# IMPACTS OF CLIMATE CHANGE ON MAIZE PRODUCTION IN NZOIA RIVER, BASIN, KENYA

**BY**

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**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN SCHOOL OF ENVIRONMENTAL STUDIES, DEPARTMENT OF ENVIRONMENTAL PLANNING, MONITORING AND MANAGEMENT, OF UNIVERSITY OF ELDORET, KENYA.**

**SEPTEMBER, 2016**

# DECLARATION

**Declaration by Candidate**

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# DEDICATION

This work is dedicated to my Family: My husband Benson and children: Emma, Joy, Andrew, Mercy and Ruth.

## ABSTRACT

Reports on Global research on climate change have indicated that there is an increasing trend of climate change and variability. This increasing climate variability is known to affect the human systems and livelihoods in particular the agricultural sector including maize production, which is the staple food in Kenya and Africa as a whole. This study set out to examine the effects of climate change on maize production in the Nzoia River Basin in Kenya. The specific objectives were to: Determine the climate change and variability patterns in the Basin; assess the impacts of climatic change on maize production in the basin; document practices and technologies related to climate change adaptation in maize production among the communities; propose mitigation and adaptation strategies and policies to control the adverse effects of climate change on maize production in the Basin. The study was grounded in the Anthropogenic warming theory on climate change which suggests that human emissions of greenhouse gases are causing catastrophic rise in global temperatures, and the Human forcing theory which posits that human activities have transformed the earth’s surface by clearing forests, irrigating desserts and building cities and thus affecting the climate. The study adopted the quantitative, descriptive and correlative research design. The multistage, purposive and random sampling strategies were used to obtain 276 households, 22 government representatives and two civil society organizations for sampling. The primary data was collected using questionnaires, interview schedules, photographs and maps, whereas secondary data was collected from documented data. The primary data was analysed using Statistical Package for Social Scientists (SPSS) whereas secondary data from Kenya Meteorological Service (KMS) and Ministry of Agriculture was analyzed using Microsoft excel. Results were presented in form of tables, percentages, charts and graphs. The results showed a general decrease in annual rainfall pattern. The seasonal rainfall trends showed variations with MAM seasonal rainfall showing a decreasing pattern characterized with erratic rains and delay in the onset of the rains. The JJAS and OND rainfall seasons showed increasing rainfall trends. There was a general increase in annual temperature pattern. All The seasonal temperatures showed an increasing trend. The delayed and erratic rainfall pattern causes disruption in the planting calendar of the farmers. Lack of adequate rainfall at critical stages of maize development such as germination, flowering, tasselling, and cobbing causes low yields. Increased temperatures and reduced rainfall causes wilting of the crop. It can also cause increased incidences of pests and diseases. Measures to adapt to the changing climate patterns include: integrated crop production, planting on the onset of the rains, planting drought tolerant and early maturing crops, promoting sustainable agricultural land use management among others. The study concluded that climate change and climate variability is taking place in the basin and it has an effect on maize production. The study recommends the promotion of integrated farming, planting on the onset of rainfall, development and availability of early maturing and enhancing household adaptive capacity among other strategies. Suggested area of further research include, assessing how different management methods will affect maize production under the changing climate changes in the Basin.

# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

## LIST OF PLATES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ASALS | Arid and Semi-Arid Lands |
| ASDS | Agricultural Sector Development Strategy for Agriculture |
| Asl | Above sea level |
| CA | Conservation Agriculture |
| CDM | Clean Development Mechanism |
| DNA | Designated National Authority on Climate Change |
| EMCA | Environmental Management and Coordination Act, |
| ENSO | El- Nino Southern Oscillation |
| ERS | Economic Recovery Strategy |
| EU | European Union |
| GCM | General Circulation Model |
| GCMS | General Circulation Model |
| GDP | Gross Domestic Product |
| GHG | Green House Gases |
| GIS | Geographical Information Systems |
| IPCC | Intergovernmental Panel on Climate Change |
| ITCZ | Inter - Tropical Convergence Zone |
| ITCZ | Inter- tropical Convergence Zone |
| JJAS | June, July, August September Rainfall Season |
| KALRO | Kenya Agricultural Research Institute |
| KMD | Kenya Meteorological Department |
| MAM | March April May Rainfall season |
| MDG | Millennium Development Goal |
| NAAIAP | National Accelerated Agricultural Input Acquisition Programme |
| NAPCC | National Action Plan on Climate Change |
| NCRS | National Climate Change Response Strategy |
| NEMA | National Environment Management Authority |
| NGOs/CBOs | Non-Governmental Organization/Community Based Organization |
| OND | October, November December Rainfall Season |
| QBS | Quasi-Biennial Oscillation |
| R&D | Research and Development |
| SCFs | Seasonal Climate forecasts |
| SPSS | Statistical Package for Social Scientists |
| SRA | Strategy for Revitalizing Agriculture |
| SRES | Special Report on Emission Scenarios |
| SST | Sea Surface Temperature |
| SRTM | Shuttle Radar Topography Mission |

| | |
|---|---|
| UNFCC | United Nations Framework on Climate Change |
| WMO | World Meteorological Organization |

## OPERATIONAL DEFINITION OF TERMS

**Adaptation to climate change:** Are the adjustments to natural or human systems in response to actual or expected climate stimuli or their effect, which moderates harm or exploits beneficial opportunities.

**Climate Change:** is the large scale, long-term shift in the planet's weather patterns or average temperatures. It refers to the permanent shifts in the traditional space-time patterns of the natural climate variability.

**Climate variability**: refers to variation in the mean state and other statistics (such as standard deviations, the occurrence of extremes) of the climate on all spatial and temporal scales beyond that of individual weather events. It may be due to natural internal processes within the climate system or variations in natural or anthropogenic external forcing

**Integrated farming**: Combined farming of the maize crop and other crops and animal enterprises on the same piece of land by a farmer.

**Mitigation to climate change:** Efforts that seek to prevent or slow down the increase of atmospheric GHC concentration by limiting current or future emissions and enhancing potential sinks for GHGs. Involves taking action to reduce the impact of human activity on the climate system, primarily through reducing greenhouse gas emissions

**River basin:** Is the portion of land drained by River Nzoia and her tributaries. It encompasses all of the land surfaces dissected and drained by many streams and creeks that flow downhill into one another and eventually into one river.

**ACKNOWLEDGEMENT**

This work could not have been completed without the assistance and cooperation of various personalities. I have consulted so many people that I could not possibly enumerate all of them here. I wish to particularly thank my supervisors Eng. Prof. Emmanuel C. Kipkorir and Prof. Paul Omondi for their tireless guidance and personal input during the study. I wish to also acknowledge the support accorded to me by the all the staff in the school of Environmental studies and in particular the Department of Environmental Planning, Monitoring and Management towards completing this thesis.

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I also wish to thank NEMA for giving me one year study leave that helped me to collect data. Finally I wish to appreciate the support I received from my husband Benson Mbaisi and children Emma, Joy, Andrew, Mercy and Ruth for their unwavering support during the study period. Above all I thank the Almighty God for the strength and tenacity that enabled me to complete this work.

# CHAPTER ONE

# INTRODUCTION

## 1.1 **Background to the Problem**

Climate is the pattern of weather averages, extremes and variability, timing and spatial distribution of weather elements (IPCC, 2004, IPCC, 2007, Parry 1990, RoK, 2008). Climate governs all aspects of sustainability of our livelihoods systems and is therefore a key factor in agricultural production. Observations across different climates and locations reveal climate sensitivity of crops and farming systems. For a given crop, under given technologies in a given location, agricultural yield increases with temperature to a threshold and then starts declining. There is need therefore, to analyze the sensitivity of the crops to understand their thresholds and advice farmers appropriately.

Impacts of global climate change on agricultural crop production are very significant despite technological advances in plant breeding, fertilizers and irrigation systems. Droughts, soil degradation have continued to cause deterioration in food production. Climate change results from increased emissions and subsequent concentration of gases referred to as greenhouse gases in the atmosphere due to human activities. Increased concentration of these gases cause global warming accompanied by a shift in rainfall pattern. Land presently not available for agriculture, could, with increased temperature and rainfall support crops whereas in other regions, droughts may become more frequent hence affecting maize production.

Climate change and variability are considered to be the major threats to agricultural production. The widespread poverty, recurrent droughts and overdependence on rain fed agriculture, and few coping mechanism such as adjusting the cropping calendar to synchronize crop planting and the growing period with moisture availability based on rainfall focus, changing maize varieties and diversification from traditional maize crops to other types of crop such as millet and sorghum increase people's vulnerability to climate change. In the face of global environmental change, climate risk management is increasingly recognized for its essential role of ensuring the sustainability of development processes. Climate change is altering the exposure of countries to weather related hazards, often exacerbating already existing vulnerabilities. Over the recent decades, the worldwide occurrence of weather related disasters and socioeconomic impacts have increased. This is linked to a variety of factors, including demographic, economic and environmental trends (Sperling, 2008). Global warming will alter average climatic conditions in which development processes take place and affect the exposure to extreme events (IPCC, 2007). Awareness of global warming has increased rapidly among scientists, policy makers, and the general public over the past decade.

Ninety percent of the twenty one million of Kenya's population living in rural areas derive its livelihoods directly from farming. Agriculture contributes 26% to the Gross Domestic Product (GDP) and sixty percent to foreign exchange earnings. However, while one third of total land area is arable and found in the highlands, coastal plains, the low rainfall that coincides with high evaporation rates limits the available water for agricultural activities. Due to climate change, the originally medium to high potential land is increasingly converting into arid and semi-arid lands (ASALs). This has affected human settlement and land use hence causing widespread agricultural failures, resulting in millions of casualties and massive loss of assets (RoK, 2008).

Farmers should take different adaptation measures depending on their initial climate conditions. A farmer in a wet location would choose vegetables more often than a farmer in a dry location would do. Farmers may chose not to irrigate given that sufficient rainfall is available to support cultivation. Farmers are observed to make management decisions on their farms to maximize profit. Through generations of learning by doing, most farmers know what choices work best on their farms. With changing conditions farmers must determine how to adapt and how to change these choices (Seo, Mendelson, Kurukulasunya et al, 2008).

## 1.2 Statement of the Problem

Global research experts have indicated that there is an increasing trend of climate change and variability. This increasing climate variability is known to cause various impacts on human systems and livelihoods in various areas, in particular agricultural production including maize production which is the staple food in Kenya and Africa as a whole. Sowunmi & Akintola (2001) indicated that climate variability and change have a direct, often adverse influence on the quantity and quality of agricultural production. They showed that climate of an area is highly correlated to the vegetation and by extension, the type of crop that can be cultivated. The climate of the Nzoia River Basin is mainly tropical humid. The climate of the upper part is mainly highland equatorial receiving well distributed rainfall throughout the year. The middle of the basin receives high rainfall throughout the year whereas the lower part has two rainy seasons, the long and short rains.

Maize is the primary staple food crop in Kenya and it occupies the largest hectares and is widely grown all over the country. However, the Nzoia River, especially the upper and middle part of the basin is known to be the bread basket of Kenya because it produces most of the maize that feeds the country and for export. Studies have shown that climate variability is a major threat to agricultural production. This coupled with widespread poverty, recurrent droughts and overdependence on rain fed agriculture and a few coping mechanisms can increase people's vulnerability to climate change. Maize production in the basin is depended on rainfall and is likely to be affected by climate change and variability.

In their studies, Rosenweig and Parry, 1994 observed that climate sensitivity of crops and farming systems are different across different climates and locations. For a given crop, under given technologies in a given location, agricultural yield increases with temperature to a threshold and then starts declining. There is a narrow optimal range for each farming system. There is need therefore, to analyze the sensitivity of our crops to changes in climate to facilitate adaptations and advise farmers appropriately (Senelwa, 2012). The climate sensitivity varies depending on weather, yet farming depends entirely on rainfall or irrigation, and whether farmers specialize or practice mixed farming and other farm management practices.

IPCC, 2007 indicated that Africa would be one of the most exposed continents to suffer the devastating effects of climate change and climate variability with colossal economic impacts because it often lacks adaptive capacity. The African rain fed Agriculture is viewed by many observers to be the most vulnerable sector to climate variability and the potential impacts of climate change on agriculture are highly uncertain. The IPCC report revealed that the overall global warming is expected to add in one way or another to the difficulties of food production and scarcity.

Temperature influences the growth and development of plants (Chi-chung, 2004; Bancy 2000). The higher the temperature, the faster plants grow. Higher temperatures will therefore enhance agricultural productivity. However, higher temperatures will also result in increase in atmospheric evaporation demand. Where moisture is not limiting, higher temperatures and higher carbon dioxide concentration will lead to increased crop yield. However, a change in one climate variable alters the behavour of other variables in rain fed agriculture. Associated impacts of increasing temperature, changing rainfall patterns can lead to increase or decrease of maize yield in the basin.

Agriculture in developing countries is one of the most vulnerable sectors of the global economy to climate change. Farmers, therefore, are likely to be hard hit if they do not adjust to new climates. They should embrace different adaptation measures depending on their initial climate conditions. Farmers, through generation of learning by doing, are known to make management decisions on their farms to maximize their profits by making choices that work best for them.

Studies show that resource-poor farmers and communities use a variety of coping and adaptive mechanisms to ensure food security and suitable livelihoods in the face of climate change and variability (Seo & Mendelsohn, 1994; Rok, 2008). However, the adaptive capacity and choices are based on a variety of complex causal mechanisms.

Maize is a staple food to the local people of Nzoia River Basin and the country as a whole. Maize production in the basin relies on weather. Due to reliance on rain fed farming, maize production is likely to bear the brunt of the unpredictable rainfall and temperature patterns due to climate change and variability (RoK, 2010).

Oseri and Masarirambi, 2011 indicated that there are significant variations in spatial and temporal patterns of rainfall which affect crop production including maize which is rainfall dependent. A change in one climate variable alters the behavour of other variables in rain fed agriculture. Associated impacts of increasing temperatures, changing rainfall patterns and intensity can lead to reduced agriculture yield. While studies recognize that climate variability and change have impacts on maize production, the extent and nature of these impacts is as yet uncertain. Farmers are observed to make management changes in response to the changes in rainfall and temperature patterns in the basin. Adaptation is deemed to be taking place already but seldom in response to climate change alone.

The purpose of this study therefore is to examine the impacts of climate change on maize production in the Nzoia River Basin, using maize as a case study.

**1.3 Research Objectives**

The general objective of this study was to assess and analyze the impacts of climate change and variability on agricultural production of maize in Nzoia River basin. The specific objectives were:

1. To determine the climate change and variability patterns in the Nzoia River Basin.

2. To assess the impacts of climatic changes to maize production in the Basin

3. To assess the practices and technologies related to climate change adaptation and maize production among the residents in the Basin.

4. To propose mitigation and adaptation strategies, policies and develop a management plan to control the adverse effects of climate change on maize in the Basin.

## 1.4 Research Questions

The key research questions that this study sought to answer were**:**

1. What are the changes in the climate patterns of the Basin over the last thirty years?

2. What are the impacts of climate change on maize production in the Basin?

3. What are the practices and technologies related to climate Change adaptations and maize production among the communities in the Basin

4. What are the mitigation measures that can be proposed to arrest the adverse effects of climate change on maize production in the Basin?

## 1.5 Study Assumptions

The study was based on the following premises.

1. There are changes in the climate patterns in the Nzoia River Basin.

2. The changes in the climate patterns are affecting maize production in the Basin.

3. There are measures and adaptation strategies that could be developed to mitigate Climate Change in the Basin.

### 1.6 Justification and Significance of the study

Climate variability has been and continues to be the principal source of fluctuations in global food production in countries of the developing world. Rainfall variability is a threat to food production especially maize production which is a staple food in Kenya. Climate variability presents a challenge for researchers attempting to quantify its local impact due to the global scale of likely impacts and the diversity of agriculture systems. Similarly, the effects of climate on vegetation can be dramatic, due to variations in the amounts of $CO_2$ available for photosynthesis. In addition, climatic factors such as temperature, precipitation, moisture and pressure affect the development of plants either alone or by interacting with other factors. Considerable research has been carried out on the effects of weather/climate on agricultural production, but few works have been specific on the effects of climate change on Maize production.

Kenya periodically experiences extreme weather events, including cyclic droughts and floods which result in massive crop failures, livestock losses as the country is over-dependent on rain-fed agriculture. The two also result in land degradation in terms of soil erosion, food shortages and over-exploitation of natural resources particularly in the arid and semi-arid areas of the country. Incidences of pests and diseases also increase in crops and livestock.

Changes in climate have a direct impact on agriculture. However, our current knowledge on climate change, particularly at the national and regional level is limited. On this strength the Intergovernmental Panel on Climate Change (IPCC) working group 1990, recommended that further national and international research should be undertaken to determine regional effects of climate change on crop yield, livestock production and production cost, identify agricultural management practices and technologies appropriate for changed climate and initiate and maintain integrated monitoring systems for terrestrial and marine ecosystem among other research areas (IPCC,1990).

Nzoia River Basin is of great economic importance at local as well as national levels especially in the agriculture, tourism, fishing, mining and transport sector.  The basin is also the main source of water for domestic, agricultural and commercial use. The Nzoia River Basin ecosystems have supported and nurtured human communities for several millennia. The economy of the region is still largely rural and more than ninety per cent (90%) of the population earns its living from agriculture and livestock.  With the changing climate there is need to determine how these changes are impacting on the crop yield, and identify agricultural management practices and technologies appropriate for changed climate.

There is a compelling scientific consensus that human activities are changing the world's climate. The evidence that climate is happening, and that man-made emissions are its main cause, is strong and indisputable. The intergovernmental Panel on Climate change highlights that we are already experiencing the effects of climate change and if these changes deepen and intensify, as they will without the right responses locally and globally, we will see even more extreme impacts.

Climate change has become a dominant issue in international and national policy arenas. The debate on the causes of climate change has given way to debate on the responses to climate change. The need for informed response strategies is voiced with increasing frequency by governments at all levels, as well as by groups in the private and non-governmental sectors. With effective climate change mitigation policies still under development, and with even the most aggressive proposals unable to halt climate change immediately, many decision makers are focusing unprecedented attention on the need for strategies to adapt to climate changes that are now unavoidable. The effects of climate change will touch every corner of the world's economies and societies; adaptation is inevitable. The remaining question is to what extent humans will anticipate and reduce undesired consequences of climate change, or postpone response until after climate change impacts have altered ecological and socioeconomic systems so significantly that opportunities for adaptation become limited.

This study examined the impacts of Climate Change on maize production in the Nzoia Basin. It sought to comprehensively document and evaluates practices and technologies related to climate change adaptations and maize production among the communities in the Basin. The study suggests appropriate mitigation and adaptation strategies that can be used to address the effects of climate change in the basin.  It also suggests possible policy measures to be implemented by various stakeholders at local, regional and national levels in order to address the adverse effects of climate change.

The findings of this study will contribute to the pool of knowledge which is vital for the government and future scholars. The knowledge will help the farming community in the basin, technical officers and policy makers to address Climate Change effects in other existing river basins. The findings from this study will also inform environmental planners and agriculturalists in the management of the agricultural resources in the basin.

### 1.7 Scope of the study

**The study was located in Nzioa River Basin. The Basin traverses Elgeyo Markwet, West Pokot, Trans Nzoia and Uasin Gishu counties in the North, Bungoma, Kakamega, Busia counties in the Western part and Siaya County in the Nyanza Region. The study focused on the effects of Climate Change on the maize production in the upper, middle and lower basin of River Nzoia. The study used maize yield as a function of rainfall and temperature climatic parameters.**

### 1.8 The study Area

1.8.1 Location and Size of the Study area

Nzoia River Basin lies between latitudes $1^0$ 30'N and $0^0$ 05' S and longitudes $34^0$ and $35^0$ 45'E. The Basin traverses Marakwet, Keiyo, West Pokot, Trans Nzioa and Uasin Gishu counties in the North Rift Valley; Bungoma, Kakamega, Butere-Mumias and Busia counties in the Western part of Kenya and Siaya County in the formerly Nyanza Province (see Fig. 1.1).

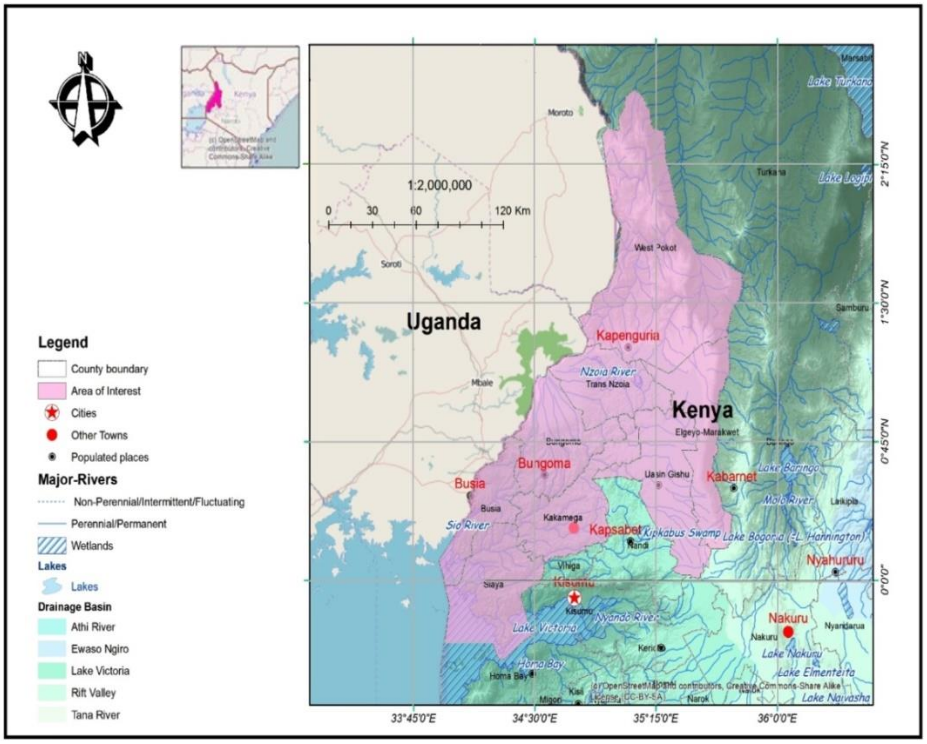



*Fig.1.1: Location of the study area* **(Source, SRTM, 2011)**

The Nzoia River Basin is an important economic region both at the local and national level especially in the agriculture, tourism and fishing sectors. The economy of this region is largely rural and more than ninety percent (90%) of the population earns its living from agriculture and livestock. Most farms are privately owned with an average size of 1-3 ha. The main food crop is maize. Others include sorghum, millets, bananas and potatoes**.**

### 1.8.2 Physiographic and Physical Factors

The quality of the natural environment is a significant determinant of the health of any given area. This is because economic development at any given time involves extraction, processing and consumption of natural resources to satisfy human needs and wants.

### 1.8.2.1 Topography and Hydrology

The Nzoia River originates from Cherengani hills at a mean elevation of 2300 m above sea level (asl) and drains into Lake Victoria at an altitude of 1000 m above sea level. It runs approximately South-West and measures about 334 km with a catchment area of about 12,900 $km^2$, with a mean annual discharge of 1777 $x10^6m^3$/year. Figure 1.2 shows the hydrology of the basin.

