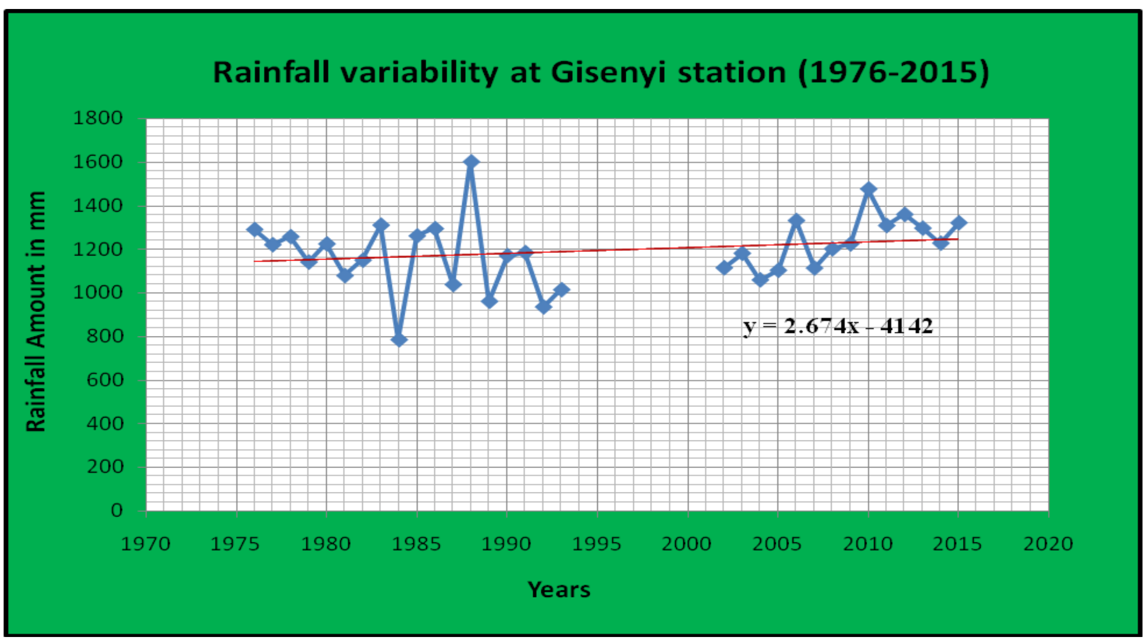


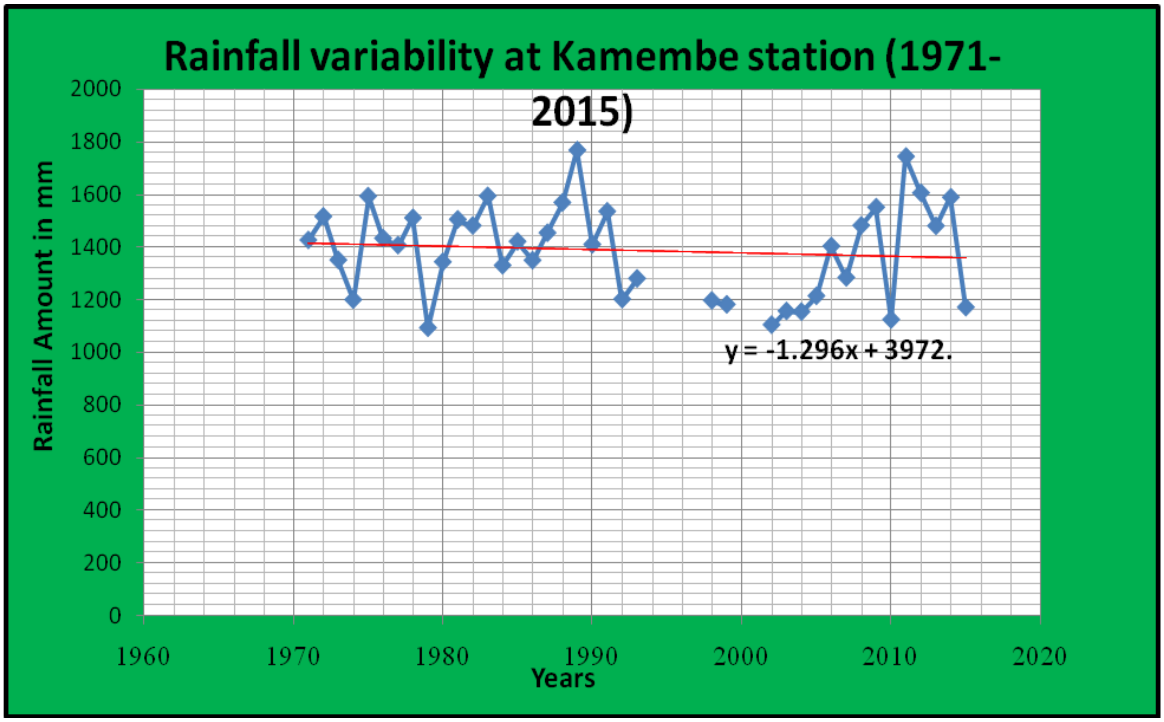

Evolution of Temperature at Kamembe: 1958-2015
Temperature in Celisius degrees
21.50
21.00
20.50
20.00
19.50
19.00
18.50
18.00
y = 0.0298x + 19.729
1957 1959 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1998 2000 2003 2005 2007 2009 2011 2013 2015
Years