Figure 1.2 depicts geographical counties covering the area of interest, superimposed on the hydrological drainage (Lake Victoria and the Rift Valley) systems of Kenya. The hydrological stream network was generated using *Shuttle Radar Topography Mission* (*SRTM*) digital elevation data

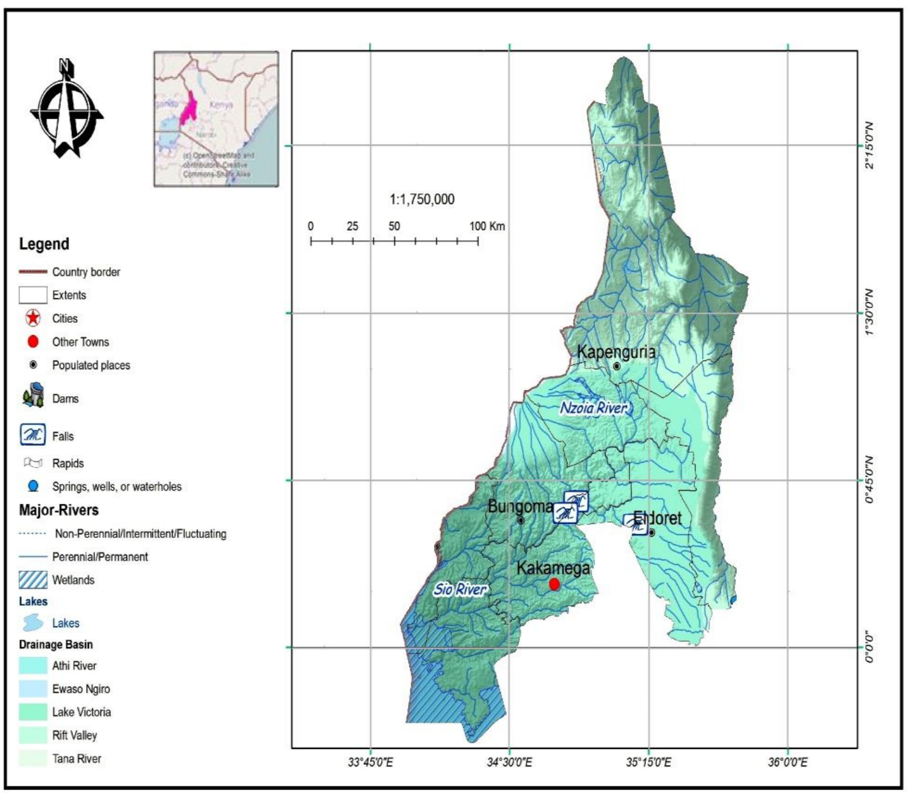


***Fig. 1.2: Topography and Hydrology of the Basin (Source, SRTM, 2011)***

Many other rivers feed the Nzoia before it discharges into Lake Victoria. The main upper course tributary is the Moiben River. The other major ones include Kwoitoboss, the Little Nzoia, the Ewaso Rongai, the Kibisi and the Kipkaren. The other tributaries into the Nzoia are the Kuywa, the Chwele, and the Khalaba discharging into the Nzoia from the north and the Lusumu and Viratsi flowing into the Nzoia from the Southern part of the Lusumu River. The Nzoia River empties into Lake Victoria in the southern corner of Lake Victoria catchment area. The river is about 220 km long along the main river channel. All other major tributaries originate from four different source regions. These regions are Mt. Elgon, Cherengany hills, Elgeyo escarpment and Nandi Hills. Mt. Elgon is in the North of the drainage basin and rises to about 4300 m above mean sea level. To the North East are Cherengany hills which rise to 3160 m above mean sea level. The Elgeyo escarpment is to the East with a maximum altitude of about 2600 m above mean sea level and the Nandi Hills are to the South and rise to 2180 m above mean sea level. Thus the River Nzoia drainage basin has the highest source region at Mt Elgon and the lowest point at the mouth of the river which oscillates only slightly with the rise or fall of the level of water in the lake.

The mean level of the Lake Victoria is approximately 1130 m above mean sea level. The mean ground slope in the upper sub-catchment is about 3.0 percent, while the rest in the lower sub-catchment which constitutes the rest of the Nzoia catchment, is only 0.2 %. This shows a fairly large potential gradient in the upper sub-catchment that the storm run-off takes little time to clear both the fields and the streams. The upper catchment has less depressions and channels storage and consequently less frequent over bank flooding. On the other hand, the lower sub-catchment has such a low potential gradient that there is very large depression and channel storage. As such over bank flooding in the lower sub-catchment is a common and expected feature over fairly small storms. Nzoia River is of international importance as it contributes enormously to the shared waters of Lake Victoria.

#### 1.8.2.2 Climate

The climate of the Basin is mainly tropical humid characterized by day temperatures varying between $16^0$C in the highland areas of Cherangani and Mt. Elgon to $28^0$C in the lower semi-arid areas on annual basis. The mean annual night temperatures vary between $4^0$C in the semi-arid areas. Mean annual rainfall varies from a maximum of 1100 to 2700 mm and a minimum of 1100 mm. The climate for the upper part, represented by the Trans Nzoia County is mainly the highland equatorial kind of climate. The rainfall is well distributed throughout the year. The slopes of Mt Elgon to the west of the County receive the highest amount of rainfall while the region bordering West Pokot receives the least. The County has a bimodal rainfall pattern with the long rains occurring in April to June, while the short rains occur from July to October.

The mean temperature of the County is 18 $^0$C; however, they vary from $10^0$C to $30^0$C. This climate favours both livestock and crop production. The average daily relative humidity is 65% and the wind speed is 2 knots, (RoK, 2013a).

The middle basin represented by Kakamega County experiences high rainfall throughout the year round. It has a bi-modal climatic pattern of rainfall with the long and short rains. The long rains start in March and end in June with the peak in May. The short rains commence in July and end in September and peaks in August. The driest months are December, January and February. Generally rain varies from 1000 mm per annum in the northern parts of the County to 2400 mm per annum in southern parts. Most rainfall received in the county comes in form of heavy afternoon showers with occasional thunderstorms.

The County has high temperatures all the year round with slight variations in mean minimum and maximum and ranges of $11^0$C to $13^0$C and $28^0$C to $32^0$C and respectively. Low temperatures are usually recorded at night while the high temperatures are recorded during the day. The mean annual evaporation ranges from 1600 mm to 2100 mm with high humidity and low evaporation rates. It’s only a few low lying parts of the County that receive annual average evaporation of more than 1800 mm (RoK, 2013b).

The lower basin falls in Busia and Siaya Counties. Busia County has several sub-counties including, Teso, Nambale, Butula, Bunyala and Samia. The County has two rainy seasons, the long rains and the short rains. The long rain season starts in March and continues into May, while the short rain season starts in late August and continues into October. The dry spells are from December through February and June-July. The mean annual rainfall for the district is 1,500 mm with most parts of the County receiving between 1,270 mm and 1,790 mm. The driest part of the County receives between 760 mm and 1,015 mm of rainfall annually and is found along the lakeshore. The mean annual rainfall in Bunyala Sub-County and Funyula Divisions is between 1,020 mm and 1,270 mm.

The climate supports two cropping seasons during the year. During the long rains, crops such as maize, sorghum, sweet potatoes, soya beans, cowpeas, green grams and beans are grown in most parts of the County. The same crops are grown during the short rains but with an addition of quick maturing crops such as kales, simsim and sunflower. The climate also supports crops that grow all the year round or have long gestation periods such as sugarcane, robusta coffee, cassava, avocados, oranges, bananas and various types of vegetables.

#### 1.8.2.3 Agro-Ecological Zones

Kenya's agricultural productivity is determined by factors such as climate, hydrology and terrain. The agro ecological factors also determine the suitability of an area for a particular land use. Land's agricultural potential can be classified as high, medium or low. The high to medium potential land comprises approximately 20% of the country's total land area. Because these areas consistently receive more rains than 1,200 mm of rainfall annually, they tend to have intensive cultivation of a large variety of crops.

Kenya has two agricultural production systems, Rain fed and irrigated. Rain fed agriculture is entirely depended on the bimodal rainfall in most parts of the country. There are two cropping seasons except in the very high altitude areas. The performance of rain fed agriculture varies spatially due to the country's diverse agro-climatic zones. In the humid high altitude areas, agriculture productivity and predictability are high. In the medium altitude, and moderate rainfall areas, arable rain fed farming is moderately suitable. However, there is a relatively high risk of crop failure due to the increased frequency of dry spells and uneven rainfall distribution.

The area experiences four seasons in a year as a result of the inter-tropical convergence zone (ITCZ).There are two rainy seasons and two dry seasons, namely, short rains (October to December) and the long rains (March to May). The dry seasons occur in the months of January to February and June to September.  However the local relief and influences of Lake Victoria modify the regular weather pattern in the Basin.

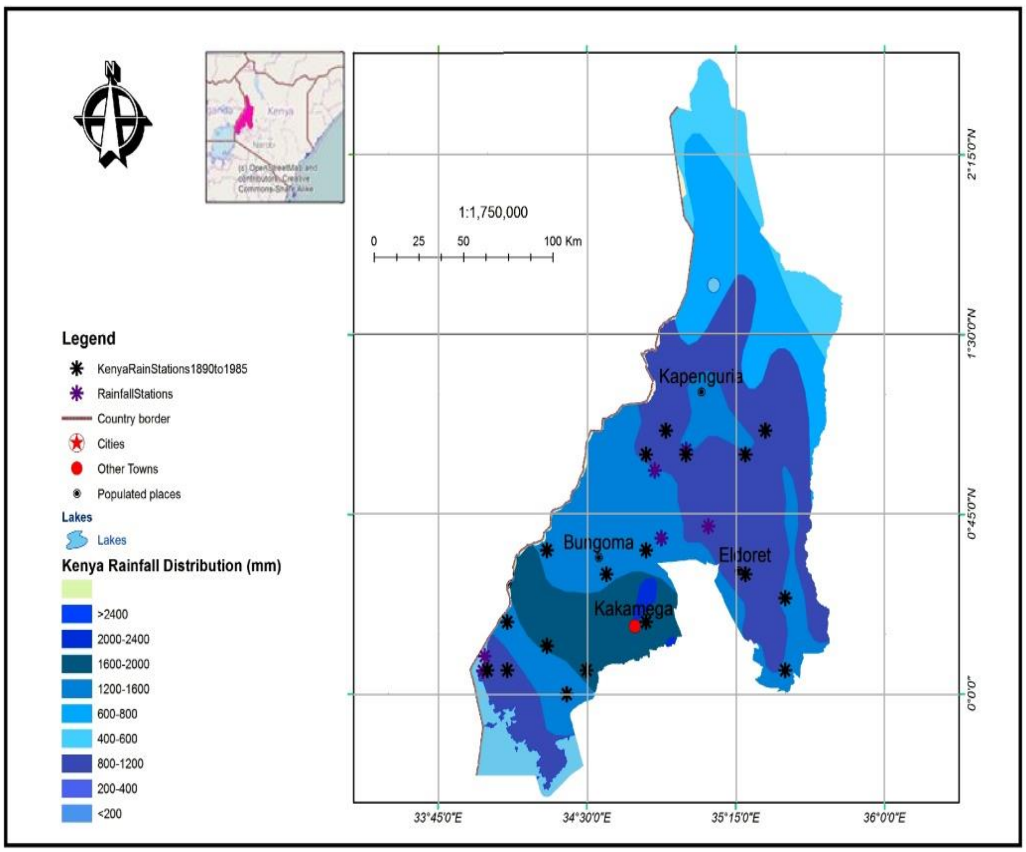



***Fig. 1.3: Spatial Locations of Rain Gauging Stations in the Basin***
***(Source, SRTM, 2011)***

#### 1.8.2.4 Soils

Most of the soils in the basin are moderately deep, generally rocky and stony consisting of well-drained red clays which have a low natural fertility. In parts of Nambale and Butula Divisions there are soils that are well drained, deep, brownish and sandy with moderate water holding capacity. In the parts of Budalangi and Funyula Divisions that adjoin Lake Victoria, soils are poorly drained and mainly of clay type due to frequent flooding. In the swamps, there are heavy clay types, which are very difficult to cultivate, both when it is dry and wet. The county has approximately 925,200 hectares (924 $Km^2$) of agricultural land. The relatively good soils of Nambale and Butula Divisions, together with the higher rainfall, promote production of a variety of crops, which are not prevalent in Budalangi and Funyula Divisions.

#### 1.8.2.5 Vegetation

The vegetation complexes can be classified into eleven groups based on the vegetation and cultivated areas maps in the National Atlas of Kenya. They are: Woodlands, Wooded grasslands, Bushlands, Grasslands, Dwarf shrub-grasslands, Permanent swamp, Barren Land, urban Land and Cultivated Land.

Vegetation in the lower basin is characterized by farming. Agriculture is dominated by cereal production but there are also large areas with perennial grasses for livestock grazing. Some areas along the river Nzoia are abandoned because of flooding (ICRAF, 2008).

#### 1.8.2.6 Land use

The Nzoia Basin has a varied landscape ranging from 1000 m at the lowlands near Lake Victoria to just over 4000 m in the highland areas of Mt Elgon. The highland areas are characterized by very steep slopes which drop sharply in Mt Elgon area but gently from Cherengany hills. From the foot slopes are the plateaus followed by undulating hills dissected by three major rivers of Nzoia, Yala, Sio and numerous tributaries. Below is the map showing the general elevation of the basin.

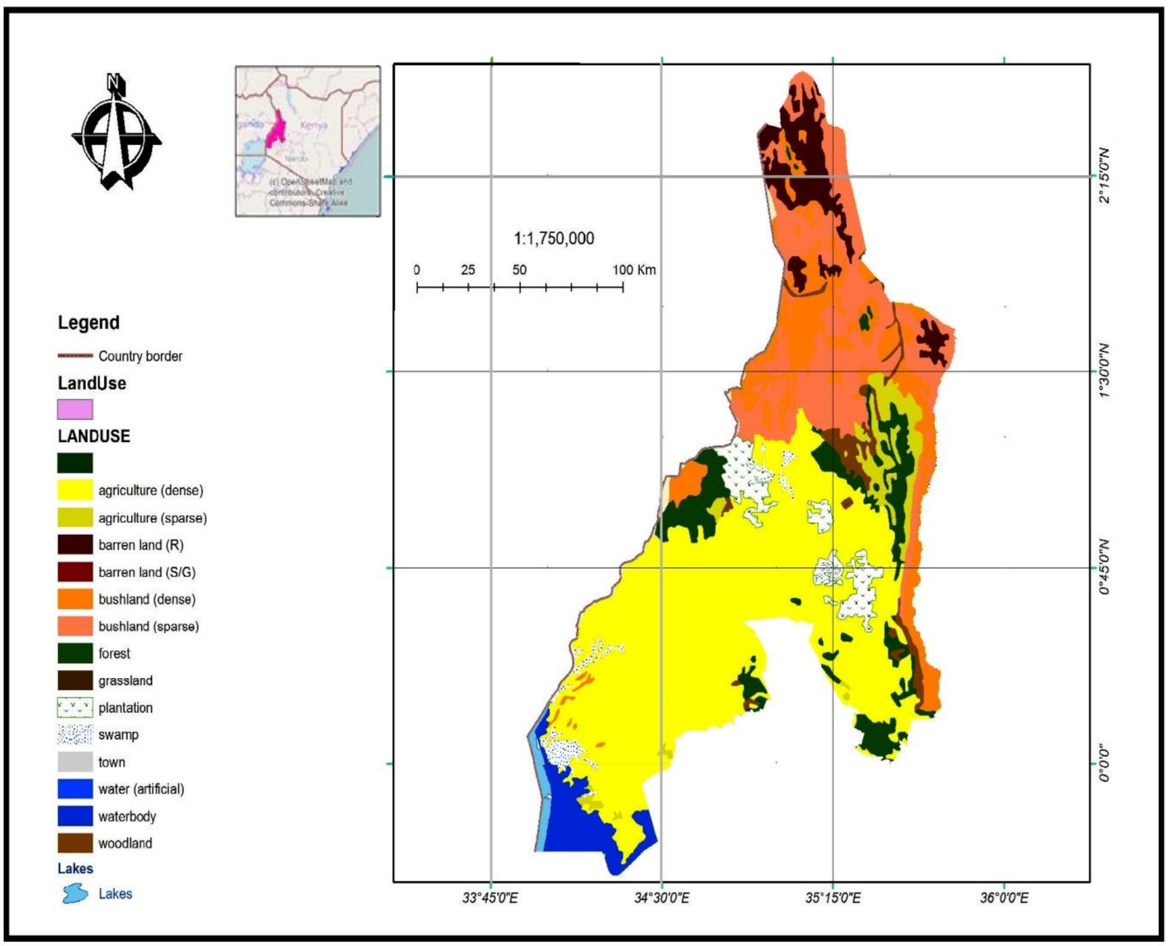



***Fig. 1.4: Land Use classification in the Basin***

**(Source, SRTM, 2011)**

The three rivers flowing through the basin are permanent throughout the year. The soils in the region are highly fertile and mean annual rainfall is relatively high. This combination of natural phenomena favours agriculture and consequently both commercial and subsistence agriculture are practiced in this region.

Different Agro- ecological zones traverse the basin. Trans Nzoia County has three distinct agro ecological zones. The Upper highland zone covers the hills and steep slopes of Mt Elgon, Cherenganyi and the boundary zone towards West Pokot County with an altitude of 2400-4313 m above sea level. The main land use is sheep, dairy farming and forest reserves. The Lower Highland zone covers the slopes of Mt Elgon and Cherenganyi hills, with an altitude of 1800-2400 m above sea level. Main activities include growing of pyrethrum, wheat, tea, maize, barley, sunflower, coffee and horticulture as well as other livestock activities such as rearing of cattle and sheep. The soils in this zone are red and brown clays derived from volcanic ash. These are fertile soils that provide continuous supply of plant nutrient during their weathering process. The Midland zone lies between altitudes of 1700-2000 metres above sea level. The mean annual rainfall is between 900-1400 mm per annum. The region includes the Endebess plains, and stretches to the Kitale plains and further towards the slopes of Cherenganyi hills. It also stretches to areas bordering Tongaren scheme of Bungoma. The land uses include Maize, sunflower, dairy, coffee, wheat, and horticulture production. The soils are well drained deep red and brown friable clays and sandy clays derived from the basement complex (RoK, 2013).

The middle basin has several counties including Bungoma, Uasin Gishu, and Elgeyo Marakwet and Kakamega County lies between altitudes of 1240-2000 metres above sea level. There are two main agro ecological zones including the upper medium and the lower medium. The other ecological zones in the county include UM, UM, UM 4 LM1 and LM 2. Maize is grown in all these ecological zones. The upper medium covers the central and southern part of the county including Lurambi, Lugari, Malava, Shinyalu and Ikolomani. Intensive maize, beans and horticulture production is carried out in this zone. A section of the population practices large scale farming. The lower medium covers a portion of the northern part of the county including Mumias, Matungu and Butere. The main activity in this zone is sugar cane production with some farmers practicing maize, sweet potatoes and cassava growing.

Busia County is found in the Low Midland (LM) zone. It is divided into four agro-ecological zones LM1, LM2 and LM4. LM1 is the sugar cane zone and covers the larger part of Butula, Matayos and Township Divisions. LM2 is the marginal sugarcane zone and is found in parts of Butula, Nambale and Funyula Divisions. LM3 is the cotton zone and covers the larger part of Funyula Division and parts of Nambale and Budalangi Divisions. LM4, the marginal cotton zone, covers parts of Funyula and Budalangi Divisions that adjoin Lake Victoria from Sio Port to Osieko.

Most parts of Busia County have sandy loam soils. Dark clay soils cover the northern and central parts of the county whereas other soil types are sandy clays and clays. These soils are good for the production of a large range of food and cash crop such as sorghum, finger millet, maize, cassava, cotton, Robusta coffee, sunflower and sugarcane. Most of the soils in Busia County are moderately deep, generally rocky and stony consisting of well-drained red clays which have a low natural fertility. In parts of Nambale and Butula divisions there are soils that are well drained, deep, brownish and sandy with moderate water holding capacity. In the parts of Bunyala and Funyula sub-counties that adjoin Lake Victoria, soils are poorly drained and mainly of clay type due to frequent flooding. In the swamps, there are heavy clay types, which are very difficult to cultivate, both when it is dry and wet.

Busia County receives an annual rainfall of between 760 mm and 2000 mm. The county experiences two rainy seasons, the long rains which peak between late march and late May and the short rains occurring between August and October. The dry season with scattered rains falls in December to February. Therefore the rainfall pattern supports two cropping seasons during the year. During the long rains, crops such as maize, sorghum, sweet potatoes, soya beans, cowpeas, green grams and beans are grown in most parts of the County. The same crops are grown during the short rains but with an addition of quick maturing crops such as kales, simsim and sunflower. The climate also supports crops that grow all the year round or have long gestation periods such as sugarcane, Robusta coffee, cassava, avocados, oranges, bananas and various types of vegetables.

### 1.8.3 Demographic Factors

According to the KNBS, 2010, the population distribution by sex, number of households, area and density of the counties in the basin is indicated in the table 1.1 below.

**Table 1.1: 2009 Population Distribution by sex, Households Land Area, density by Counties in the Basin**

| | County | Male | Female | Total | No. of HH | Land Area(Sq. Km) | Density Persons/ SqKm) |
|---|---|---|---|---|---|---|---|
| 1. | Trans-Nzoia | 407,17 | 411585 | 818757 | 170,117 | 2495.5 | 328 |
| 2. | Uasin Gishu | 448,994 | 445,185 | 894,179 | 202,291 | 3,345.2 | 267 |
| 3. | Elgeyo Markwet | 183,738 | 186,260 | 369,998 | 77,555 | 3,029.8 | 122 |
| 4. | Kakamega | 800,989 | 859,662 | 1,660,651 | 355,679 | 4,051.2 | 544 |
| 5. | Vihiga | 262,716 | 291,906 | 554,622 | 123,347 | 530.9 | 1,045 |
| 6. | Bungoma | 671,548 | 703,515 | 1,375,063 | 270,824 | 3,032.2 | 453 |
| 7. | Busia | 356,122 | 387,824 | 743,946 | 154,225 | 1,695 | 439 |
| 8. | Siaya | 398,652 | 443,652 | 842,304 | 199,o34 | 2,530.4 | 333 |
| 9. | West Pokot | 254,827 | 257,863 | 512,690 | 93,777 | 9,169.4 | 56 |
| | **Total** | **3,378,010** | **3,987,452** | **7,772,210** | **1648,849** | **29,879.6** | **3,587** |

**Source: (KNBS,1999)**

The KNBS, 2010 also indicates that the population of the Nzoia River Basin has been growing over the last four decades as shown in table 1.2 and figure below.

**Table 1.2: Population of the Trans Nzoia River Basin, 1969-2009**

| County/Year | 1969 | 1979 | 1989 | 1999 | 2009 |
|---|---|---|---|---|---|
| Trans Nzoia | 124 | 259,503 | 393,682 | 575,662 | 818757 |
| UasinGishu | 191 | 300,766 | 445,530 | 622,705 | 894179 |
| West Pokot | 82 | 158,652 | 225,449 | 308,086 | 512690 |
| Kakamega | 783 | 1,030,887 | 1,463,525 | 1,296,270 | 1660651 |
| Bungoma | 345 | 503,935 | 679,146 | 1,011,524 | 1375063 |
| Busia | 200 | 297,841 | 401,658 | 552,099 | 743946 |
| **Total** | **3694** | **2,553,563** | **3,610,979** | **4,368,345** | **6007295** |

Source: (KNBS, 1999)

### 1.8.4 Socio Economic Profile

The economy of the region is still largely rural and more than 90% of the population earns its living from, agriculture and livestock. The farms are privately owned and on average 1 – 3 hectares. However, large commercial farms with an average of 50 – 100 hectares or more characterize such counties as Trans Nzoia and Uasin Gishu. The main food crops include maize, sorghum, millet, bananas, groundnuts, beans, potatoes, and cassava while the cash crops consist of coffee, sugar cane, tea, wheat, rice, sunflower and horticultural crops. Dairy farming is also practiced together with traditional livestock keeping. In low potential areas such as the arid zones the people mainly practice agro-pastoralist which becomes more nomadic in its style as the aridity increases.

The River Basin is of great economic importance at local as well as national levels especially in such sectors such as agriculture, tourism, fishing, forestry, mining and transport. It is also the main source of water for domestic, (rural and urban water supply), agriculture and commercial sectors, as well as for very important industrial establishments in Western Kenya, namely Pan Paper Mills ( which is currently not working) Nzoia Sugar Company, Mumias Sugar Company, West Kenya Sugar and tea factory at Mudete in Vihiga District. In addition there are numerous minor sugar factories (Jageries), coffee roasters, wood processors and tea factories. Other factories are found in Eldoret, Kitale and Kapsabet. The local communities provide labor to these industries from which they obtain income to supplement those from their subsistence activities.

Maize is an important economic crop which acts as both a cash crop and food crop for the people of the region. In the lower part of the basin in Bunyala, the population is engaged in farming of crops such as maize, sugarcane, cassava and beans as well as livestock keeping. However the population growth in the basin far outstrips economic growth leading to deprivation of many households. In addition, there are many problems affecting the agriculture sector including donor dependence, high cost of farm inputs, lack of access to production assets and inhibitive cultural practices (WRMA, 2011). The lake has also unique influence on population with able bodies men engaged in fishing activities and young women engaged in selling fish catches leaving the aging population and children to take care of the farms. Extension services which are essential for propagating new technology are inadequately dispensed across the basin.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

This chapter reviews previous work relevant to the study. The review provides a conceptual grounding of the main issues that are relevant to the research

## 2.2 Climate Change and Variability

Climate change refers to the permanent shifts in the traditional space-time patterns of climate for example, a change from one climate mode to another, which is outside the normal range of natural climate variability regardless of the causes. Climate refers to the typical kind of weather that a certain location or region can expect to have from one season to the next, from one year to the next and even from one decade to the next. It is the mean condition of the atmosphere in terms of meteorological parameters such as wind, solar, radiation, temperatures, pressure, humidity, cloudiness, precipitation and their variations at a given locality averaged over a long span of time (usually over thirty years ). Such an average includes seasonal to inter-annual variations and extremes. At any one location, weather changes vary rapidly from day to day while climate is more stable.

Climatology views climate change as any permanent change or shifts in the traditional patterns of climate. However, the (UNFCC) defines climate change as a change of climate which is attributed directly or indirectly to human activities that alter the composition of the global atmosphere and which are in addition to natural variability observed over comparable time periods. Past climatic variations are attributed mainly to natural processes while the observed climate change is due to largely anthropogenic causes.

Climate change is altering the exposure of countries to weather related hazards, often exacerbating already existing vulnerabilities over the recent decades. The devastating effects of climate change are recognized today by all nations because they are likely to create serious social, political and economic problems. Increasingly, the weather we experience now in terms of amounts of rainfall/precipitation and temperatures is no longer the same as it has always been over the centuries based on previous records and scientific findings (RoK, 2006).

According to IPCC climate plays an important role in man's culture, how and where he lives, in health and sustaining plant and animal life. Climate variations in Kenya have been associated with the global climate systems such as the El Nino and La-Nina phenomena. Generally the affected parameters include rainfall, temperature, and stream flow and lake levels.

Climate change results from the increased emissions and subsequent concentration of gases referred to as greenhouse gases in the atmosphere due to human activities. Increased concentration of these gases would cause global warming accompanied by a shift in rainfall patterns. Consequently, sea-level rise and shifts in food production, water resources, biodiversity, fisheries, health and human settlement, and energy demands could occur. Rapid changes in the composition of ecosystems, some species will benefit while others will be unable to migrate or adapt fast enough and may even become extinct. Land presently not available for agriculture could, with increased temperature and rainfall support crops. In other regions, drought may become more frequent. Other possible effects include: Increase in diseases and pests due to higher temperatures; changes in the heat balance and shifts in ocean circulation which could, for instance, alter, fish productivity by varying temperatures, salinity and availability of nutrients; variations in rainfall which could greatly affect surface and ground water resources; permanent flooding of low lying islands and coastal regions, particularly densely populated fertile river deltas would be flooded due to sea-level rise.

Climate Change is a global phenomenon requiring all nations to initiate corrective measures in accordance with the United Nations Framework on Climate Change (UNFCC). Agriculture in developing countries is one of the most vulnerable sectors of the global economy to climate change. Farmers, therefore, are likely to be hard hit if they do not adjust to new climates. They should adapt different adaptation measures depending on their initial climate conditions. Farmers, through generation of learning by doing, are known to make management decisions on their farms to maximize their profits by making choices that best work for them.

Climate variability refers to variation in the mean state and other statistics (such as standard deviations, the occurrence of extremes) of the climate on all spatial and temporal scales beyond that of individual weather events. It may be due to natural internal processes within the climate system or variations in natural or anthropogenic external forcing. Climate change and variability are considered to be the major threats to sustainable development. The major areas likely to feel the impact include the economy, water, ecosystems, coastal zones, health and the distribution of population settlement and more so food security (RoK, 2010a).

The widespread poverty, recurrent droughts and floods, inequitable land distribution, overdependence on rain fed agriculture, and few coping mechanisms all combine to increase peoples' vulnerability to climate change, e.g. poor people have little protection against extreme climatic events. They have few resources for their livelihoods. Extreme weather events have serious economic implications. Floods and droughts cause damage to property and loss of life, reduce business opportunities and increase the cost of doing business (RoK, 2010).

There is increasing evidence that the world has to grapple with severer climatic events. Some of the manifestation of climate change are rising average temperatures with the last decades having got successively warmer, increasing sea level rise and the thinning of snow cover on the northern hemisphere. Climate change and variability have also led to more frequent extreme weather events such as hurricanes, erratic rainfall, flooding, more intense and prolonged droughts and devastation of some coastal areas, species extinction, and a reduction in ecosystems diversity and negative impacts on human health (IPCC, 2007). Future IPCC projection scenarios indicate an expected range of global warming between $0.3^0$ C for a scenario of constant levels of greenhouse gas (GHG) emissions to $6.4\ ^0$ C for the highest case emissions scenario.

Anthropogenic factors are thought to be the main drivers of global warming. Human activities have led to changes in the chemical composition of the atmosphere by adding more greenhouse gases (GHG) to it. Between 1970 and 2004, global GHG emissions increased by seventy percent (70 %) (IPCC, 2007).

Historical records show that climate occurrences have at times exhibited magnitudes above and below normal and these represent climatic anomalies under natural circumstances. However, since the industrial era, some human activities have led to the release of large amounts of gases into the atmosphere which is now known to affect the climate.

In Africa, climatic variations have manifested themselves through the shifting of dry land boundaries and the rise and fall of water levels in many lakes. For instance, just after the end of the last glacial period, about 10,000 years ago, the tropical North African monsoon winds were stronger than they are today and large parts of the Sahara region were vegetated and inhabited by wildlife (Okoth-Ogendo et al. 1995). The Kenyan Rift Valley lakes; Turkana, Baringo, Bogoria, Nakuru, Elementaita, Naivasha and Magadi had each occupied a much large area in the Holocene period. The occurrence of lake sedimentary deposits including the diatomite around some of these lakes is a pointer to this. The prolonged desiccation of the Sahel region over the last three decades and the drought of 1983/84 which affected most parts of Africa were evidence of climatic variations. The dependence, for example, on rain fed agriculture, livestock rearing, water resources availability and hydropower of most developing countries on climate, places these countries in a more vulnerable position.

Kenya's tropical climate is hot and humid at the coast, temperature inland and very dry in the North and North East part of the country. There is plenty of sunshine most of the year but cool conditions occur in June-July-August period. The central highlands regions are substantially cooler than the coast, with the coolest (highest altitude) regions at 15 $^{0}$C (this excludes the top of the Mount Kenya that has a temperature of about $0^{0}$C degrees centigrade) compared with 29 $^{0}$C at the Coast. Temperatures vary little throughout the year, but drop by around two degrees Celsius 2 $^{0}$C in the coolest season.

Climatic variations in Kenya have been associated with the global climate systems such as the EL-Niño Southern Oscillation (ENSO) phenomenon and Quasi-Biennial Oscillation (QBO) (Ogallo, 1992). The affected climatic parameters include rainfall, temperature stream flow, lake levels, mountain glaciers and palaeclimatological records.

Rainfall shows, strong seasonality with bimodal distribution patterns (March – May and October – November), confirming to the seasonal latitudinal migration of the inter-tropical convergence zone (ITCZ) which causes relatively a narrow belt of very low pressure and heavy precipitation that forms near the earth's equator. The exact position of the ITCZ changes over the course of the year, migrating southwards through Kenya in October to December and October and returning Northwards in March, April and May (Ogallo, 1992). This causes Kenya to experience two distinct wet periods the short rains in October to December and the long rains in March to May. The third rainfall peak (July – August) which is experienced in the western highlands is due to the incursions of moist air masses from the Atlantic ocean and the forested basin of the Democratic Republic of Congo during the Northern hemisphere summer season (Ogallo, 1997). The hottest month in Kenya (January – March) are attributed to low cloud cover. The amount of rainfall received in these seasons is generally between 50 mm to 200 mm per month but varies sometimes exceeding 300 mm per month in some regions. The classical climate (rainfall) patterns that would be generated by the large scale patterns are significantly modified by the small scale flow, patterns generated by the topographical features within the country. These are known to modulate the climate (rainfall) pattern significantly.

General circulation models (GCMs) indicate that future climatic changes in Kenya would result in an increase in mean annual temperature of 2.5 – 5.0$^0$C with a 0-25% increase in precipitation. Since the 1960's, Kenya has experienced general warming. The mean annual temperatures have increased by one degrees centigrade 1$^0$C since 1960, resulting to an average rate of 0.21 degree centigrade per decade. This increase in temperature has been most rapid in MAM (0.29 $^0$C per decade) and slowest in JJAS (0.19$^0$C per decade), (Sweeney, New and Lizcano, 2007). Research suggests that the general increase in temperature in Northern part of the country is relatively higher in other parts especially from October–February period (RoK, 2010; WMO, 2008). Similarly the decrease in Minimum temperature in the Northern part of the coastal strip is relatively higher compared to the decrease in the Southern strip over the same period. This drop ranges from one degree in Lamu in the North to 0.3 degrees in Mombasa (RoK, 2010); whereas diurnal temperatures ranges have been decreasing inland, Coastal temperatures display an increasing range. Maximum temperatures rise while minimum temperatures remain neutral or decrease. Expanding temperature results in increasing hot days and consistently cool nights and early mornings.

Global surface temperatures are strongly correlated with the Indian Ocean Sea Surface Temperature from March through June each year (William and Funk, 2010) (RoK, 2010). IPCC weather simulations and historical records significantly correlate a strong warming tendency in the Western Indian Ocean (Funk et al, 2005) likely driven by an increase in Green House Gases emissions.

Mean temperatures in Kenya follows a strong bi-modal seasonal pattern. Generally the long rains occur in the months of March to May, while the short rains occur between October- December with variations. Climate Change has affected rainfall causing extreme weather conditions including most prominently droughts, flooding and consequently erosion and soil degradation. It has additionally altered rain duration and intensity. Average annual rainfall ranges between 250 mm to 2500 mm and average potential evaporation ranges from less than 1200 mm to 2500 mm (World Bank, 2007).

### 2.2.1 Detection and Attribution of Climate Change

Detection of Climate Change refers to the identification of any statistically significant changes in the traditional patterns of climate, while attribution refers to apportionment of the changes partly or wholly to either natural or anthropogenic causes. Measurement and recording of weather elements such as rainfall, temperature, humidity and radiation are undertaken at various meteorological stations all over the world.

Analysis of records of such variables is done to obtain the general trend of regional or local climate. Changes in the mean conditions can either be attributed to normal variability or to climate change depending on the significance and persistence of such changes and their causal factors. Detection of Climate Change is done through analysis of instrumental data, proxy records of climate and by use of climate models. Attribution is, however, a much more difficult task and is mainly done using climate models (Ogallo, 1996).

### 2.2.2 Analysis of Instrumental Data

Statistical analysis of climatological records is carried out as one of the approaches for climate change detection. Records of temperatures and rainfall are commonly used in climate change studies. Analysis of temperature records have given clear signals of climate change with the trend being of temperature rise over land at night time in the Northern hemisphere. Rainfall records however, have not yielded any clear indication of climate change even though there appears to be a downward trend in the mean annual rainfall in some places (Ogallo, 1996).

There has been a 2.6% decrease in rainfall recorded between the years 1960 to 2006 in Kenya. This decrease is projected to average 15.6% by the year 2050 according to (Kirai, 2009; UNDP, 2007; RoK, 2010). In fact, whereas there is a clear trend for increase in temperature over the years, there is no generally homogenous trend regarding changes in precipitation over the years (Andresen, et al., 2008). Mean October-December (OND) rainfall for selected stations indicate over the period 1960 to 2009; indicate a mild decline in rainfall amounts over this period with a decreasing trend (RoK, 2012).

### 2.2.3 Analysis of Proxy Records

Evidence of past climatic variations and changes especially those related to warmer epoch’s have been used to estimate the magnitude of expected changes in climate due to the current global warming. Maps showing anomalies in the past mean annual air temperatures and precipitation obtained from proxy records have been reconstructed for regions mainly in the Northern hemisphere and used to estimate future conditions of climate (Budykomi, 1991). The assumption is that the current changes in the climatic variables considered, are similar to those of the earlier climatic variations. The causes of the earlier changes may not have been as a result of greenhouse gas induced warming, but if the response of the climate system was similar, then the use of these epochs and the inherent variability of climatic parameters in estimating future climate are justified.

Analyzing data from 1960 to 2009, a cohesive pattern of climate emerges in rainfall and temperature. Large parts of Kenya have experienced more than 100 mm decrease in long season rainfall as at 2009. Recent La Nina years tend to be drier whereas El Nino years tend more towards average rather than above average rainfall totals (FEWSNET**,** 2010**).** More rainfall is also expected in Northern parts of Kenya over the years.

### 2.2.4 Climate Modeling

A climate model is a simplified representation by mathematical equations of the complex interactions and processes associated with climate occurring within the earth's surface in atmosphere system. Climate modeling is a means of simulating the processes and interactions within the climate system in order to draw conclusions about the future status and trends of climate based on assumptions about the concentration of greenhouse gases or change in the amount of solar energy.

General circulation models (GCMs) which are three dimensional mathematical representation of the climate system have been used to predict climate system based on the current level of human understanding of the dynamic and physical processes in the system. Predictions of changes in the climate obtained by use of these models have much uncertainty as the descriptions or parameterization of many of the processes represented are relatively crude (IPCC, 1992). Consequently attempts have been made to give best estimates of the equilibrium climate sensitivity.

### 2.2.5 Crop Modeling

Climate variations, continuous increase in population pressure and market infrastructure are driving forces that reduce agricultural productivity. Changes in climate scenarios are of vital importance for rain fed agriculture as a change in one climatic variable alters other variables which include temperature, precipitation and solar radiation. Associated impact of increasing temperature, changing rainfall pattern and intensity has led to reduced agricultural productivity and yield over the world. Water availability through rainfall has become a limiting factor to crop productivity due to lack of decision support and management strategies like suitable sowing time, appropriate genotypes and cropping systems under changing climate.

Crop simulation models consider the complex interactions between weather, soil properties and management factors which influence crop performance. Crop simulation models have developed over many years in recital with advances in crop physiology, crop ecology, and computing technology (Ahmed, 2011 and Luedeling, 2011).

## 2.3 Impacts of Climatic Change on Maize Production

Maize (*Zeamays*) originates in the Andean region of Central America. It is one of the most important cereals both for human and animal consumption and it is grown for grain and forage (FAOSTAT, 2000). The crop is grown in climates ranging from temperate to tropic during the period when mean daily temperatures are above $15^0$C and frost free.

Adaptability of varieties in different climates varies widely. Successful cultivation markedly depends on the right choice of varieties so that the length of growing period of the crop matches the length of the growing season and the purpose for which the crop is to be grown. Variety selection trials to identify the best suitable varieties for given areas are frequently necessary.

When daily temperatures, during the growing season are greater than 20 $^0$C, early grain varieties take 80- 110 days and medium varieties 110-140 days to mature. When grown as a vegetable, these varieties are 15-20 days shorter. When mean daily temperatures are below 20 $^0$C, there is an extension in days to maturity of 10-20 days for each 0.5 $^0$C decrease depending on variety, and at 1.5 $^0$C the maize grain crop takes 200-300 days to mature. With mean daily temperatures of 10 -15$^0$C the maize is mostly grown as a forage because of the problem of seed setting and grain maturity under cool conditions. For germination, the lowest mean daily temperature is about 10$^0$C, with 18-20$^0$C being optimum. The crop is very sensitive to frost, particularly in the seedling stage but it tolerates hot and dry atmospheric conditions so long as sufficient water is available to the plant and temperatures are below 45$^0$c. Temperature requirements, expressed as sum of mean daily temperatures, for medium varieties are 2500 to 3000 degree days, while early varieties require about 1800 and late varieties 3700 or more degree days.

The plant does well on most soils but less so on very heavy dense clay and very sandy soils. The soils should preferably be well, aerated and well drained as the crop is susceptible to water logging. The fertility demands for grain maize are relatively high and amount, for high-producing varieties, up to about 200 kg/ha N, 50 to 80 kg/ha P and 60 to

100 kg/ha K. In general the crop can be grown continuously as long as soil fertility is maintained. Maize is moderately sensitive to salinity.

### 2.3.2 Water requirement for maize production

Maize is an efficient user of water in terms of total dry matter production and among cereals; it is potentially the highest yielding grain crop. For maximum production, medium maturity grain crop requires between 500 and 800 mm of water depending on climate as indicated in Table 2.1. To this water losses during conveyance and application must be added. The crop factor (KC) relating water requirements (ETm) to reference evapotranspiration (ETo) for different crop growth stages of grain maize is for the initial stage 1.05-1.2 ( 15 -30 days) ,the development stage 0.7-0.85 (30-45 days) the mid-season stage 1.05 -1.2 ( 30 -45 days), during the late season stage 0.8 -0.9 ( 10-30 days),and at harvest 0.55-0.6 (days), during the late season stage 0.8 -0.9 (10-30 days), and harvest 0.55-0.6.

**Table 2.1: Agro-Climatological Maize Crop List for Western Kenya**

| Growing Period | Maize Variety | Average No, of days to physiological maturity/Harvest | Altitude according to growing period | Required well distributed rainfall in growing period | Optimum Yield Kg/Ha |
|---|---|---|---|---|---|
| Short | Maseno Double Cobber | 85-105/100-120 | 1000-1600 | 500-750 | 4000kg/ha |
| Medium | H511 | 100-130/100-150 | 1000-1800 | 450-700 | 5200 |
| | H515 | 100-130/100-150 | 1000-1800 | 480-750 | 5850 |
| | H622 | 140-155/160-190 | 1200-1700 | 550-880 | 5400 |
| | H623 | 150-165/170-195 | 1200-1700 | 600-950 | 6300 |
| | H612,H613 | 160-18/190-220 | 1500-2100 | 600-950 | 6000 |
| | H614,H625 | 150-180/180-205 | 1500-2100 | 650-1000 | 8000 |
| | H6210,H6213 | 150-180/180-205 | 1500-2100 | 680-1050 | 10,500 |
| | H7801 | 165-185/195-220 | 1500-2100 | 700-1100 | 7800 |
| Medium – Long | H611D, H626 | 165-190/190-230 | 1500-2100 | 600-950 | 8500 |
| | H627,H628 | 165-190/190-230 | 1500-2100 | 600-950 | 9000 |
| | H6212 | 165-190/190-230 | 1500-2100 | 600-950 | 10,500 |
| | H629, H6211 | 170-220/220-250 | 1500-2100 | 700-1100 | 9500 |
| | H613D | 180-230/230-270 | 1500-2100 | 700-1100 | 8,000 |
| Long – Medium | H611 | 180-200/225-245 | 1800-2100 | 600-900 | 5900 |

**Source: Kenya National Crop Variety List, Kephis, 2003**

### 2.3.3 Water supply and Maize crop yield

Frequency and depth of irrigation and rain has pronounced effect on grain yield. Maize appears relatively tolerant to water deficits during the vegetative and ripening periods. Greatest decrease in grain yields is caused by water deficit during the flowering period including tasselling and silking and pollination, due mainly to a reduction in grain number per cob. This effect is less pronounced when in the preceding vegetative period, the plant has suffered water deficits. Severe water deficits during the flowering period, particularly at the silking and pollination, may result in little or no grain yield due to silk drying. Water deficits during the yield formation may lead to reduced yield due to reduction in grain size. Water deficit during the ripening period, has little effect on grain yield.

The effect of limited water on maize grain yield is considerable and careful control of frequency and depth of irrigation is required to optimize yields under conditions of water shortage. Where water supply is limited it may, therefore be advantageous to meet, as far as possible, full water requirement (ETm) so as to achieve near maximum yield from a limited acreage rather that to spread the limited water over a large acreage. Maize flourishes on well drained soils and waterlogging should be avoided, particularly during the flowering and yield formation periods. Waterlogging during flowering can reduce grain yields by 50 % or more. Where rainfall is low and irrigation water supply is restricted, irrigation scheduling should be based on avoiding water deficit during the flowering period, followed by yield formation period.

### 2.3.4 Impacts of rainfall variability on maize yield

Various studies by IPCC have pin pointed Africa to be one of the most exposed continents to suffer the devastating effects of climate change and climate variability with colossal economic impacts because it often lacks adaptive capacity. The African rain fed Agriculture is viewed by many observers to be the most vulnerable sector to climate variability and the potential impacts of climate change on agriculture are highly uncertain. The report revealed that the overall global warming is expected to add in one way or another to the difficulties of food production and scarcity. The report indicated that reduced availability of water resource would pose one of the greatest problems to agriculture and food production.

Factors such as endemic poverty, bureaucracy, lack of physical and financial capital, frequent social unrest and ecosystem degradation contribute to Africa's vulnerability to climate variability. Over the years, factors such as small fragmented landholdings and minimal access to agricultural inputs, reduced employment opportunities, market inefficiencies and high HIV/AIDs prevalence have contributed to chronic food insecurity and gradually weakening livelihoods. In addition, the agricultural system is dominated by a single crop which is maize and coupled with the extensive dependence on rain-fed agriculture which will further increase household vulnerability, due to erratic rainfall and weather variability.

Oseni and Masarirambi (2011) reported that rainfall trends showed significant variations in spatial and temporal patterns of both total annual and planting seasons rainfall which affected crop production including maize crop which is rainfall dependent. Climate variability affects maize yield and the various crop process and activities in maize production. The study also indicated that there has been a significant fluctuation in maize yield and production trends in terms of maize area, production in tons, trends in hectare. The study found out that maize production has been on a steady decline due to erratic rainfall variability and the area planted with maize has also been reduced to adapt to the anticipated drought period. The risk associated with climate variability of maize production in general depends mainly on the growth stage of the maize crop, when the weather aberration occurs. However, other factors such as poor accessibility to inputs partly due to increased prices may have also contributed to decline in maize yield.

The agricultural system which is dominated by a single crop, maize, which is largely dependent on rain-fed agriculture has declined over the years due to rainfall variability and drought subsequently increasing household's vulnerability to erratic weather and food insecurity. Minimal shocks to maize production due to weather vagaries, therefore has a profound impact on the ability of rural households, especially the chronically and resource poor to maintain their food security.

Extreme climate variability conditions due to global warming phenomenon have greatly affected the spatial and temporal distribution of rainfall in most parts of the world including Kenya. In as much as climate variability and change are inevitable, maize production systems should be able to adapt to weather fluctuations and climatic aberrations to minimize their negative effects. Wang et al., (2011) projected that in general, the future yield would decrease in the main growing areas but increase in a few other areas. Some of these areas were likely to experience a significant yield reduction due to the increasing dryness. In contrast, a favorable rise in yield emerged for the current marginal maize growing regions i.e. some unsuitable areas at present could have a doubled maize yield in the 2050's. However, their study projected that yield changes were significantly different from one region to another (Wang, et al., 2011).

Climate change has an impact on maize phenology since temperature changes influence the schedule of maize sowing, flowering and grain filling. Spatially, the sowing date of maize will slightly advance in the future due to the warming trend in the spring. The projections of climate change revealed that the sowing date was 1-5, 3, and 4 days earlier in 2020, 2050 and 2070 respectively, than the baseline for the main cropping areas. The advances were due to the comparatively lower sowing temperature threshold of April and May that could be easily surpassed during future warming. Phonologically, the early sowing helps to prolong the maturity season of the current early maize cultivar in the East and is a favorable change for maize yield.

Similarly to the sowing date changes, there was also a more homogenous pattern for the flowering dates which were 2, 3, and 4 days earlier for 2020, 2050 and 2070. Distinctive from the changes in sowing and flowering phases, the entire number of maturity days (from sowing to harvest) was predicted to shrink, ranging from about 10 to 30 days shorter in the next few decades, but lengthened by 8 to 22 days in some areas. With regard to the grain filling period, despite the advance in both sowing and flowering date (1 to 5 days earlier), the changes in reproduction phase (period after flowering, including tasselling and grain filling, may contribute to most of the changes in maize hence it is likely that the varied length of the reproduction phase may be linked to yield changes.

Three periods of the growing phase were considered: The period from sowing to tasselling to the beginning of grain filling and from grain filling to maturity.

The shrinking of the maize filling period represented more than half of the overall reduction of the growth season. The grain filling was prolonged despite the shortening trend in the periods from sowing to flowering. The possible increase in maize yield in cold countries can be attributed to the improvement of local thermal conditions as regional warming develops, which could significantly extend the grain filling phase.

The arid and semi-arid zones will expand into most parts of the present cropping areas. Furthermore, the changes in thermal resources due to regional warming will accelerate crop growth for the present maize cultivars. The growth period, in particular the grain filling phase is projected to be shortened by about 10 to 30 days in the current main cropping regions, leading to a decreased maize yield.

Nyabundi and Njoka (1991) indicated that, if unchecked, carbon dioxide concentration will double by the year 2050 and the joint effect of all greenhouse gases will lead to a rise in global temperature of 1.5-5$^{0}$C by the same year. Global warming of that magnitude will lead to increased precipitation and rise in sea level which together with the effect of high carbon dioxide concentration and high temperature per se will have important consequences in agriculture and forest productivity and management. It is also recognized that human activities can also influence climatic change and its impacts. Increase in carbon dioxide content in the atmosphere is increasing annually by approximately billion tones as a result of utilization of fossil fuels, although the situation is further aggravated by deforestation which removes forest sinks.

Carbon dioxide is the primary substrate of photosynthesis. At its current atmospheric level of about 330 parts per million (ppm), carbon dioxide frequently limits photosynthesis and productivity of plant systems. It is expected therefore that increasing carbon dioxide concentration will raise productivity and yield of both agricultural plant products and forests. Increasing carbon dioxide concentration will also boost growth rate of weeds, many of which grow more rapidly than crop plants even at current carbon dioxide levels.