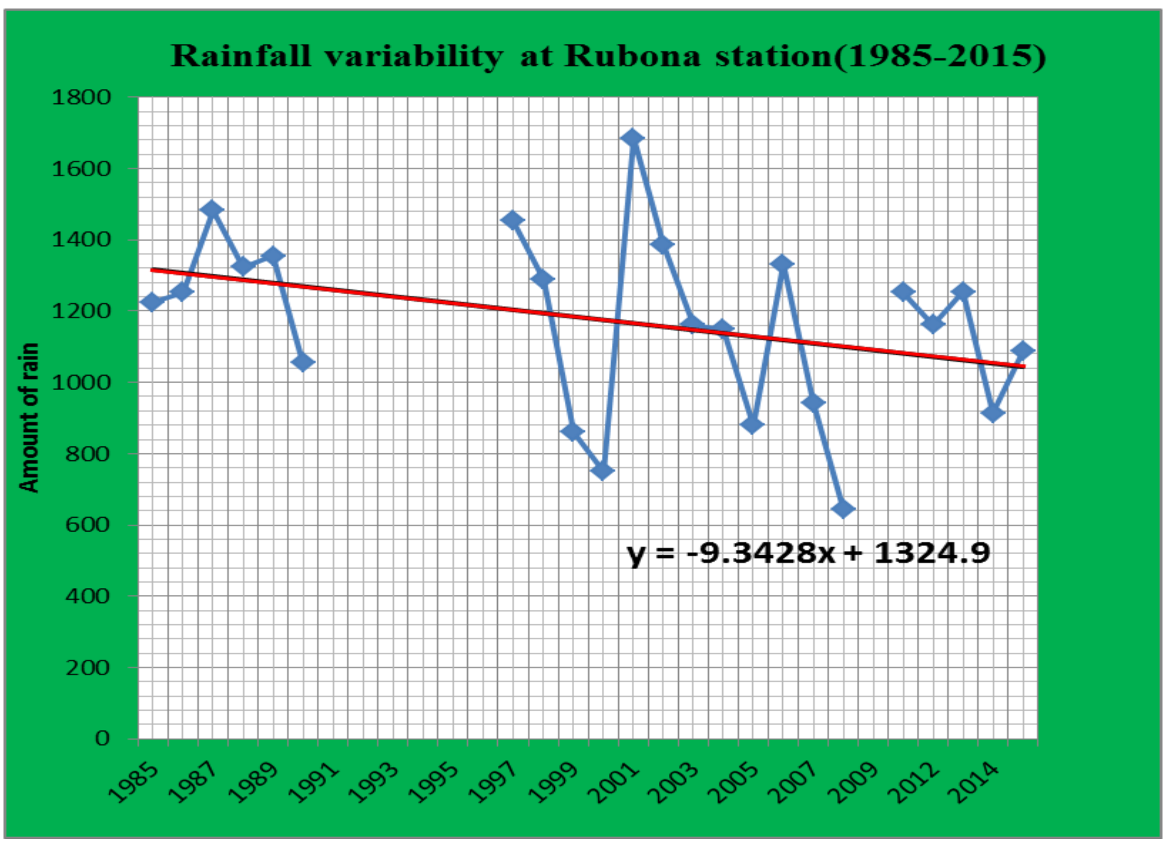

Evolution of Temperature at Gisenyi: 1975-2015
Temperature in Celisius Degrees
21.00
20.50
20.00
19.50
19.00
18.50
18.00
y = 0.0183x + 19.926
1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 2002 2004 2006 2008 2010 2012 2014
Years

Appendix 3: Trends of Rainfall at Kanombe, Kamembe, Gisenyi and Rubona stations






Rainfall variability at Kamembe station (1971-2015)
Rainfall Amount in mm
Years
y = -1.296x + 3972.
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1960
1970
1980
1990
2000
2010
2020


Rainfall variability at Rubona station(1985-2015)
Amount of rain
y = -9.3428x + 1324.9
0
200
400
600
800
1000
1200
1400
1600
1800
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2012
2014