Further increased growth rate of plants, will lead to rapid exploitation of soil nutrients and water so that application of higher levels of fertilizer will be necessary. Considering that most of our African farmers operate at low input levels, crop yields may drop. In areas with low rainfall, rapid growth early in the season may utilize much of the soil water so that there is little left for reproductive growth which comes later in the season.

It has also been reported that plants grown under high carbon dioxide concentration tend to be of low quality, leaves are relatively richer in carbohydrates, but poorer in nitrogen. Pests feeding on such plants tend to eat more in order to gain enough nitrogen. We thus expect pest damage with increase in atmospheric carbon dioxide. This is a great concern in Africa where we already have high pest incidence.

### 2.4.2 Impacts of temperature variations on Maize yield

Temperature influences growth and development of plants. The higher the temperature, the faster plants grow and mature. Higher temperatures will therefore enhance agricultural and forest productivity. High temperature will also result in increase in atmospheric evaporation demand and the resulting high rate of evaporation will place more demand on irrigation water and limit dry land farming. Where moisture is not limiting, higher temperature and higher carbon dioxide concentration will lead to increased crop yield.

Higher temperatures increase mineralization of organic matter, thus reducing organic matter content of the soils. The problem is already significant in Tropical Africa and leads to reduced soil fertility and poor soil structure. Higher temperatures will have the impact of increasing post-harvest spoilage of crops and putrefaction of animals' products such as meat and milk. High temperatures coupled with high atmospheric humidity also favours development of animal and crop pests diseases and will accentuate these problems which are already contributing to a large extend to agricultural and forest losses in Africa.

It is predicted that the doubling of atmospheric carbon dioxide level and the resulting greenhouse effect will raise the mean global rainfall by 7-11% (Nyabundi and Njoka, 1991). However, unless there is a change in the direction, duration and occurrence of the rain-causing winds, the added rainfall will only fall in the already wet areas and may cause more havoc than good to agriculture. More rainfall, higher temperature and higher concentration of carbon dioxide may aggravate the problem of weeds in cultivated areas and the resultant competition may reduce crop yields. High rainfall will also increase nutrient leaching and hence necessitate higher rate of fertilizer application. Incidences of floods and soil erosion will also increase. Increased precipitation would greatly increase agricultural production in Africa if it brings more land from ASALs into agricultural production. Drought is the single most important factor limiting agriculture and livestock production in Africa.

Arising mainly from thermal expansion of the oceans, a sea level rise of 20-140 cm is expected by the year 2030.The impact of such a rise in agriculture will be particularly serious in estuaries and deltas of major African rivers where extensive areas are reclaimable for crop cultivation. If the sea rises were to rise one meter, protective structures would have to be constructed to protect delta agriculture and settlements. Sea level rise will increase intrusion of saline water further up into river mouths. For example, in River Zambezi, sea water has been traced to 80 km upstream at the current sea level. Further rise in sea level will worsen this situation and render longer stretches of Africa main rivers unsuitable for irrigation use (Nyabundi & Njoka, 1991). In countries like Egypt, whose agricultural mainstay depends almost exclusively on irrigation, the damage that would be caused cannot be overemphasized. Enhanced tidal wave erosion which will accompany sea level rise will cause loss of coastal mangrove forests which act as buffers between forest water and saline sea water. Fresh water aquifers along the coast will be made saline and the use of ground water for irrigation and livestock will be limited.

## 2.4 Strategies to Control Adverse Effects of Climate Change in Maize Production

Various studies have recognized that climate variability and change have an impact on food production. However the extent and nature of this impact is as yet uncertain. The key issue therefore, in relation to the potential impact of climate variability and change on food security in Africa, encompass not only a narrow understanding of such impacts on food production but also a wider understanding of how such changes and impacts might interact with other environmental, social, economic and political factors that determine the vulnerability of households, communities and countries as well as their capacity to adapt.

The goal of adaptation is to develop flexible and resilient societies and economies that have the capacity to address both challenges and opportunities presented by changing climatic conditions. Societies need to be more flexible and resilient to a wider range of potential changes and impacts. Thus, they need to reduce vulnerability and enhance the capacity to minimize risks so that vulnerability to future climate events is reduced.

A number of studies have been undertaken that show that resource poor farmers and communities use a variety of coping and adaptive mechanisms to ensure food security and suitable livelihoods in the face of climate change and variability. Adaptive capacity and choices however, are based on a variety of complex causal mechanisms, crop choices, for example are not on factors such as cultural preferences palatability and seed storage capacity. Researchers also indicate that elements of social capital (such as associations, networks and levels of trust) are important determinants of social resilience and responses to climate change but how these develop and are used in mitigating vulnerability remains unclear.

Adaptation to climate variability and change are those actions or activities that people undertake, individually or collectively, to accommodate, cope with, or benefit from the effects of climate change. Climate change adaptations may also be seen as those measures that enable the natural systems and communities to cope with the adverse effects of climate variability and change. It incorporates a wide range of measures that would increase the resilience of the environment and communities to the possible adverse effects of climate variability and change. Coping with or managing climate variability and change in maize production system requires a combination of adaptation and mitigation measures that involve the choice of maize practices and understanding of climate science by agricultural experts and the community.

Adaptation to climate change is deemed to be taking place already, but on a limited basis, and seldom in response to climate change alone. Many adaptations can be implemented at low cost, but there are no comprehensive estimates of adaptation costs and benefits. Furthermore, adaptive capacity is uneven across and within societies, and, the communities and different rates of climate change may yield different response curves and vulnerabilities. Pulwarty et al. (http://www.nap.edu/catalog/12545.html) reiterated the need for research to support mitigation and adaptation strategies. He indicated that there is some evidence of feedback effects of climate extremes, and the models incorporate population, affluence, resources, and technology; however, information about culture, communication, context, and capacity variables was missing. There is need for researchers in the field of vulnerability, impacts, and adaptation to work with decision making groups to identify the important research questions and not just communicating scientific information and assume it will reach the proper audiences.

Although there are numerous programs and activities to reduce climate-related risks and increase resilience at regional, national, and local scales, few climate change adaptation initiatives have been evaluated, and evaluation criteria have not been established, so the effectiveness in reducing vulnerability to the range of climate projections is unknown. Better understanding could facilitate learning, such as comparisons of costs and benefits, and ways to overcome constraints. Results could be integrated into national and regional plans for development, land use, water use, and diffusion efforts. Climate adaptation may synergize with, or require tradeoffs with other development priorities. Climate services might help to provide anticipatory coordination as well as anticipatory technology as a way of improving self-organization. Research is scant on economic and social costs and benefits of adaptation measures involving ecosystem protection, health interventions, and land use. Particular adaptations might have broader implications for economic growth and employment.

Wang et al.(2011); Oseni and Masarirambi (2011) proposed a range of possible strategies such as adjusting the cropping calendar to synchronize crop planting and the growing period with soil moisture availability based on season climate /rainfall focus. Changing sowing schedules and in response to the future warmer climate, shifting to an earlier sowing date may alleviate the negative effect of high temperature on grain filling, but its effect on maintaining production, was not as high as expected. However, postponing the sowing date to delay grain filling until late summer or early autumn with the optimal temperature for grain formation, the yield loss could be significantly reduced.

Other measures included changing the maize variety to plant a drought tolerant or early maturing variety or the use of genetically modified maize were acceptable; Diversification from traditional maize crops to other types of crops such as millet and sorghum, which can withstand drought and higher temperatures; Optimizing water-use efficiency by improving irrigation facilities bringing more agricultural land under irrigation to maize production and introducing water saving techniques as used in sugarcane production; The changes in dryness and length of grain filling are the two main reasons why the future maize yield may decline. Therefore, potential adaptations can be achieved by improving irrigation efficiency and changing the sowing schedule or introducing new cultivars that require longer thermal accumulation in response to the predicted increases in the maize growth season.

There is need to allocate adequate funding to the Meteorological Department to procure latest equipment and build capacity in climate data collection, storage, analysis and forecasting. It is evident that the two main adaptation measures would be to increase the irrigation efficiency and to change the maize cultivar. The improvement in irrigation faculty can provide a better water supply for crops and help maintain the current yield, but they become less effective during the second half of this century. For semi-arid regions, improvement of irrigation efficiency is necessary in order that the present irrigation quota can still satisfy the water demand in maintaining the baseline yield level; otherwise, there may be a high risk of reduction in maize production.

The other adaptation is switching to new maize cultivars that would suit the changed thermal conditions. As maturity period of the current cultivars is likely to be shortened by 20 to 30 days, in the coming decades, alternative cultivars that have a longer grain filling stage should be introduced, since grain filling stage plays a primary role in yield. Compared to optimizing irrigation strategies, the option of cultivar switching is likely to be a long term adaptation. A final Adaptation option might be switching to different crops. However, the effects would rely heavily on the predictability of techniques transformations, which is beyond the scope of this study.

Provision of appropriate crop insurance coverage to maize farmers to reduce the risk associated with reduced maize production and yield losses caused by climate variability is very important. Crop insurance is purchased by agricultural producers, including farmers, ranchers, and others to protect themselves against either the loss of their crops due to natural disasters, such as hail, drought, and floods, or the loss of revenue due to declines in the prices of agricultural commodities**.** Agricultural insurance is considered an important mechanism to effectively address the risk to output and income resulting from various natural and manmade events. Agricultural Insurance is a means of protecting the agriculturist against financial losses due to uncertainties arising from named or all unforeseen perils beyond their control (AIC, 2008).

Agricultural insurance is one method by which farmers can stabilize farm income and investment and guard against disastrous effect of losses due to natural hazards or low market prices. Crop insurance not only stabilizes the farm income but also helps the farmers to initiate production activity after a bad agricultural year. It cushions the shock of crop losses by providing farmers with a minimum amount of protection. It spreads the crop losses over space and time and helps farmers make more investments in agriculture. It forms an important component of safety –net programmes as is being experienced in many developed countries, (Rachu & Chand, 2008). However crop insurance should be part of overall risk management strategy.

Crop insurance protects farmers' investments in crop production and thus improves their risk bearing capacity. Crop insurance facilitates adoption of improved technologies, encourages higher investments resulting in higher agricultural production. Crop credit insurance also reduces the risk of becoming defaulters of institutional credit. The reimbursement of indemnities in the case of crop failure enables the farmers to repay his debts and thus, his credit line with the formal financial institution is maintained intact.

A properly designed and implemented crop insurance programme will protect the numerous vulnerable small and marginal farmers from hardship, bring in stability in the farm incomes and increase the farmer production. It was observed that insured household invest more on agricultural inputs leading to higher output and income per unit of land.

The risk bearing capacity of an average farmer in the semi-arid tropics is very limited. A large farm household or a wealthy farmer is able to spread risk over time and space in several ways; he can use stored grains or savings during bad years, he can diversify his crop production across different plots. At a higher level of income and staying power, the farmer would opt for higher average yields or profits over a period of time even if it is achieved at the cost of high annual variability on output Crop insurance is based on the principle of large numbers. The risk is distributed across space and time. The losses suffered by farmers in a particular locality are borne by farmers in other areas or the reserves accumulated through premiums in good years can be used to pay the indemnities. Thus, a good crop insurance programme combines both self as well as mutual help principle. Crop insurance brings in security and stability in farm income. Crop insurance protects farmers' investment in crop production and thus improves their risk bearing capacity. Crop insurance facilitates adoption of improved technologies, encourages higher investment resulting in higher agricultural production.

The farmer is likely to allocate resources in profit maximizing way if he is sure that he will be compensated when his income is catastrophically low for reasons beyond his control. A farmer may grow more profitable crops even though they are risky. Similarly, farmer may adopt improved but uncertain technology when he is assured of compensation in case of failure. This will increase value added from agriculture, and income of the farm family

### 2.4.1 Climate Modeling

A climate model is a simplified representation by mathematical equations of the complex interactions and processes associated with climate occurring within the earth’s surface in atmosphere system. Climate modeling is a means of simulating the processes and interactions within the climate system in order to draw conclusions about the future status and trends of climate based on assumptions about the concentration of greenhouse gases or change in the amount of solar energy.

General circulation models (GCMs) which are three dimensional mathematical representation of the climate system have been used to predict climate system based on the current level of human understanding of the dynamic and physical processes in the system. Predictions of changes in the climate obtained by use of these models have much uncertainty as the descriptions or parameterization of many of the processes represented are relatively crude (IPCC, 1992). Consequently attempts have been made to give best estimates of the equilibrium climate sensitivity.

According to Inter-Governmental Panel on Climate Change report, the atmospheric concentration of carbon dioxide ($C0_2$) has increased by 31% since 1750 and that, three quarters of the anthropogenic emissions of Carbon dioxide to the atmosphere during the past 20 years are due to fossil fuel burning (IPCC, 2001). The rest is predominantly due to land use change, especially deforestation. Similarly, the atmospheric concentration of methane ($CH_4$) has increased by 1060 ppts (151%) over the same period and continues to increase.

### 2.4.2 Crop Modeling

Climatic variations, continuous increase in population pressure and market infrastructure are driving forces that reduce agricultural productivity. Changes in climatic scenarios are of vital importance for rain fed agriculture as a change in one climatic variable alters other variables which include temperature, precipitation and solar radiation. Associated impact of increasing temperature, changing rainfall pattern and intensity has led to reduced agricultural productivity and yield over the world. Water availability through rainfall has become a limiting factor to crop productivity due to lack of decision support and management strategies like suitable sowing time, appropriate genotypes and cropping systems under changing climate.

The climate is being changed abruptly due to variation in rainfall pattern, dry spells, intermittent droughts and floods (Ahmed, 2011). Peterson (1993) suggested that a systematic approach to the study of soil and crop management problems is useful for testing present research knowledge. Finding the best option and mimic climatic degradation are two key factors under contemplation in agronomic research to enhance crop productivity. Crop simulation models proved to be efficient substitute for agricultural systems under diverse climatic conditions. These models aid in decision making tools and sustainable agriculture.

Crop simulation models consider the complex interactions between weather, soil properties and management factors which influence crop performance. Crop simulation models have developed over many years in recital with advances in crop physiology, crop ecology, and computing technology.

Robust crop modeling requires detailed knowledge of a host of factors that influence cropping systems such as the crop variety planted, sowing densities and fertilization regimes (Luedeling, 2011). The crop variety needs to be defined by a comprehensive set of crop attributes describing crop phenology, (the timing of development stages in response to weather photosynthetic rate. Crop yields can be simulated quite reliably once all this factors and reliable weather and soil information is available. Plant and crop models are now regularly used to calculate transpiration at the canopy level, to predict the consequences of climate changes on crop production, or to design new cropping systems.

## 2.5 Policies and Strategies on Climate Change and Agriculture

The constitution of Kenya provides that every person has a right to a clean and healthy environment which includes the right to have the environment protected for the benefit of present and future generations through legislation and other measures (RoK, 2010). The constitution also provides that the state shall ensure sustainable exploitation, utilization, management and conservation of the environment and natural resources and ensure the equitable sharing of the accruing benefits. It also provides that the state shall utilize the environment and natural resources for the benefit of the people of Kenya. In this regard therefore, the constitution provides ground for the formulation of adaptation and mitigation legislations, policies and strategies to address the adverse effects of climate change to guarantee the right to a clean and healthy environment.

### 2.5.2 Vision 2030

The Vision 2030 was the country's development blueprint covering the period 2008-2030.Its aim was to transform Kenya into a newly industrializing, middle income country providing a high quality of life to all its citizens by the year 2030. The country aims to have a clean, secure and sustainable environment by 2030. Some of the strategies were to promote environmental conservation in order to provide better support to the economic pillar flagship projects and to achieve the Sustainable Development Goals (SDGs). Under such an environment, Kenya is expected to raise incomes in agriculture, livestock and fisheries even as industrial production and the service sector expand. This will be accomplished through an innovative commercially oriented and modern agriculture.

### 2.5.3 Environment Policy

The national environment policy aims to provide a holistic framework to guide the management of the environment and natural resources in Kenya. It ensures that the linkage between environment and poverty reduction is integrated in all government processes and institutions in order to facilitate and realize sustainable development at all levels in the context of green economy.

The National environment policy recognizes that climate change is a reality and that human activities are largely responsible for increasing concentration of GHG in the earth’s atmosphere. Kenya, like many other countries is concerned about climate change and its impacts. The policy proposes two approaches of addressing climate change, mitigation measures aimed at tackling both the causes of climate (GHG) emissions and the adaptations measures to cope with the impacts of climate change.

The policy also recognizes that Kenya experiences heavy devastating floods during strong EL Nino events and severe droughts during the La-Nina events. The economic impacts of the floods cut across all the key sectors of the economy including the agriculture sector. Agriculture production, industrial processing manufacturing, tourism, infrastructure and public health are impacted the most. It is expected that with climate change the frequency and intensity of extreme weather events such as floods and droughts will increase.

### 2.5.4 Environmental Management and Coordination Act

The Act is the principle instrument of the Republic of Kenya for the management of the environment (RoK, 1999). It provides for the relevant institutional and legal framework for the coordination of environmental management including establishment of the NEMA, which is the Designated National Authority (DNA) and the National Implementation Entity for the Adaptation Fund.

### 2.5.5 National Climate Change Response Strategy

Rain-fed agriculture is the second largest contributor to the country's GDP, with tea, coffee and horticulture contributing greatly to the country's foreign exchange earnings. Given its reliance on weather, agricultural production bears the brunt of climate variability and change. Strategies, such as building or enhancing systems for conveying climate information to rural populations are very important.

The Government and development partners need to provide support to the Kenya Meteorological Departments (KMD's) Early Warning Systems to facilitate the timely dissemination of projected and downscaled weather information to farmers. This will enhance farmers' resilience to the impacts of climate change, e.g. through altering the timing of planting dates to adapt to changing conditions, promoting irrigated agriculture by developing irrigation schemes along river basins, construction of water basins and pans, but also reconfiguring irrigated production systems to use water more efficiently and to accommodate the use of marginal quality water, addressing land degradation by building soil and stone bunds, creating grass strips and contour levelling as well as incorporating trees or hedgerows. These measures will increase rain-water infiltration, reduce run-off during floods, reduce soil erosion, and help trap sediments including dead plant matter, promoting conservation agriculture (CA), whose aim is to achieve sustainable and profitable agriculture and ultimately improve farmers' livelihoods through the application of the three CA principles: minimal soil disturbance, permanent soil cover and crop rotations.

The (RoK, 2010) recognises that in Kenya, the most vulnerable sectors include agriculture, tourism, infrastructure, health, and natural resources especially biodiversity. Rain-fed agriculture is the second largest contributor to the country's GDP, with tea, coffee and horticulture contributing greatly to the country's foreign exchange earnings. In this regard, therefore, some of the interventions in the sector include: Support for community-based adaptation diversifying rural economies, e.g. through value addition to agricultural products and financial support for sericulture and apiculture with the aim of reducing reliance on climate-sensitive agricultural practices; creation of functional linkages with development partners for technology enterprise initiatives; Re-invigorating agricultural research and development (R&D) to produce crop varieties that can withstand projected climate variability. Specific agricultural research areas that address climate change need to be undertaken; Developing an innovative Insurance Scheme – low premium micro-insurance policy which together with low interest loans will insure farmers against crop failure due to droughts, pests or floods ;Enhancing agricultural extension services to train farmers on how to better cope with climate variability and change; Strengthening integrated and environmental friendly pest management systems to cope with increased threats from insects, pathogens, and weeds, and developing proper food storage facilities to cater for surplus harvest while promoting traditional and modern food preservation methods.

### 2.5.6 The Economic Recovery Strategy for wealth and Empowerment Creation

The Economic Recovery Strategy for Wealth and Employment Creation (ERS) was launched in May 2003, with an overall goal of growing the economy to create more jobs and wealth so that we can move people from poverty to prosperity (RoK, 2003). The ERS laid emphasis on economic growth, creation of wealth and employment as a means of eradicating poverty and achieving food security. The strategy identified agriculture as the leading productive sector for economic recovery. In addition, the strategy recognized that revival of agricultural institutions and investment in agricultural research and extension were critical and essential for sustainable economic growth (RoK, 2003)

### 2.5.7 Strategy for Revitalizing Agriculture

Strategy for revitalizing agriculture (SRA) was published by sector ministries in 2004 with the aim of transforming agriculture into a viable and vibrant sector that is commercially oriented and internationally competitive (RoK, 2004). The SRA was launched to build and elaborate on the ERS with respect to the agricultural sector. This was because it was recognized that the agricultural sector's contribution was key to attaining the objectives of the Economic Recovery Strategy for Wealth and Employment Creation. In five years, the prosperity of farmers had been increased by providing them with better prices, for instance maize prices per 90-kilogram bag increased from Ksh. 800 to KS. 1,300. Prior to 2008, agriculture had been revitalized and was on the path to further development. Kenyan farms and firms were successful and confident of the future.

### 2.5.8 The Agricultural Sector Development Strategy

This strategy was the Government's commitment to the farmers and rural people of Kenya. It positioned the agricultural sector as a key driver for delivering the ten (10) per cent annual economic growth rate envisaged under the economic pillar of the Vision 2030. It provided a guide for the public and private sector's effort with regard to the development challenges facing the agricultural sector, (RoK, 2009). As the backbone of our economy, the sector's Vision of "Food Secure and Prosperous Nation" was not only appropriate, but also in tandem with the Vision 2030 of 'A Globally Competitive and Prosperous Nation'. Besides ensuring food security and nutrition for all Kenyans, the sector was also expected to generate income and employment especially in the rural areas.

Less than twenty per cent 20% of Kenya's land mass has high to medium agricultural potential supporting about seventy five per cent 75% of the population. The remaining over eighty per cent (80%) lies in the ASALs, where sustainable rain-fed production of crops is limited by water deficits. This clearly showed that there was pressure on land with agricultural potential and population migration to the ASALs was likely to increase. Moreover, it was an indication that the country is poorly endowed with potential for rain-fed agriculture. This meant that rain-fed agriculture alone could not meet the challenge of achieving food security.

African Governments, regional bodies, development partners, and agricultural and other stakeholders meeting in Maputo in 2003 identified irrigation as a priority area for investment to accelerate agricultural growth. Maputo declaration 2003 recommended 10% of Government expenditure to agriculture sector. Projected budgetary support for the sector currently is only 4%. Clearly, this is not adequate to support the outlined programmes for poverty and hunger reduction. Concentration of resources is required to bridge the enormous budgetary deficit.

In view of the foregoing, water resources management and development cannot be viewed in isolation, but as an integral part of the resources of watersheds. Properly managed and developed watersheds can contribute to sustainable flow and availability of water (blue and green in the form of soil moisture, groundwater and surface water). Therefore, managing water resources in an ecologically sustainable manner by taking into consideration proper land use and an integrated development of resources that involves agriculture (livestock, crop, fishery and agro-forestry), natural resources (forest, range, wildlife), environment and human resources is critical.

To address these challenges, the Government will develop and implement policy, legal and institutional reforms on security of land tenure, land use and development, and sustainable environmental conservation. Development of the National Land Policy was initiated in 2004 with a view to addressing land administration and management problems. It provided an overall framework and defined the key measures required to address the critical issues of land administration, access to land, land use planning, restitution of historical injustices, environmental degradation, conflicts, unplanned proliferation of informal settlements, out-dated legal framework, institutional framework and information management.

Food security is a major water resource related issue in southern-Saharan Africa, where about one third of the population is living in drought prone areas, with a growing season that is too short to support reliable rain-fed agricultural production. In the past, African farmers had developed traditional agriculture systems with high levels of resilience not only to climatic variability but also to change in the political and economic conditions. Current growth in food production is only about half of what is accessible to low – income sectors.

The public and decision makers have become aware that responses to climate change are of utmost urgency. They want to know what they can do now. Even without this new pressure, policy makers operate on shorter decision horizons than researchers do. Few think farther ahead than 8 years at most. There is need for the research community to lay out longer-term agendas and needs. Pragmatically, researchers can accommodate this discrepancy by offering short-term messages. That doesn’t mean abandoning longer-term analysis and planning, rather, it means interacting with the public on practical and effective terms. Yet climate is an unprecedented policy challenge and will require public institutions to change the way they do business and at the same time, there is a longer-term need to develop in-depth, rigorously tested research on vulnerability, impacts, and adaptation, including model comparisons and large-scale comparative studies. Especially for that longer-term need, the rigor of vulnerability, impacts, and adaptation research needs sharpening, Not necessarily through the use of quantitative models, but through enhanced data collection, availability, and analysis, and a spectrum of research methods that can continue to address uncertainties.

### 2.6 Integrated Climate Change Planning for Agriculture

Planning refers to the process of deciding what to do and how to do it. Planning helps communities to create their preferred future and good planning makes progress towards paradise while bad planning leaves a legacy of problems and disputes (Littman, 2013). Planning occurs at many levels, from day to day decisions made by individuals and family, to complex decisions made by businesses and governments. Planners facilitate decision making by coordinating information and activities to create a logical, systematic decision making process that results in the best actions. They translate theoretical goals into specific actions. The planning process consists of steps that identifies or responds to problems and opportunities associated with a specific state or local concerns and culminate in the selection of a recommended plan.

Integrated river basin management is the management of water systems as part of the broader natural environment and in relation to their socio economic environment. It includes land use planning, agricultural policy and erosion control, environmental management and other policy areas that cover all human activities that affect water fresh systems (Gonzalez et al., 2012). Implementation of integrated river basin management plans involves a coordinated management of the protection and use of all water bodies so that ecosystem functions are also taken into account which provides options for trans boundary cooperation. However, challenges among different groups and water users may also arise.

Gonzalez et al., (2012) in developing the integrated management plan for Danube River Basin, indicated that there is need to consider behavioral and technological measures as well as policy approaches in developing agricultural management plans for a river basin. Some of the behavioral measures included strengthening and focusing the exchange among institutions in administering and implementing relevant legal and policy frameworks. Other measures included: forecasting and early warning service aimed at improving early warning systems for climate and hydrological extreme events; monitoring including introduction of automatic weather stations and connection with hydrological stations for automatic monitoring and software control; research to identify knowledge deficit and identification of areas in agriculture that are particularly affected by climate change and the adaptation options to reduce the vulnerability; economic analysis of the costs of adapting to climate change in the agriculture sector; promotion and application of methodological standards for climate proofing infrastructure including integration of climate consideration into EIA and SEA procedures. promotion of risk management that fully exploits the potential of protective measures  such as land use planning and early warning systems in a coordinated way; dialogue, participation, information exchange and social networking including better communication among institution, collaborative and partnership strengthening by building networks, creating supportive social structures , improving the quality of climate knowledge; sustainable and integrated management of natural resources and integration of climate change issues, knowledge transfer to enhance sharing of research information on climate change; policy approaches such as harmonization of national legislations concerning climate change and creating a supportive institutional framework and creating supportive social structures and insurance system to protect farmers from the economic impacts of extreme climate events.

Planning for maize production requires an understanding of the different behavior of maize under the changing climatic conditions as indicated by different agro climatic conditions spread out in the basin. The humid and cool regions benefit from yields in contrast to warm and dry regions due to increasing droughts. The earlier flowering seasons and longer vegetative periods results in more growing degree days. Earlier flowering and maturity but a shortening of the vegetative period particularly the grain filling period leads to reduced yield. Agriculture experts opined that increasing temperatures and not precipitation amounts is the main climatic factor responsible for reducing yield.

One of the challenge or knowledge gap is that the yield of maize may increase or decrease depending on the management method, the natural prerequisite, and agricultural policy and therefore climate change scenarios may be difficult to interpret.

## 2.7 Theoretical and Conceptual Framework

### 2.7.1 Theoretical Framework

Available observational evidence indicates that the regional changes in climate, particularly increases in temperatures, have already affected diverse set of physical and biological systems in many parts of the world. These effects include lengthening of the growing seasons, decline of plant and animal populations and earlier flowering (IPCC, 2001).

Precipitation related impacts may be important but at present, there is a lack of systematic concurrent climatic biophysical data of sufficient length (two or more decades) that are considered necessary for assessment of precipitation impacts. Factors such as land use change and pollution also act on these physical and biological systems, making it difficult to attribute changes to particular causes in some specific cases. However, taken together, the observed changes in these systems are consistent in direction and coherent across diverse localities, with expected effects of regional changes in temperatures. Thus, there is collective evidence that recent regional changes in temperature have had discernible impacts on many physical and biological systems.

The Anthropogenic Global Warming theory on climate change contends that human emissions of greenhouse gases, principally carbon dioxide, methane, and nitrous oxide are causing a catastrophic rise in global temperatures (Bast, 2010). The mechanism whereby this happens is called, the enhanced greenhouse effect. Energy from the sun travels through space and reaches the earth. The Earth's atmosphere is mostly transparent to the incoming sunlight, allowing it to reach the planet's surface where some of it is absorbed and some is reflected back as heat out into the atmosphere. Some greenhouse gases in the atmosphere absorb the outgoing reflected or internal thermal radiation, resulting in the earth's atmosphere becoming warmer than it otherwise might be.

Other theories in the climate change debate include the cloud formation and Albedo theory by Yogesh Sud. This theory contends that changes in cloud coverage in the tropics acted as a natural thermostat to keep sea surface temperatures (SST) between 28 $^{0}$C and 30 $^{0}$C.Their analysis suggested that as SSTs rise, air at the base of the clouds is charged with moist static energy needed for clouds to reach the upper troposphere, at which point the cloud cover reduces the amount of solar radiation received at the surface of the sea and cool and dry down drifts promote ocean surface cooling. The thermostat –like control tends to ventilate the tropical ocean efficiently and help contain the SSTs between $28^0$C-$30^0$C.This phenomenon is expected to prevent SSTs from rising any higher in response to enhanced carbon dioxide induced radiative forcing.

Another theory on Human Forcing besides Greenhouse Gases contends that although the natural causes of climate variations and changes are undoubtedly important, the human influences are significant and involve a diverse forcing including, but not limited to the human input of carbon dioxide (Pielk Sr., 2009). This theory holds that mankind's greatest influence on climate is not its greenhouse gas emission but its transformation of Earth's surface by clearing forests, irrigating deserts and building cities. These human forcings have local and regional effects on climate equal to or even exceeding that of anthropogenic greenhouse gas emissions.

The theory on Planetory motions posits that most or all of the warming of the latter part of twentieth century can be explained by natural gravitational and magnetic oscillation of the solar system induced by the planets movement through space. These oscillations modulate solar variations and/or other extraterrestrial influences of the earth, which then drive climate change. Variations in the planets movement through space accounts for climate change on a decadal scale as well as millennial scale (Scaffeta et al., 2009). This could happen through two mechanisms: the varying tidal gravitational and magnetic forces of the planet on the sun, in particular Jupiter and Surtun, modulate the terrestrial climate. The varying gravitational and magnetic field generated by the movement of Jupiter and Surtun modulate some terrestrial orbital parameters for example the spinning of Earth, known as the Length of the day (LOD) which then drives the ocean oscillation and consequently the climate (Scaffeta et al., 2009).

According to IPCC 2001, the human systems that are sensitive to climate change include agriculture and food security. The projected adverse impacts based on models and other studies include a general reduction in potential crop yield in most tropical and subtropical regions for most projected increase in temperatures and also a general reduction, with some variation in potential crop yields in most regions in mid-latitudes for increases in annual average temperatures of more than a few degrees Celsius. The projected beneficial impacts based on models and other studies include: increased potential crop yields in some regions at mid-latitude for increase in temperature of less than a few degrees Celsius.

The response of crop yield to climate varies widely, depending on the species, cultivar, soil condition, treatment of carbon dioxide direct effects and other local factors. In the tropics, where some crops are near their maximum temperatures tolerance and where dry land agriculture predominates, yield would decrease generally with even minimal changes in temperatures, where there is a large decrease in rainfall; crop yields would be even more adversely affected. With autonomous agronomic adaptation, crop yields in the tropics will tend to be less adversely affected by climate change than without adaptation. Higher maximum temperatures will be generally detrimental to numerous crops.

Important advances in research on the direct effects of carbon dioxide on crops suggests that beneficial effects may be greater under certain stressful conditions, including warmer temperatures and droughts. In expensive, farm level agronomic adaptation such as altering of planting dates and cultivar selection have been simulated in crop models extensively. More expensive and, directed adaptations such as changing land use allocations and developing and using irrigation infrastructure, have been examined in as small but number of linked crop–economic models, integrated models and econometric models.

If the emissions of GHG continue to grow as currently projected, (the so called business as usual scenario), the global mean temperature will increase by 0.2 $^{0}$C-0.4$^{0}$C per decade over the next century. There is a quite clear indication that a warming of the globe has occurred over the past century, amounting to 0.3$^{0}$C -0.6$^{0}$C. Much of this warming has been concentrated in two periods, between 1920 and 1940 and since 1975; the six warmest years on record have all been in the 1980's. The size of this warming is broadly consistent with the predictions of climate models but because of the natural variability, they have detected the unequivocal signal of man-made climate change.

In many regions of the world, agriculture production is currently limited by climate, most of this limitation being in developing countries. Insufficient rainfall is the main climatic limit in these areas, curtailing the growing period available for crops. Overally,63% of the land area of developing countries is climatically suited to rain fed agriculture, but this endowment varies considerably between regions (Parry, 1990).The potential base for rain fed agriculture is therefore very limited in some regions and any further curtailment of potential due to changes of climate could severely strain their ability to feed local population.

There is a strong indication that marginal agriculture and marginal farmers may be most vulnerable both to short term variations of weather and longer term changes of climate. This marginality can be construed in a number of ways spatial or economic or social. Agriculture may be marginal in a spatial sense when types of farming are practiced at or near the edge of their appropriate climate region. Relatively small changes of climate in these areas could substantially alter the potential for agriculture thus creating a mismatch between existing farming systems and prevailing climatic resources for agriculture.

Marginal farmers with low level of financing are likely to have fewer resources to deploy in adapting to climate change. There are some rural groups that may be discussed as socially marginalized, that are, where they have become isolated from their indigenous resources base and forced into marginal economies that contain fewer adaptive mechanisms for survival. In each of these instances of marginality there may thus be a proneness to impact from changes of climate simply because of the limited resources available for the adaptation needed either to benefit fully from positive effects of changes of climate or to mitigate successfully the negative effects.

Parry (1990) argued that to determine the likely effects on agriculture, there is need to know how changes of climate will occur regionally and seasonally. In almost all regions of the world, in both the core food exporting regions of today and in areas that are not self–sufficient in food changes in crop–water availability are likely to be the most important for agriculture. While we cannot be certain about the regional pattern of soil moisture changes that may occur, there are regions in the world where the GCM predictions are in some agreements. The significance of decreases in soil water will vary considerably from region to region according to weather they occur during the growing or non-growing season.

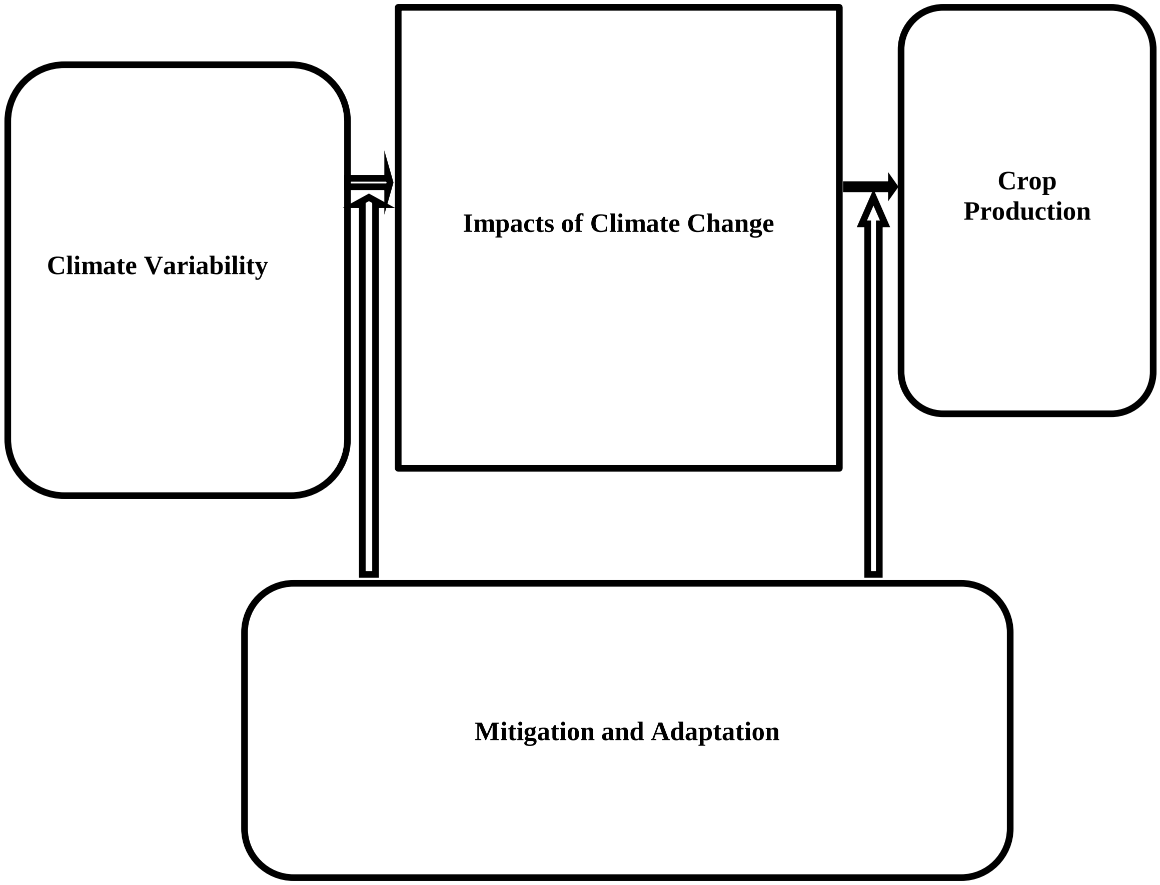
As important for agriculture as possible, changes in mean climate may be changes in the variability of climate, particularly in the frequency of extreme weather events (such as severe storms, heat waves and damaging frosts) that today exact a major toll on food output. Few farmers for example, plan their activities on their expectation of the average return on farming. They generally gamble on good years and insure against bad ones. Any changes in the frequency of good and bad years can thus have a major effect on profitability of agriculture. Unfortunately, little is known at present about the likely changes in measures of climate variability due to greenhouse gas forcing. Much more work on this issue is needed before we can fully evaluate the effects of GHG forcing on the effects of extreme weather on agriculture. However, even if we assume that the same distribution of extremes around the mean is maintained, changes in mean climate can be expected to increase markedly the frequency of extreme events such as hot days likely to cause heat stress for crops.

Parry (1990) also examined various methods of impact assessment in which he looked at the impact approach method that characterized on extensive efforts in 1970s to estimate the possible effects of long term climatic change on crop yields and agricultural production. The emphasis was a search for a simple connection between a potential climatic change and its likely effect on an exposure unit (in this case, food production). With the benefit of hindsight, we now know that so many intervening factors can operate that it may be quite misleading to treat the three study elements (Climate change, exposure unit, and impact) in isolation from their milieu, for example, many of the reduced rainfall may not, only be felt directly by plants and animals, through a decrease in crop water availability but also through changes in soil structure and nutrient status due to rates of soil erosion being altered  under their condition. Since 1980, there has been increasing emphasis on attempting to understand the interaction that might relate climatic change to its potential response by assuming that a climatic event is merely one of the many processes (both biophysical and socio economic) that may affect the exposure unit –agricultural production.

IPCC (2001) indicated that climate change; especially increases in temperature have affected a diverse set of physical and biological systems in many parts of the world. These changes include lengthening of the growing seasons, decline of plant and animal populations and earlier flowering. The study noted that there is lack of systematic concurrent climatic biophysical data of sufficient length that are considered necessary for assessment of precipitation impacts. Factors such as land use change and pollution also act on these physical and biological systems, making it difficult to attribute changes to particular causes in some specific cases.

This study was guided by the Anthropogenic warming theory on climate change which contends that human emissions of greenhouse are causing a catastrophic rise in global temperatures (Bast, 2010). Another theory that was considered was the Human forcing theory which posits that Human activities have transformed the Earth's surface by clearing forests, irrigating deserts and building cities and thus affecting the climate and having effects like those of the Anthropogenic Warming theory.

### 2.7.2 Conceptual Framework




**Source: (Author, 2011)**

**Fig.2.1 Conceptual Framework**

### 2.8 3. Contextual Outlook

Climate variability is the greatest threat to maize production. The variability is characterized by the rising temperatures, erratic rainfall, delayed rainfall, prolonged or intermittent drought and extreme weather events. Such variability have impacts on crop production which include mineralization of organic matter in the soil leading to poor soil fertility and hence poor crop yield; increase in pest and diseases; increase in post-harvest losses increase in growth rate of weeds that compete for water and nutrients; increase in cost of production as a result of re-ploughing and replanting in the event of a crop failure. All this will eventually lead to poor maize production in most maize growing areas.

Some of the mitigation and adaptation measures that the farmers could adapt will include adjusting the crop calendar based on the season or rainfall focus; change to drought tolerant or early maturing varieties; diversification from traditional maize growing to other crop enterprises. In addition provision of credit facilities and crop and weather insurance will also help to mitigate against the adverse impacts of climate change.

# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.1 Introduction

The methods of research included interview schedules, questionnaires, observation and review of documented information from research work already done, maps, journals and books. It covers the nature and sources of data, target population and unit of analysis, sampling frame and sample size, population distribution and sampling procedures, and data collection and data analysis.

## 3.2 Research Design

This study set out to examine the effects of climate change on maize production in the Nzoia River Basin. It sought to obtain information that would best describe the effects of the changing climate pattern on maize and also determine the current state of maize production and land use. The study adopted the explorative, quantitative, descriptive, and evaluative research design. The strength of explorative design lies in its flexibility of design, which easily allows different aspects of the problem to be considered. It involved the survey of concerned literature, the experience survey and analysis of insights stimulating examples (Kothari, 1995). Its strengths also lie in purposive or judgemental sampling.

## 3.3 Target population

Population refers to the entire group of individuals having a common observable characteristic Mugenda, (1999).This study targeted all the households growing maize in the Nzoia River Basin. According to (KNBS, 2013), the human population of the basin is approximately 7,772,210 and that of the households is 1,648,849.

### 3.4 Sample size and methods of sampling

According to Krejcie and Morgan (1970), as the population increases, the sample size increases at a diminishing rate and remains relatively constant at slightly more than 380 cases. In this regard, the formula:

$$S= X^2 NP (1-p)/d^2 (N-1) +X^2P (1-P)$$

Where

**S**=required sample size

$X^2$=the table value of chi square for 1 degree of freedom at the desired confidence level

**N**= the population size

**P**= the population proportion (assumed to be .50 since this would provide the maximum sample size.)

**d**: The degree of accuracy expressed as proportions (.50)

Using this formula and the population of the basin, the sample size for the basin was calculated as shown in Table 3.1.

The multistage and multiple sampling strategies were used to obtain the sample size required for the study. The Basin was stratified into three based on the agro-ecological zones: the upper zone, the middle zone and the lower zone.  The three different zones have different maize production potentials, where maize is dominantly grown in the upper zone and the middle zone is a transition from the high maize growing production potential to the dry part with low maize growing potential. These zones are characterized by three agro ecological zones which include mostly, the high potential in the upper part of the basin, the middle potential in the middle part of the basin and the low potential in the lower part of the basin.

The upper part of the basin is composed of many counties including West Pokot, Elgeyo Markwet, Trans Nzoia and Uasin Gishu. Trans Nzoia County was purposively sampled to represent the upper part of the basin. The county was selected because of the widespread maize growing by farmers and it's considered to be one of the bread basket counties of this country and also due to ease of access by the researcher.

The middle basin was composed of Kakamega, Vihiga, Butere and Bungoma County. Kakamega County was selected to represent the middle zone. For the lower part of the basin, which composed of the Busia and Siaya Counties, Busia County was selected. Bunyala District was selected for sampling.

Data from Port Victoria forest station as shown in fig.1.3 was analyzed to give the trends of rainfall in the lower part of the basin. Each of the three strata was further stratified into counties for ease of analysis. One county from each of the selected stratum was selected for further analysis. Trans-Nzoia West Sub- County, was purposefully selected because ease of access by the researcher to represent the counties in the upper region. It was also deemed to be the bread basket for maize in the country. Kakamega County was selected to represent the middle region.

Lugari Sub County in Kakamega County was purposively chosen for sampling because it is the sub-county in the middle basin where maize is largely grown and it is also in the transition zone between the high potential to the lower potential areas of Busia County. The lower zone was represented by Busia County. The former divisions and locational boundaries were used to randomly select the division and locations where the household interviews were carried out. In addition, by the help of the agricultural officers, and the administration officers, a list of farmers who had lived in the division for over 30 years, was generated and out of this list, ten farmers were randomly selected for interviewing.

**Table 3.1: Number of respondents interviewed**

| County | Zone of Basin | Population | Sample | Response by county | Response by segment |
|---|---|---|---|---|---|
| Trans Nzoia | upper basin | 170,117 | 40 | 40 | |
| UasinGishu | upper basin | 202,291 | 47 | 47 | |
| Elgeyo Marakwet | upper basin | 77,555 | 18 | 18 | |
| West Pokot | upper basin | 93,777 | 22 | 22 | 127 |
| Kakamega | middle basin | 355,679 | 83 | 83 | |
| Vihiga | middle basin | 123,347 | 29 | 29 | |
| Bungoma | middle basin | 270,824 | 63 | 63 | 175 |
| Busia | lower basin | 154,225 | 36 | 36 | |
| Siaya | lower basin | 199,034 | 46 | 46 | 82 |
| **Total population and sample** | | **1,646,849** | **384** | **384** | **384** |

**Source: (Author, 2011**)

A total of two hundred and sixty seven (267) households were interviewed. The households were obtained as indicated in the Table 3.2 below.

***Table 3.2: Number of respondents interviewed***

| AE Zone | County | HH interviewed |
|---|---|---|
| Upper Zone | Trans-Nzoia | 123 |
| Middle Zone | Kakamega | 101 |
| Lower Zone | Bunyala | 52 |
| **Total** | | **276** |

**Source: (Author, 2011)**

A representative of the Agriculture Secretary in Kilimo House, Nairobi, was interviewed to give the policy perspective on the issues under research. The Ministry of agriculture officers working in the basin were also interviewed; they included the County Director of Agriculture officers in Trans Nzoia, Kakamega and Busia counties, Divisional Agricultural Officers and the Locational Agricultural Officers of the respective units randomly selected were also interviewed. Purposive sampling was also used to identify and interview other relevant government departments, CBOS and NGOs who could give relevant information on the research topic.

**Table 3.3: Agricultural officers interviewed**

| | Level of Agricultural officers interviewed | NO. |
|---|---|---|
| 1. | Representative of Agriculture Secretary | 1 |
| 2 | County Directors of agriculture | 3 |
| 3 | Division Agriculture officers | 9 |
| 4 | Location Agriculture Officers | 7 |
| | **Total No. of officers interviewed** | **20** |

**Source : ( Author, 2011)**

### 3.5 Nature and Sources of Data

The data obtained included the socio-economic characteristics of different groups of people and localities (households) resource endowments, land use and production; climatic variability and patterns; effects of climate change; mitigation and adaptation practices and policy recommendations.

Data on rainfall and temperature were obtained from the Kenya Meteorological Department, whereas data on maize production in bags per acre and general agronomic practices was obtained from the Ministry of Agriculture, Livestock and Fisheries and also from the household interviews. Data on Population was obtained from Ministry of Planning and Devolution and also from the household interviews. Other sources of data and information such as policy development on climate change issues, was obtained from the Ministry of Environment, Water and Natural Resources, Kenya Agricultural Research Institute and other NGOs and CBOs working in the study area. Two types of data were obtained; primary and secondary data.

**i) Sources of Primary Data**

Data was obtained from household head respondents and the observations made and recorded by the researcher in the field. The aim was to know the type of land use activities being carried out, and obtain the general perceptions of the respondents on climate change and its effects on maize production. The interviews gave a chance for face-to-face interaction between the researcher and the respondents in the field. The interviews were useful in collecting socio-economic information from a cross section of the farming community members in order to gain understanding of the wide range of views from different individuals. The respondents to the questionnaires included household heads, opinion leaders, government departmental heads and representatives from NGO's and CBO's operating in the area. Observations were made and photographs taken to give lasting impressions of the state of maize production at the time of research.

**ii) Sources of Secondary Data**

Secondary data was obtained from published and unpublished information sources. NGO's, CBO's, relevant references, publications, maps, development plans, annual reports from government departments, other academic studies in other areas, books periodicals and journals. Various institutions were visited to gather information. They included Kenya National Bureau of Statistics, Ministry of Lands and Settlement, Ministry of Agriculture offices, University of Eldoret, Kenya Agricultural Research

Institutes (KALRO), Kenya Meteorological Service and the Department of Remote Sensing and Resources Surveys.

### 3.6 Data Collection Instruments

Instruments that were used in data collection included: Household questionnaires as indicated in appendix 1, interview schedules for government officers as shown in appendix II and III, photographs, observation sheets and maps.

#### i) Questionnaire

The Household questionnaire was administered to farmers or household heads. Questionnaire administration was used in a systematic way to obtain relatively objective information from responds. They were developed to address specific research questions. The institutional questionnaires were administered to Government departmental heads, NGO and CBOs.

#### ii) Interview Schedule

Interview schedules were used in gathering information from various institutions, which included Kenya Forest Service, Ministry of lands and settlement, the local authorities, Ministry of Agriculture, Livestock and Fisheries, Ministry of Environment, Water and Natural Resources and Department of Remote Sensing and Resources Surveys. This enabled the respondents to give the required information orally and also help the researcher to stay focused on the subject of study. The interview schedule ensured a face to face encounter with the respondents. This helped to get in-depth information that could have been missed out in the questionnaire.

#### iii) Photographs

They were used to capture lasting impressions of the field situation with regards to activities carried out. They were used to supplement other techniques used in the field to gather information.

#### iv) Maps and observation sheets

The maps assisted in evaluating the trends and patterns of impacts of climate change. They helped to locate where various land use activities were located. Observation sheets were used to note the nature, intensity of different impact of climate change and other activities or phenomena in the field.

#### v) Review of Documented Data

These included materials already processed and published. They were obtained from magazines, journals, development plans, maps and other published and unpublished reports. These materials were obtained from libraries, resource centres and various government ministries, departments and parastatal offices and the internet.

### 3.7 Data Collection

Three sets of data were collected.

#### i) Primary data

Primary data was collected from the farmers in the Nzoia river basin. The data included: land use, type of farm entity, tenure type, planting date, harvesting date, area of land cultivated, area of land under maize cultivation and quantity of maize harvested per unit area.

Data on the respondents understanding of climate change, effects on maize growing and yield was also obtained from respondents through the household interviews. Data on mitigation and adaptation practices and policy recommendations was obtained from respondents through household interviews, focus group discussions, using the questionnaire for the household interviews, semi-structured questionnaires and key informant approaches.

The data and information obtained from the study was used to analyze the climatic variability in the basin, the effects of the variability on agricultural production and also the coping strategies, used by farmers in the basin. Some of the obtained information was very useful in suggesting policy recommendations to address the adverse effects of climate change.

**ii). Secondary Data collection**

To determine the rainfall and temperature trend, linear regression techniques were applied to the data collected from the Kenya Metrological Department. This was done by the use of Microsoft's excel computer software (version 2010). The software was used to develop the trend lines and also to compute the co-efficient of determinant ($R^2$) which was used to draw conclusions. The purpose of this exercise was to establish the rainfall and temperature pattern exhibited.

Data on maize production and agro-ecological /climate zones was obtained from the Ministry of Agriculture, Livestock and Fisheries for a period of thirty years from 1961-2012. The data obtained included the area under maize production for the sampled counties and the yield in bags per hectare for the study period. This data was used to generate regression models that were used to analyze the maize production in the basin over the study period.

To achieve the second objective, which was to examine the nature of relationship between climate change and maize production, data on maize production for the 30 years (1961-2012) sought from the Ministry of Agriculture was correlated with the rainfall and temperature trends observed over the same period.

**3.8 Validity and Reliability**

Validity is the degree to which an instrument measures what it purports to measure. It is the accuracy, truthfulness and meaningfulness of inferences that are based on data obtained from the use of the tool (Mugenda, 1999).Validity is determined by the presence or absence of systematic error in data (Kothari, 2004). To ensure validity of the instruments used in this research, the tools were developed and submitted to the supervisors for review. After review and discussions, their comments were incorporated before proceeding to the field.

Reliability of the instruments is the measure of the degree an instrument used in research would yield the same results of data after repeated trials (Mugenda, 2008). It is the consistency of the measurements accuracy or precision of a measuring instrument

(Orodho, 2003). In this regard; the questionnaires were structured in a way that specific information was obtained from the various respondents. The questionnaires were constructed using simple, clear language which respondents could easily understand. These questions were structured or arranged according to objectives to guide the information flow and to also exhaustively gather information. The data collection instrument was piloted in the study area before the research began. The adjustments were made after the piloting exercise.

### 3.9 Data Analysis

The study made use of both qualitative and quantitative methods of data analysis. The data on rainfall and temperature from the Kenya meteorological Service and area under maize cultivation and yield of maize in bags per hectare was analyzed by using Microsoft excel computer software to generate trend lines and compute the coefficient of determinant $R^2$ which was used to draw conclusions. Data from the household questionnaires and interview schedules was cleaned, organized and coded before analysis using SPSS. This involved conversion of data into numerical codes and frequency tables and percentages obtained. Qualitative data analysis was used for non-empirical data such as maps and photographs. From the above, there were trends in food production; history of rainfall and temperature changes observed and perception of farmers was obtained. Regressions were generated and deductions made according to Best and Kahn, 1998.

### 3.10 Data presentation

The quantitative data was presented using tables, charts and percentages. The qualitative data was presented by use of maps and photographs. Descriptions and analysis of the problems identified was made in the report.

**Table 3.4: Summary of objectives, measurable variables, and Research Design and Data** Analysis methods

| **Objective** | **Measurable Variable** | **Research Design** | **Data Analysis** |
|---|---|---|---|
| Climatic variability and patterns | Annual Rainfall<br>MAM Rainfall<br>JJAS Rainfall<br>OND rainfall<br>Perception of farmers on rainfall variation<br>Annual minimum and maximum Temperatures<br>MAM minimum and Maximum temperatures<br>JJAS minimum and Maximum temperatures<br>OND minimum and Maximum temperatures<br>Perception on changes in temperatures | Quantitative | Regression<br>Microsoft Excel |
| Impacts of climatic changes to agricultural production | Yield per unit areas | Quantitative<br>Descriptive<br>Survey | Regression<br>Correlation<br>Microsoft Excel |
| Practices and technologies related to climate change adaptation | Technologies used by farmers to mitigate climate change | Survey<br>Qualitative analysis | Correlation<br>Description<br>SPSS |

**Source: (Author, 2011)**

# CHAPTER FOUR

# RESULTS AND ANALYSIS

## 4.1 Introduction

This chapter deals with the results and analysis of the findings. It provides information on the variations of rainfall and temperature, and how the variations of these parameters affect maize yield.

## 4.2 Population and socioeconomic characteristics

### 4.2.1 Age of the household head

The average age of the household head interviewed ranged between the ages of 41-50 years of age as shown in Figure 4.1 below. This composed of twenty seven percent (27%) of all the household heads interviewed. These farmers had been growing maize and could give a good account of changes in climatic variability and how it has affected maize production in the basin and also other non- climatic issues affecting maize production as well. They also shared their experiences on how they have been adapting and coping with the climate variability over the years. They also made suggestions on what the government and other stakeholders in the maize production sector could do to address climate change.

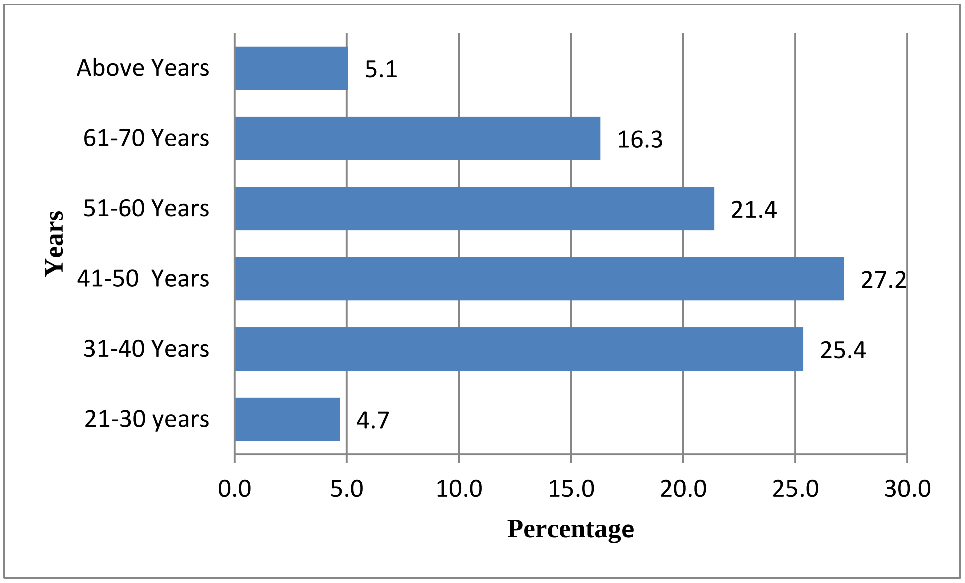



*Figure 4.1: Ages of the household heads interviewed* **Source: (Author, 2011)**

### 4.2.2 Period of farmers Residence

Most of the household heads interviewed had different periods over which they had stayed in the land they were occupying. Historically, land in the upper part of the basin, including Trans Nzoia West which was sampled was occupied by the white settlers. The white settlers practiced large scale maize farming in the upper part of the Nzoia. This land was further divided and sold to the local people in parcels of thirty acres of land. These big parcels of land have been further subdivided and sold to other buyers over time since independence. In this regard, therefore, the household heads interviewed had different periods over which they had occupied the land. Thirty point four percent of the household heads interviewed indicated that they had stayed in the basin for over thirty years as shown in figure 4.2. Fifteen percent (15.9) % and Eighteen percent (18.8%) indicated that they had lived in the basin for over 11-15 years and 6-10 years respectively.

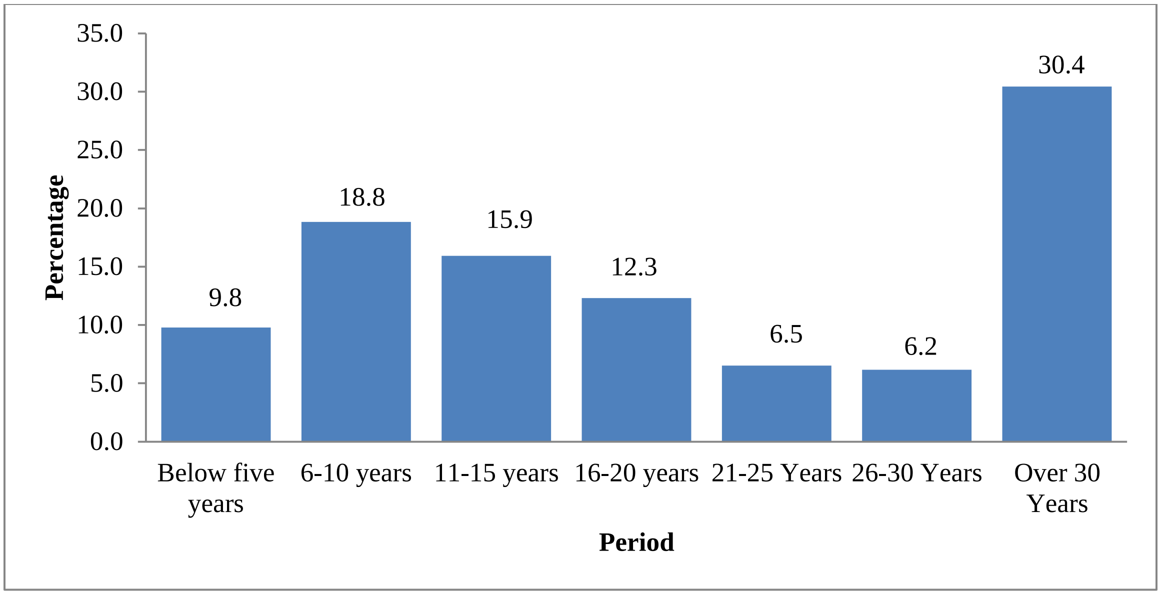



***Figure 4.2: Time the household head had occupied on the piece of land***

**Source: (Author, 2011)**

### 4.2.3 Level of education

Forty two percent (42%) of the household heads interviewed indicated that they had obtained secondary school level of education as indicated in figure 4.3. Eight percent (8%) indicated that they had no form of education. This indicates that the level of literacy in the farming community in the basin is fairly good and therefore, the farmers can be informed and taught to make informed decisions in farming.

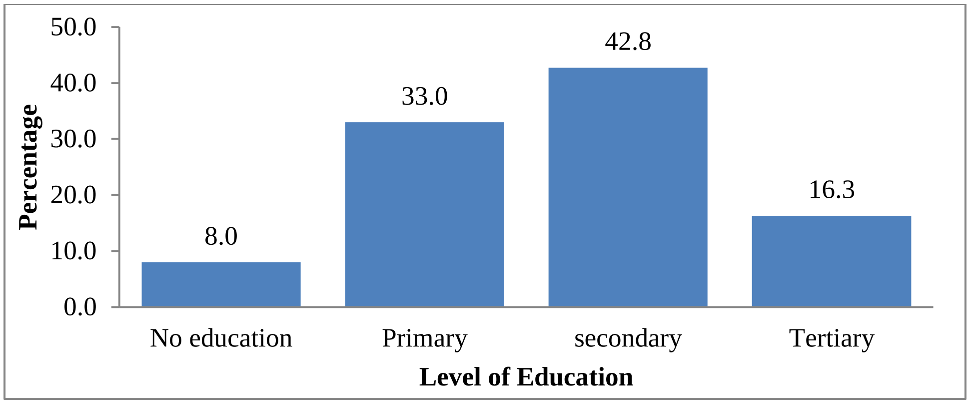



***Figure 4.3: Level of education of the household head*** **Source: (Author, 2011)**

### 4.2.4 Occupation of the household head

Most of the household heads interviewed indicated that farming is their primary occupation. Eighty eight point four percent (88.4 %) of those interviewed said that farming was their occupation whereas four point three percent (4. 35) indicated that they also did business alongside farming. This indicated the importance of maize farming as a source of livelihood for many people in the basin as shown in figure 4.4.

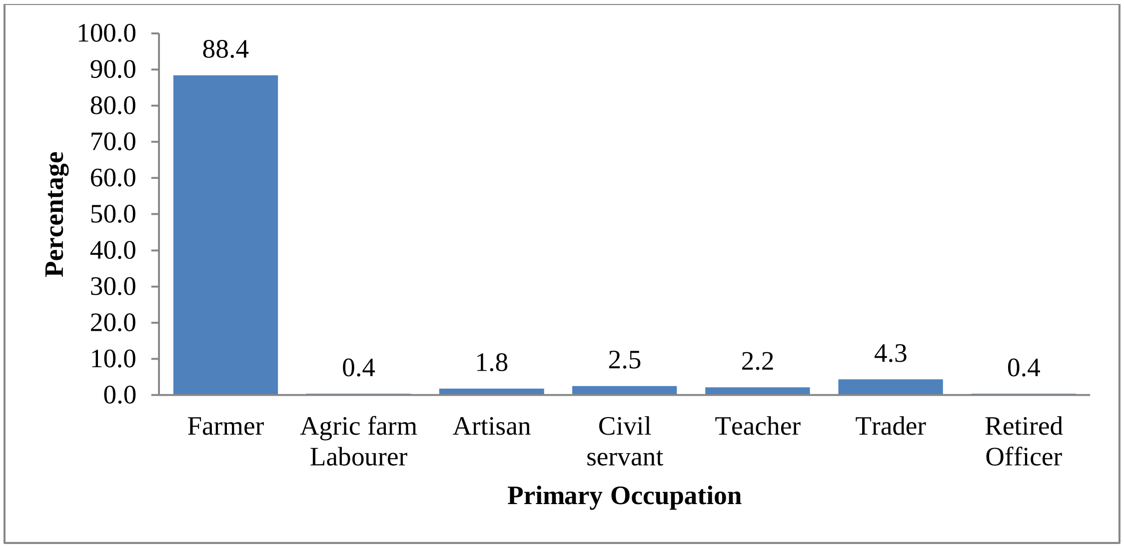



***Figure 4.4: Primary occupation of the respondents*** **Source: (Author, 2011)**

### 4.2.5 Level of Household income

The household interviews also revealed that fifty six percent (56.5%) of the household heads earn a monthly income of above fifty thousand Kenya shillings (Khs.50, 000) from farming as indicated by figure 4.5. Only two point nine percent (2.9%) earn between one hundred thousand to five hundred thousands, but below Ksh. 100,000. However, thirty point one percent (30.1%) of the farmers earn an average income of less than 10,000 per month. This indicates that quite a large population of the people earn very little from the maize production which they may not rely on to sustain their livelihood. This is also corroborated by Table 4.1 which indicates that the main source of income for the household heads interviewed is crop farming.

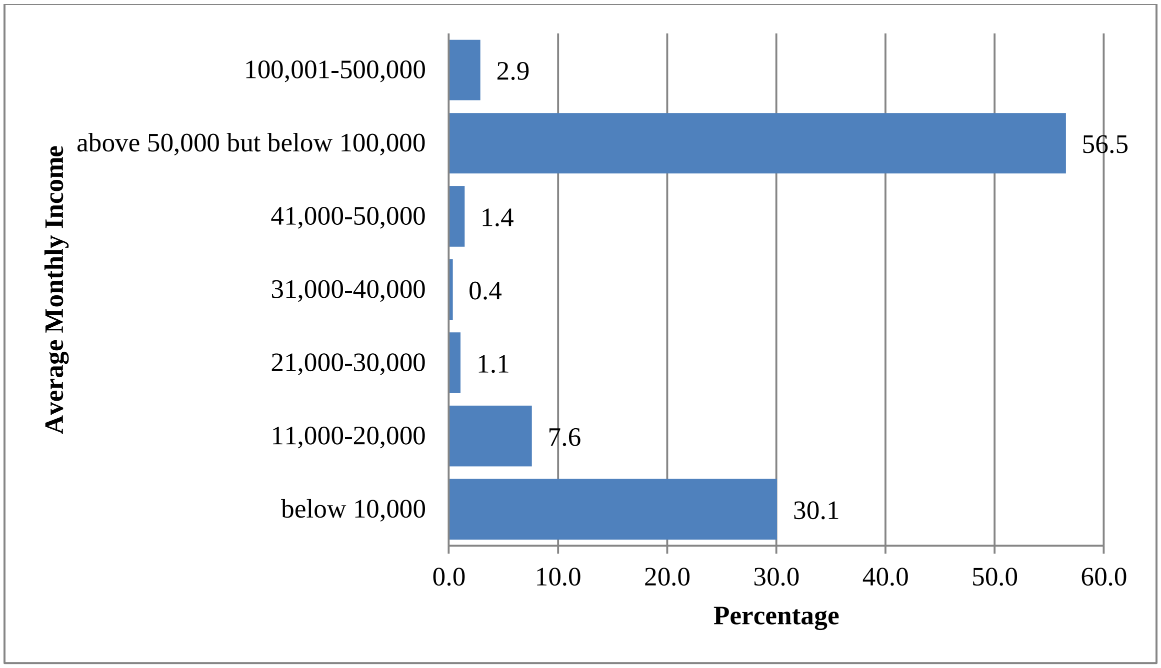



*Figure 4.5: Level of income of the household head* **Source: (Author, 2011)**

*Table 4.1: Sources of income for the last 12 months*

| Source of income | Percentage |
|---|---|
| Business | **15.7** |
| Crop Farming | **30.6** |
| Dairy farming | **23.6** |
| Horticulture | **6.6** |
| Real estate | **0.8** |
| Salary | **5.4** |
| Wages | **0.4** |
| Pension | **3.7** |
| Poultry | **9.5** |
| Bee keeping | **0.4** |
| Live stock | **1.7** |
| Fish farming | **1.7** |

**Source: (Author, 2011)**

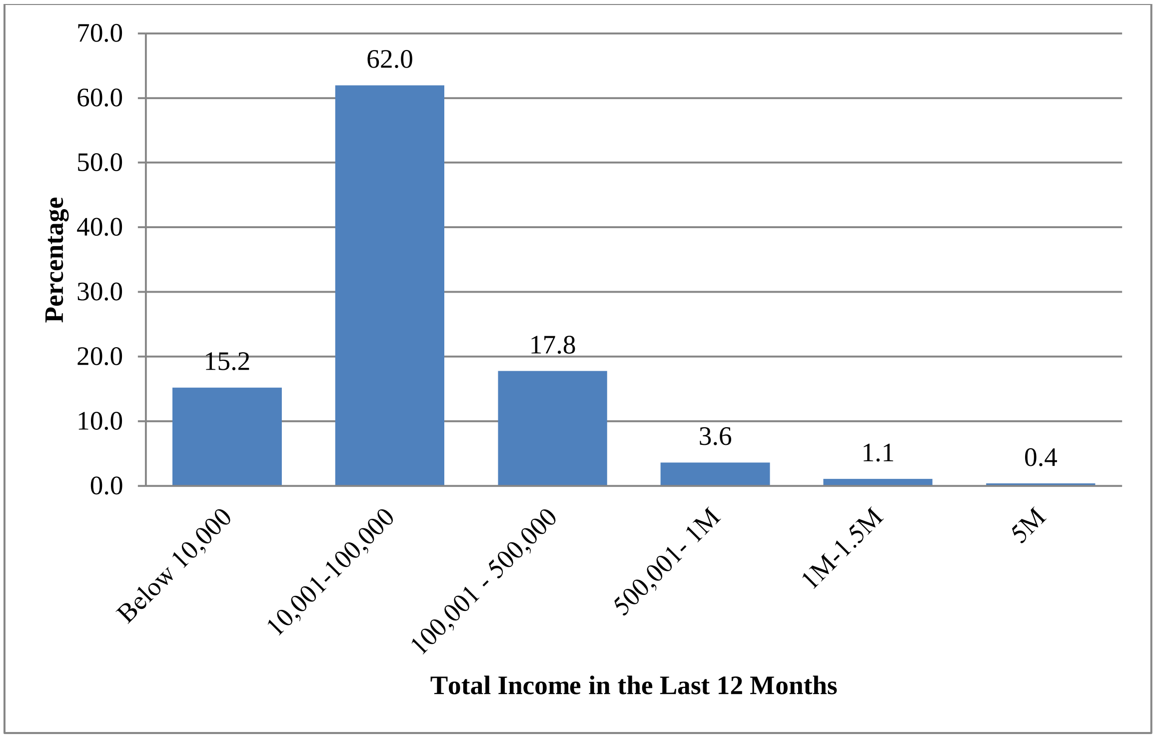



***Figure 4.6: Household income from maize*** **Source: (Author, 2011)**

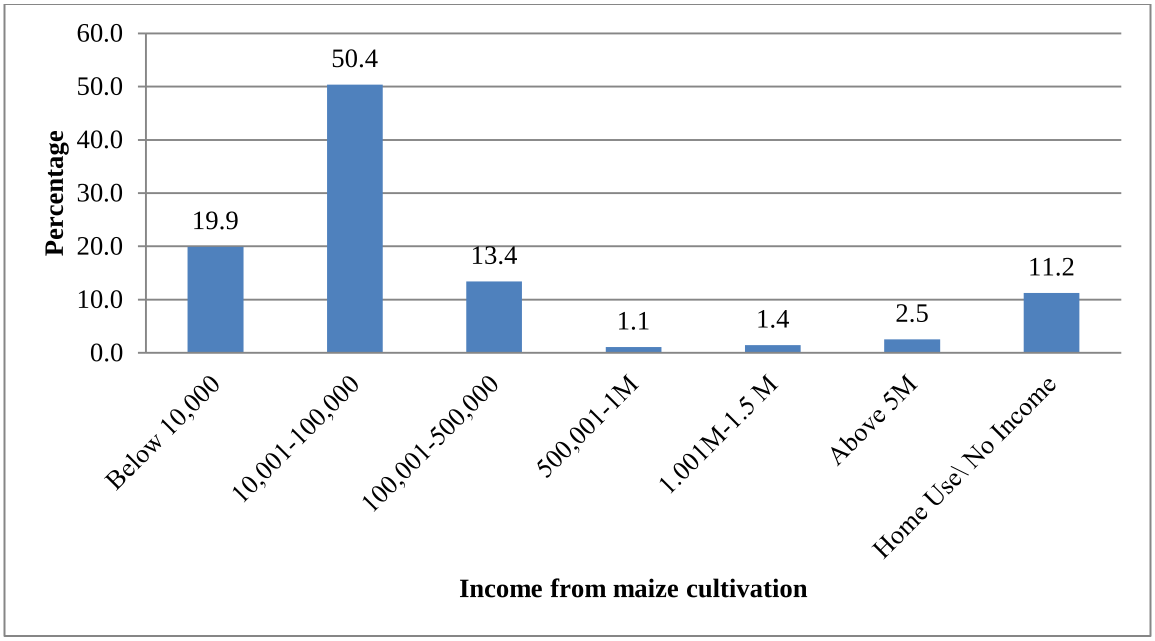



***Figure 4.7: Land use and economic activities*** **Source: (Author, 2011)**

## 4. 3 Climate change patterns in the Nzoia River Basin

### 4.3.1 Rainfall Trend in the Nzoia River Basin

Kenya has suffered from excessive and deficient rainfall in recent years. There are three observed extreme events of flooding that occurred in the Basin including 1980, 1989 and 2004 which were basically El-Nino events. La Nina related droughts in the last 20 years, 1983/84, 1991/92, 1995/96/1999/2000, 2004/2005 and 2009/2010.The El-Nino related floods of 1997/98 were very severe events, enhanced by unusual pattern of SST in the Indian Ocean. The most recent EL-Nino (1997/98) and La-Nina (1999/2000) were the most severe in 50 years (RoK, 2012).

### i) Overall Basin

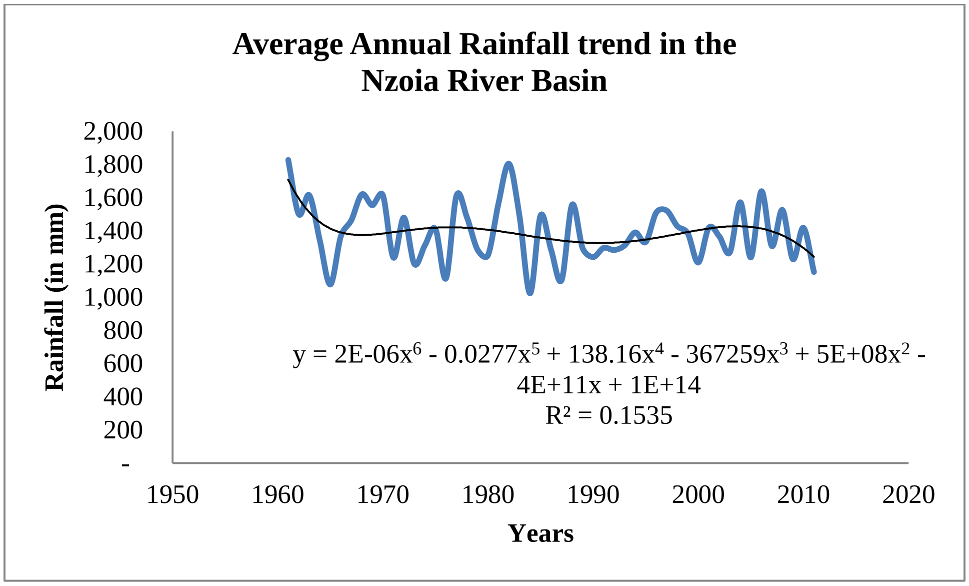



***Fig. 4.8: Annual rainfall trend of the Nzoia River Basin*** **Source: (Author, 2011)**

The results of the polynomial regression model as shown in Figure 4.8 yielded the equation with an $R^2$ of 0.15 suggesting that the predictive power of the regression trend was at fifteen (15%) per cent. The polynomial linear regression function was adopted as the most predictive growth model. The $R^2$ for the trend line was 0.1535.

Annual rainfall in Kenya follows a strong bi-modal seasonal pattern (RoK, 2012). Generally, the long rains occur in the month of March to May, while the short rains occur between October and December with variations. From the results in figure 4.8, there is decreasing pattern in precipitation over the years of study. Other than for the case of the three years, where there was El-Niño, the annual rainfall in the other years shows relative stability with insignificant growth.

### ii) Upper Basin

The average rainfall for Kitale was analyzed to represent the upper part of the basin. From Figure 4.9, the average rainfall pattern was found to be increasing over the study period.

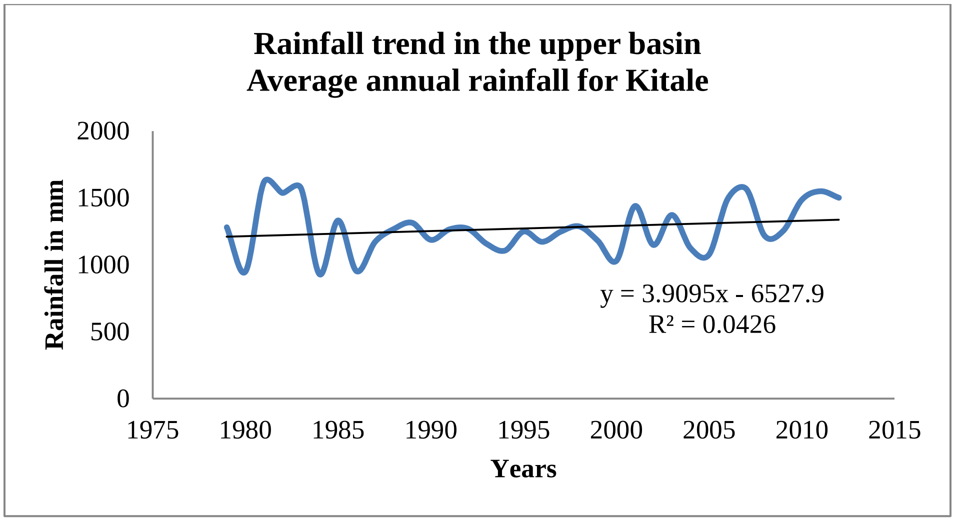



***Fig. 4.9: Rainfall Trend for Kitale over the study period*** **Source: (KMS, 2011)**

As seen from figure 4.9, the rainfall seems to have increased at a rate of 3.9 mm per annum over time. The R2 was determined as 0.0426. A further analysis into the rainfall behavior in the seasons showed that the rainfall amounts over the MAM season showed a decreasing trend over the study period as shown in Figure 4.10.

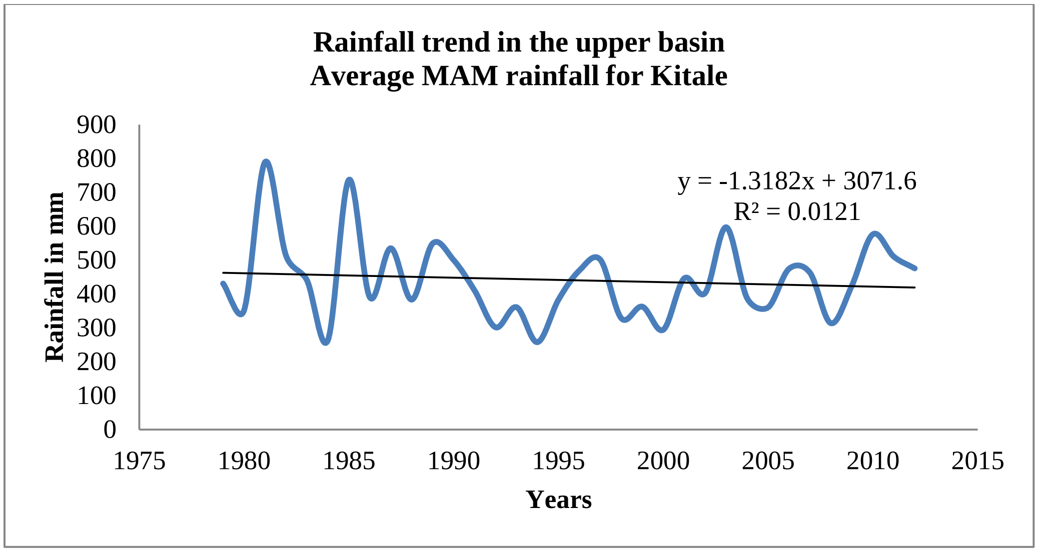



***Fig. 4. 10 The rainfall trend over the MAM season for Ki tale*** **Source: (KMS, 2011)**

As seen from Figure 4.10 MAM rainfall seemed to have been decreasing at a rate of 1.32 mm annually in the last 30 years. The $R^2$ for the MAM rainfall season trend over time was calculated as 0.0121. Analysis into the JJAS rainfall season however, showed that there is a slight increase in the amount of rainfall received over the JJAS season over the years of study as shown in Figure. 4.11.

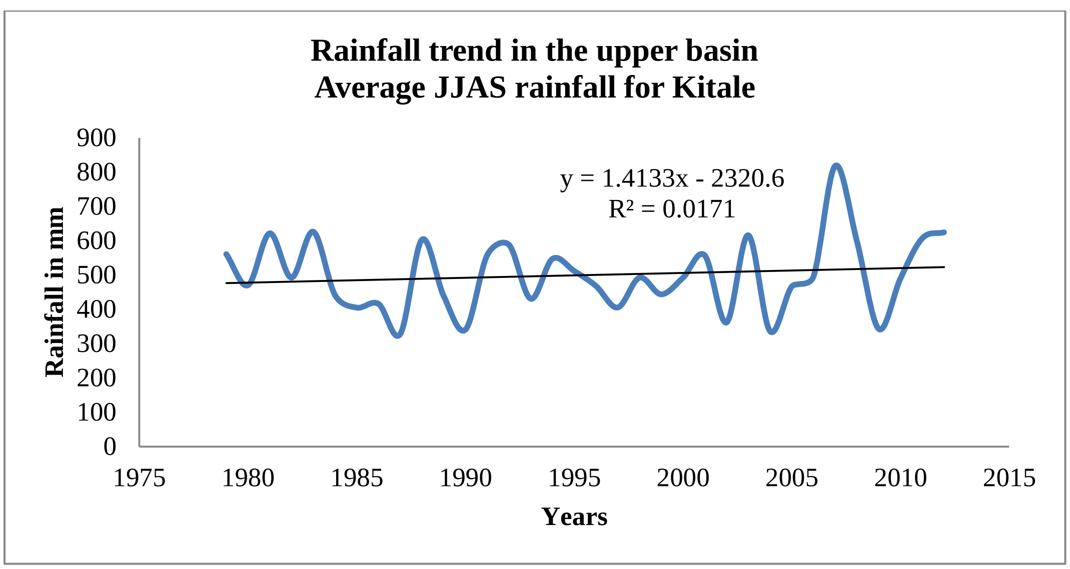


*Fig. 4.11: Rainfal l pattern of JJAS rainfall pattern for Kitale* **Source: (KMS, 2011)**

The JJAS rainfall for the upper basin was increasing at the rate of 1.41 mm annually over the period of study. The $R^2$ for the JJAS rainfall season was calculated as 0.0171. Notably, the OND rainfall amount over the years has a significant increase as shown in Figure 4.12. The OND rainfall for the upper basin seemed to have been increasing at a rate of 4.05 mm annually over the period of study depicting a rapid increase. As such, OND is the most likely variable that is influencing the average annual rainfall in the upper basin to be on an increasing trend.

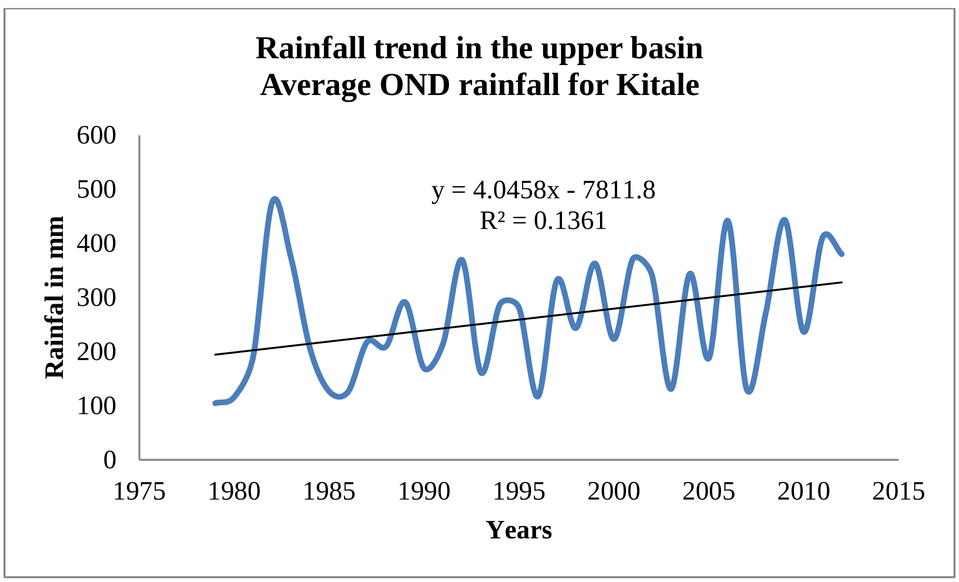



*Fig. 4.12: Rainfall trend for OND for Kitale* **Source: (KMS, 2011)**

The $R^2$ for the OND rainfall was 0.1361

### iii) Middle Basin

The middle basin was composed of the Kakamega, Vihiga, and Bungoma County. For the analysis of the middle of the basin, Kakamega Meteorological Department data, as shown in figure 1.3 on rain gauge stations was analyzed to give the rainfall trend to represent the middle basin. The station had a fairly good data that spanned from the 1960's as opposed to other stations whose data was available but for shorter periods. The rainfall pattern showed a different behaviour pattern from the upper basin as shown in Figure 4.13.

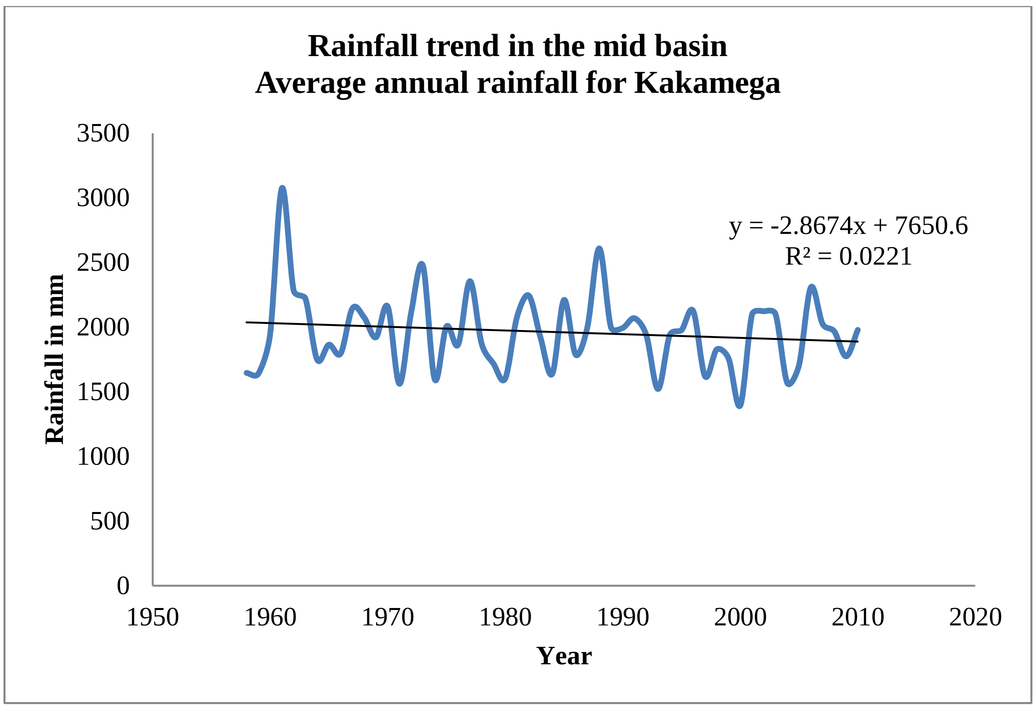



***Fig 4.13:Annual rainfall trend for Kakamega*** **Source: (KMS, 2011)**

The results in Figure 4.13 showed that the annual rainfall for the middle part of the basin was decreasing at an average rate of 2.87mm annually. The $R^2$ for the average rainfall in the middle basin was 0.0221**.** Further analysis of the MAM rainfall results were as shown in Figure 4.14.

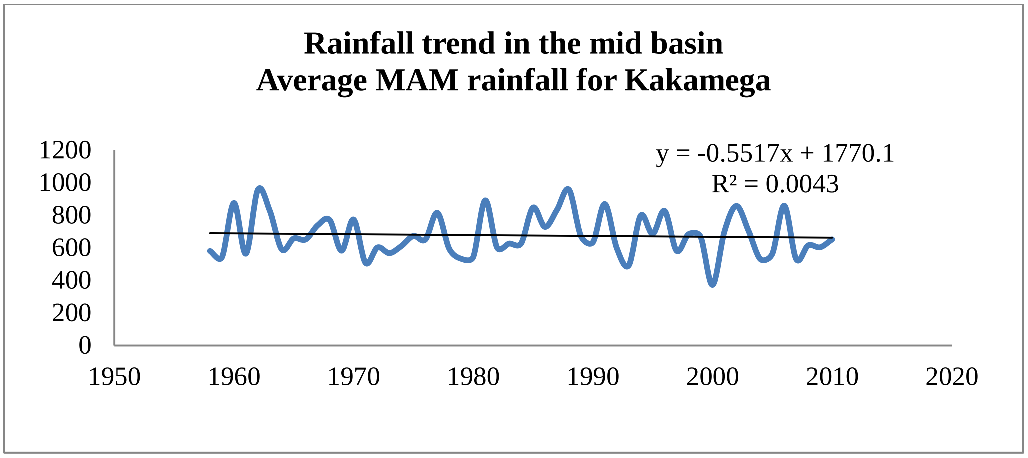



***Fig. 4.14 Rainfall trend for MAM for Kakamega*** ***Source: (KMS, 2011)***

The seasonal behavour of rainfall in Figure 4.14 revealed that the MAM rainfall were deacreasing at a rate of 0.6 mm annually. The $R^2$was determined as 0.0042.The pattern for JJAS rainfall were negligibly decreasing as shown in Figure 4.15

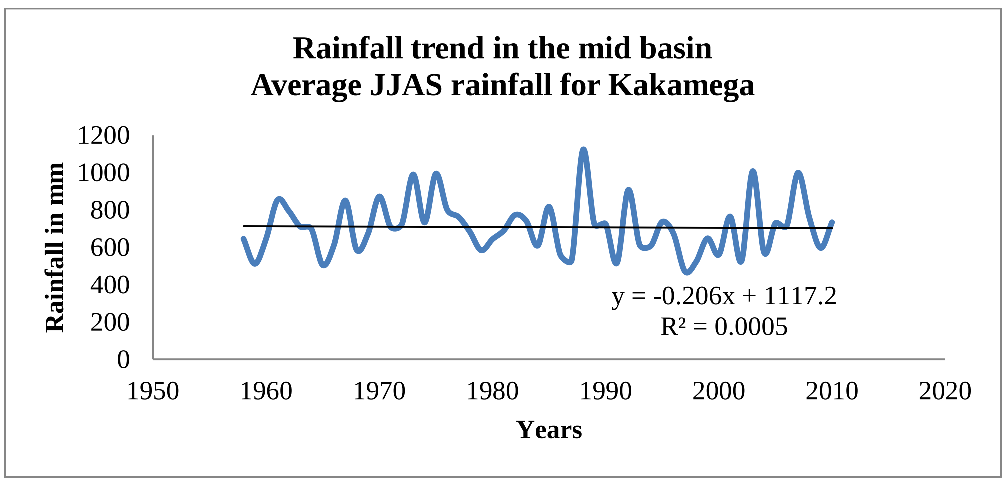



***Fig.4.15: Rainfall trend for JJAS rainfall for Kakamega*** **Source: (KMS, 2011)**

Analysis showed that the JJAS rainfall pattern was decreasing rather insignificantly at a rate of 0.21 mm annually. The $R^2$ was determined as 0.005. Analysis into the OND rainfall season revealed that the rainfall recorded over the study period was also decreasing as shown in Figure 4.16.

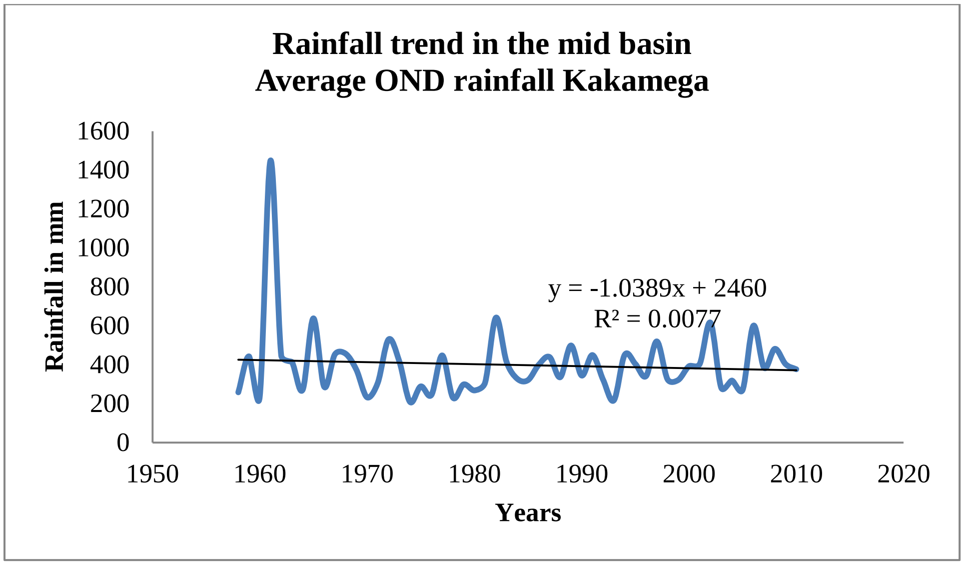



***Fig. 4.16: Rainfall pattern for OND for Kakamega*** **Source: (KMS, 2011)**

The OND rainfall trend in the mid basin assumed a general decrease of 1.03 mm annually. The $R^2$ was determined as 0.0077.

### iv) Lower Basin

Analysis of the rainfall received in the Port Victoria station showed that the annual rainfall over the study period was relatively unchanged as shown in Figure 4.17.

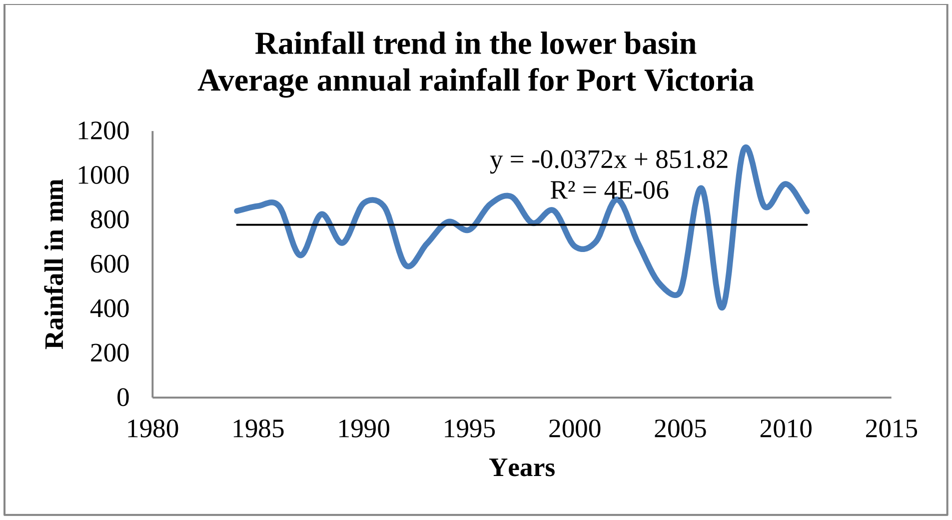



***Fig 4.17: Annual rainfall trend for Port Victoria*** **Source: (KMS, 2011)**

While Figure 4.17 revealed a negligible decrease of average annual rainfall of 0.04 mm annually, the analysis of the seasonal rainfall showed a lot of rainfall variability. The MAM seasonal rainfall showed a significant decrease in rainfall amounts received over the years as shown in Figure 4.18.

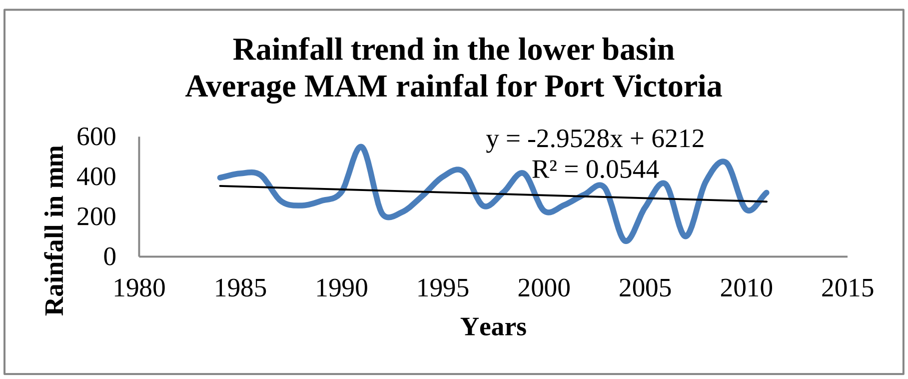



***Fig. 4. 18: Rainfall trend for MAM for Port Victoria*** **Source: (KMS, 2011)**

As shown in Figure 4.18, the MAM rainfall was decreasing at a rate of 2.95 mm annually. This was confirmed by the R2 which was calculated at 0.0544. However, the rainfall amounts for the JJAS season showed a relative increase over the study period as shown in Figure 4.19.

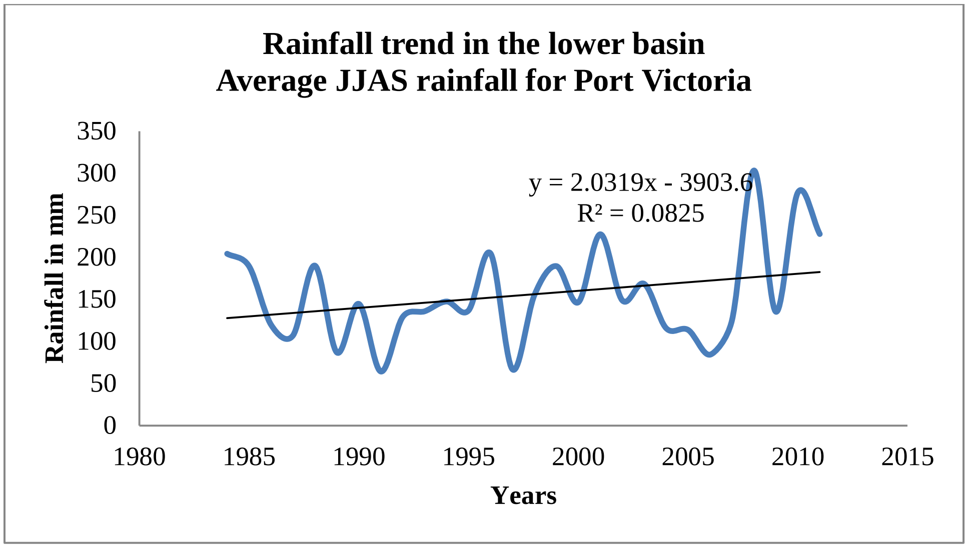



***Fig. 4.19: Rainfall trend for JJAS for Port Victoria*** **Source: (KMS, 2011)**

The JJAS rainfall was increasing at a rate of 2.03 mm annually as shown in Figure 4.19, with $R^2$ of 0.0825. The rainfall pattern for the OND season, showed an increasing pattern over the period under consideration as shown in Figure 4.20.

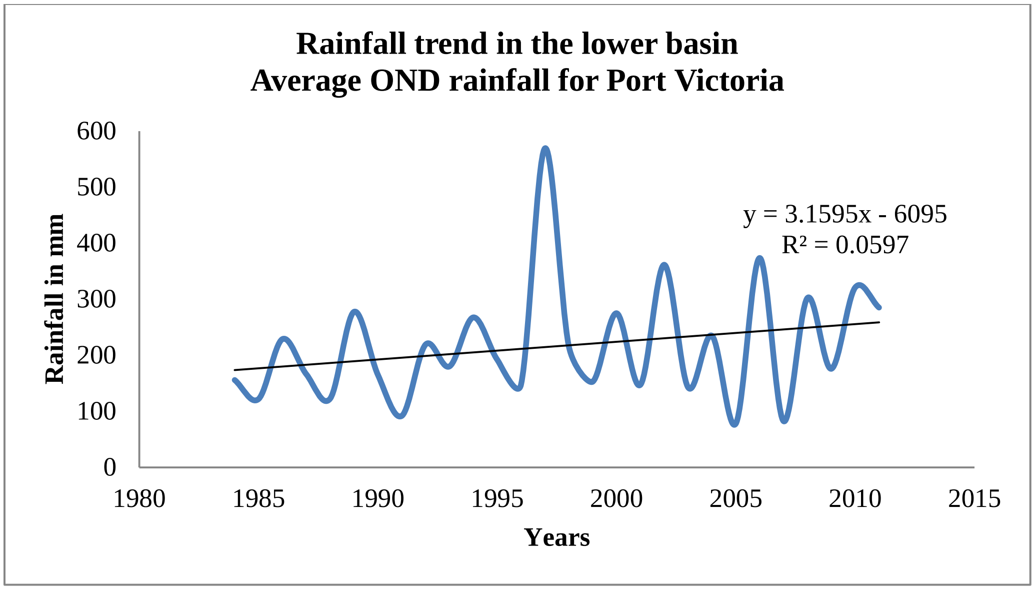



***Fig.4.20: Rainfall trend for OND for Port Victoria*** **Source: (KMS, 2011)**

As shown in Figure 4.20, the OND rainfall was increasing at a rate of 3.16 mm annually with an $R^2$ of 0.0597.

**4.3.2 Perception of farmers on the changes in rainfall**

When the farmers in the basin were interviewed, 73 % of them indicated that they had observed a decrease in the rainfall pattern as shown in Table 4.2. Further analysis of the farmers in the different segments of the basin revealed that 93% of the farmers in the upper basin indicated that they had noticed a decrease in the rainfall pattern over the study period. Only 13 % of the farmers in the lower basin indicated that they had noticed a decrease in the rainfall pattern. This corroborates the findings of the instrumental data obtained from the KMD and analyzed in figure 4.9 which indicated that the rainfall in the upper basin especially in Kitale had decreased. However, the same data showed that the annual rainfall in Port Victoria did not change significantly as shown in figure 4.17. But on analyzing the seasonal rainfall it showed that OND rainfall in the lower part had increased over the study period as shown in Figure 4.20.This is also the reason why the farmers in the lower basin plant their crop of maize crop in the short season rainfall.

***Table 4.2: Perception of farmers on the rainfall trends***

| | **Trans Nzoia West** | | **Kakamega** | | **Busia** | | **Total** | |
|---|---|---|---|---|---|---|---|---|
| | **Frequency** | | | | | | | |
| Increase in precipitation | 8 | 3 | 3 | 1 | 1 | 0 | 12 | 5 |
| Decrease in precipitation | 93 | 36 | 62 | 24 | 33 | 13 | 188 | 73 |
| Changes in onset of the rains | 13 | 5 | 16 | 6 | 1 | 0 | 30 | 12 |
| Increase in frequency of droughts | 2 | 1 | 3 | 1 | 2 | 1 | 7 | 3 |
| No change | 0 | 0 | 1 | 0 | 2 | 1 | 3 | 1 |
| don't know | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| Decrease in precipitation and changes on the onset of rains | 0 | 0 | 0 | 0 | 3 | 1 | 3 | 1 |
| Changes in onset of rains and increased frequency of drought | 0 | 0 | 0 | 0 | 15 | 5 | 15 | 5 |
| **Total** | **116** | **45** | **86** | **33** | **57** | **22** | **259** | **100** |

**Source: (Author, 2011)**

When the respondents were asked to indicate the type of changes they had observed, 16% in Trans Nzoia West, 33% in Kakamega and 57 % in Busia indicated they had observed a delay in the onset of the rains over the study period as indicated in Table 4.3 below.

Regarding the density of the rainfall, 35% in Trans Nzoia West, 28% in the Kakamega and 11% in Busia indicated that they had noticed a lighter density in the amount of rainfall over the study period. This also corroborates the findings in the instrumental data analyzed in Figure 4.8 showing a reduced amount of rainfall over the study period. 18 % of the farmers in the Trans Nzoia West indicated that the rainfall had become unpredictable over the study period as indicated in table 4.3 below.

**Table 4.3: Perception of farmers on observed changes in the rainfall in the Basin**

| | **Trans Nzoia West** | | **Kakamega** | | **Busia** | |
|---|---|---|---|---|---|---|
| | **Frequency** | **Percent** | **Frequency** | **Percent** | **Frequency** | **Percent** |
| Delayed onset | 13 | 16 | 19 | 33 | 25 | 57 |
| Light Density | 29 | 35 | 16 | 28 | 5 | 11 |
| Poor distribution | 2 | 2 | 6 | 10 | 4 | 9 |
| Unpredictable | 15 | 18 | 2 | 3 | 3 | 7 |
| High Density | 16 | 20 | 11 | 19 | 3 | 7 |
| Early Onset | 2 | 2 | 0 | 0 | 0 | 0 |
| Normal distribution | 5 | 6 | 4 | 7 | 4 | 9 |
| **Total** | **82** | **100** | **58** | **100** | **44** | **100** |

**Source: (Author, 2011)**

Discussions with the Agricultural officers both in the upper and lower basin confirmed that they had also observed a reduction in the amount of rainfall received over the years. However, the effect on maize production of rainfall really depended on onset of the rains and the general distribution of the rain throughout the growing period (Mugalavai, 2013).They also indicated that if the rains decreased at some of the critical stages of maize development, then the yield was adversely affected. The results showed large variability in rainfall with occurrence of extreme events in terms of droughts and floods. The rainfall trends in the basin showed significant variations in spatial and temporal patterns both of total annual and seasonal rainfall which affect crop production especially maize which is rainfall depended.

The erratic pattern of rainfall gets farmers off-guard and destabilizes their planning. Most farmers normally plant on the onset of the rains. The table 4.4 below shows the planting dates for maize in the basin. The planting dates vary depending on the times they receive the rainfall. Farmers in Trans Nzoia West start their planting in early March but have their peak planting in mid-March when most farmers plant their crop and that is also when they receive the peak rainfall. However quite a substantive number plant their crop in early April. This is because the rainfall pattern in the Trans Nzoia seemed to be continuous. There is no clear dry spell at this particular period; however such crops do not perform well when there is dry spell at the reproductive stage depending on the growing season and the variety grown.

**Table 4.4: Planting dates for maize in various counties**

| | Trans Nzoia West | | Kakamega | | Busia | |
|---|---|---|---|---|---|---|
| | **Frequency** | **%** | **Frequency** | **%** | **Frequency** | **%** |
| Late February | 9 | 7 | 0 | 0 | 7 | 14 |
| Early March | 18 | 15 | 12 | 13 | 23 | 45 |
| Mid-March | 42 | 34 | 44 | 49 | 16 | 31 |
| Late March | 25 | 20 | 11 | 12 | 4 | 8 |
| Early April | 19 | 15 | 17 | 19 | 0 | 0 |
| Mid April | 10 | 8 | 5 | 6 | 1 | 2 |
| Late April | 1 | 1 | 1 | 1 | 0 | 0 |
| **Total** | **124** | **100** | **90** | **100** | **51** | **100** |

**Source: (Author, 2011)**

There is a significant difference in the planting dates among the upper, middle and lower basin. Farmers in the upper basin had their peak planting date throughout March and up to mid-April. This is quite a long span of planting since a delay in planting once the rains start affects the maize yield in a significant way. The farmers in the Kakamega County started their planting in early March and peaked in early April. Those in Busia started in late February to Mid-March but most of them planted in Mid-March.

The farmers in the Trans Nzoia West have a long span of the planting season because the rains start late and extend further into the JJAS season. For the farmers, every time there is rainfall, it presents an opportunity to plant. The challenge is presented when the planted crop does not get the right amount of rainfall during the critical development stages leading to poor yields. Farmers are not sure when to plant, while others wait for the rains to stabilize before they plant. In this way, the farmers lose out when the rains disappear earlier than expected.

The farmers in the basin grow a range of varieties from the short season to medium and long season varieties as shown in figure 4.21, showing the varieties of maize commonly grown in the basin.

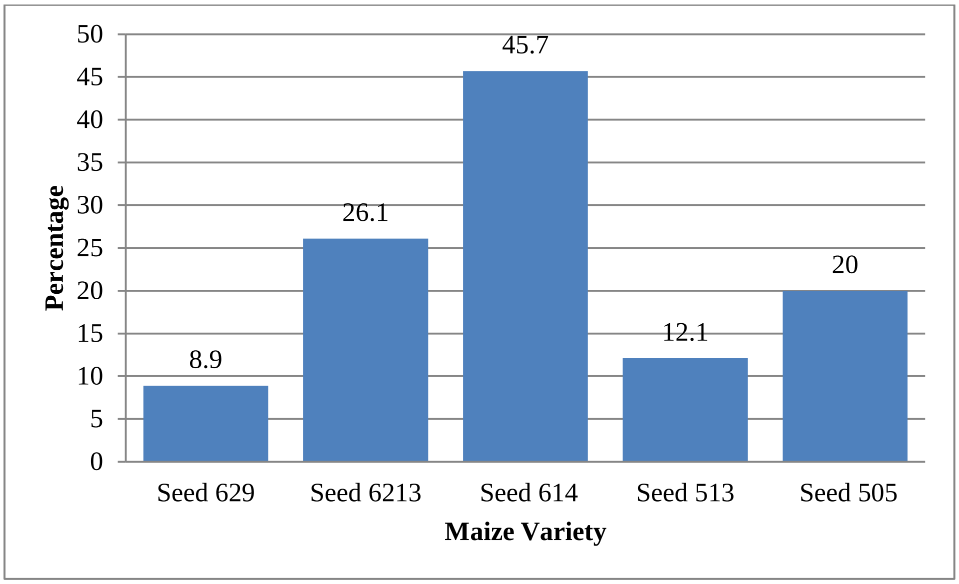
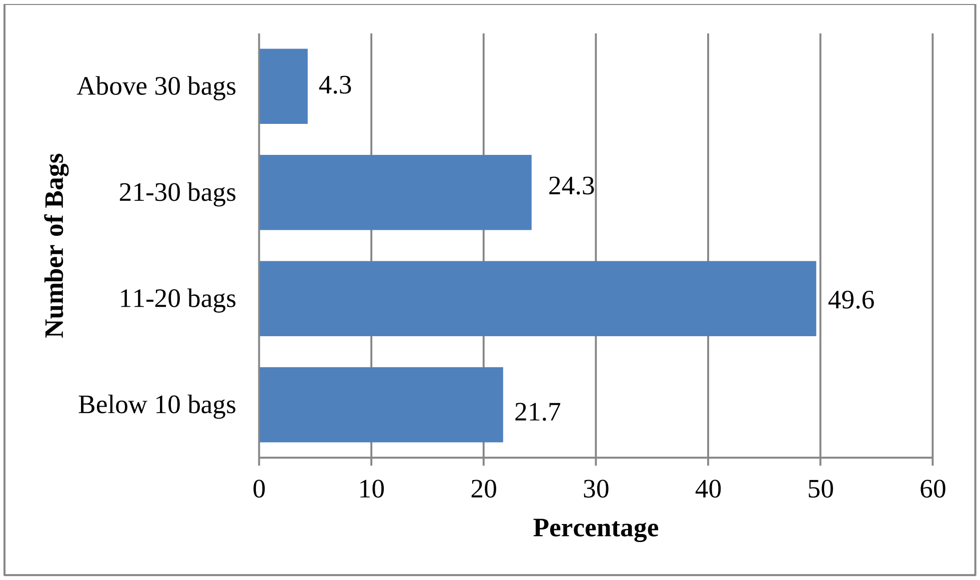



***Fig. 4.21:Varieties of maize planted in the Nzoia River basin*** **Source: (Author, 2011)**

From 4.21, the varieties grown in the basin conform to the recommended varieties for the basin in terms of crop variety altitude and rainfall amount. However the challenge is in distribution of the received rainfall over the growing period to enable the farmers to realize the optimum yield as shown in Table 2.1.The average yield realized by the farmers is in the basin is 11-20 bags as shown in fig. 4.22. Given that the commonly grown variety of maize is the H 614, whose optimum yield is 35 bags per acre, there is a great difference of 25 bags which are not realized due to rainfall variations and farmers not planting at the right time to realize maximum yield.




***Fig, 4.22: Average yield of maize by farmers in the basin*** **Source: (Author, 2011)**

The findings corroborates the finding of the RoK, 2010 which indicated that Kenya has seen a 2.6 % decrease in rainfall between 1960 and 2006. The decrease is projected to average 15.6% by the year 2050 (Kirai, 2009; UNDP, 2007; RoK 2010). Andresen et al., 2008 also indicated that there is no homogenous trend regarding the changes in precipitation over the years. This necessitates the need to analyze the sensitivity of our crops to changes in rainfall and climatic variability to facilitate appropriate adaptation measures and advise our farmers appropriately.

### 4.3.3 Temperature trend in the Nzoia River Basin

From the regression models, the polynomial regression model was adopted and the results were as shown in Figure 4.23

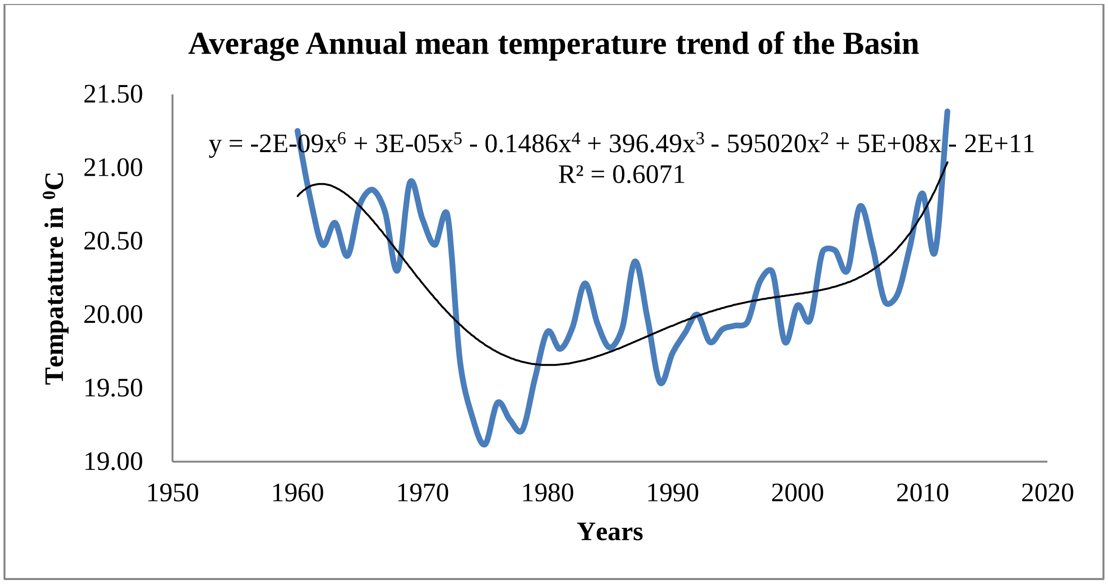



***Fig. 4.23 Annual mean temperature trend of the Basin*** **Source: (KMS, 2011)**

The results of polynomial regression modeling yielded the equation: -

$Y = -2E\text{-}09x^6 + 3E\text{-}05x^5 - 0.1486x^4 + 396.49x^3 - 595020x^2 + 5E{+}08x - 2E{+}11$

The equation yielded $R^2$ of 0.607 suggested that the predictive power of the regression trend was at sixty one percent. The polynomial linear regression function was adopted as a more appropriate growth model since it had a high $R^{2.}$ The value of $R^2$ being 0.607 suggests that the remaining 0.383 would be taken care of by the error term. Generally, the temperature was initially seen to be falling from 1960 to 1979 when the trend changes direction to an upward trend. The intensity of the trends was as shown in Figures 4.24 and 4.25.

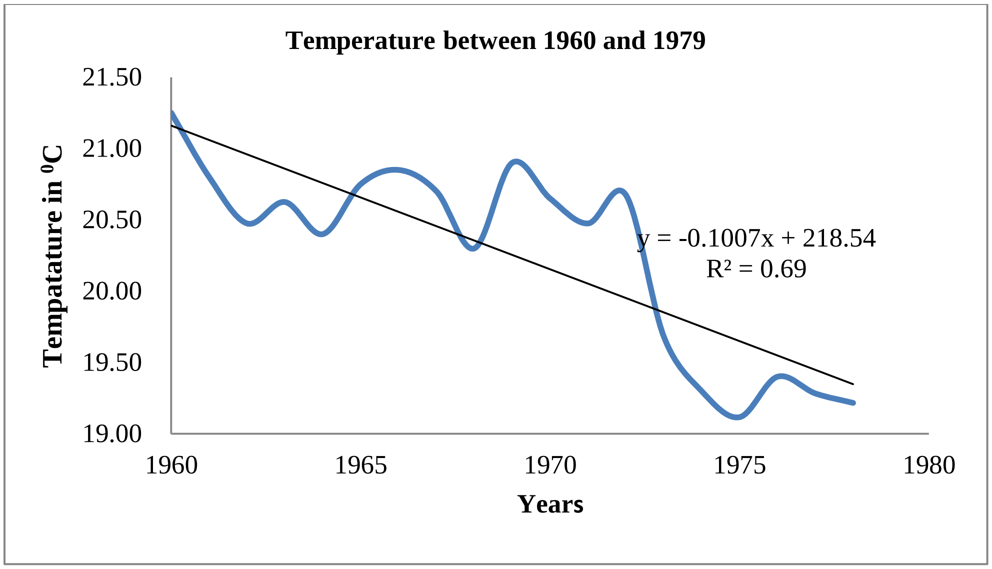



***Figure 4.24 Annual mean Temperature between 1960 and 1978*** **Source: (KMS, 2011)**

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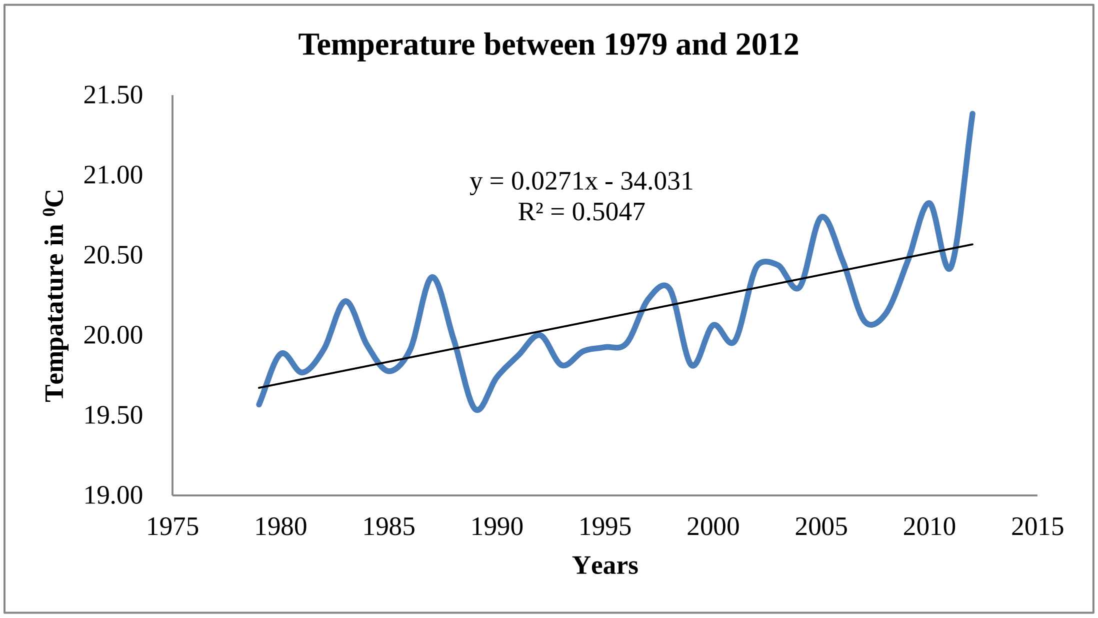


***Figure 4.25 Annual mean Temperature trend between 1979 and 2012***
**Source: (KMS, 2011)**

Between 1960 and 1982 the temperature in the basin

This was determined as 0.69 depicting a strong negative relationship between temperature and time which was significant. Figure 4.25 shows the basin warming up at an annual rate of 0.027$^{o}$C from 1979 to 2012. The $R^2$ was 0.50 also confirming a strong positive relationship which was significant.

The seasonal temperature variations for MAM, JJAS and OND for the period between 1960 and 2012 depicted a similar trend for the average temperatures as shown in Figure 4.26.

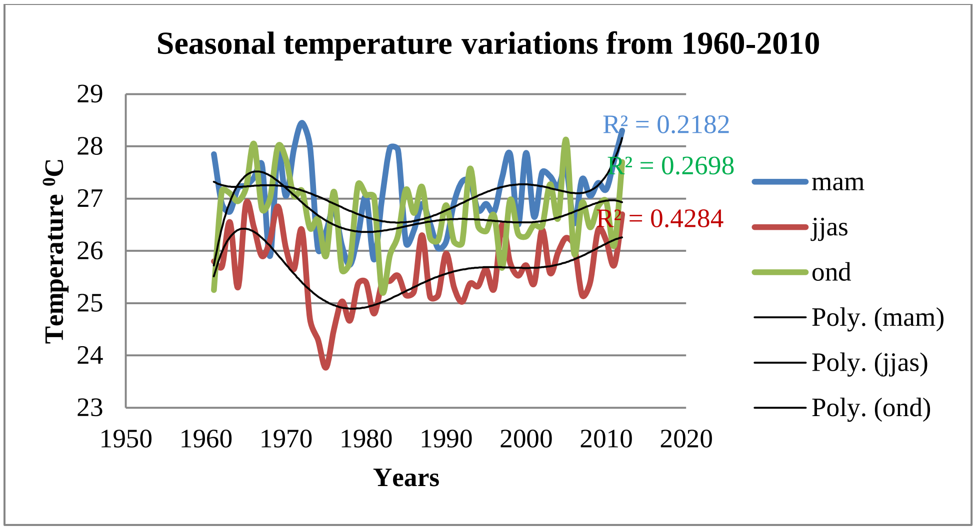


***Fig.4.26 Seasonal temperature variations from 1960-2010*** **Source: (KMS, 2011)**

From Figure 4.26, it is evident that MAM, JJAS and OND temperatures are falling between 1960 and 1979 when the trend changes direction to an upward trend between 1980 and 2012.

### i) Upper Basin

The results indicated that there were variations in the temperature of the basin and that there is an increasing trend in the temperature. Figure 4.27 and 4.28 summarizes the average maximum and minimum temperature trend for the upper basin.

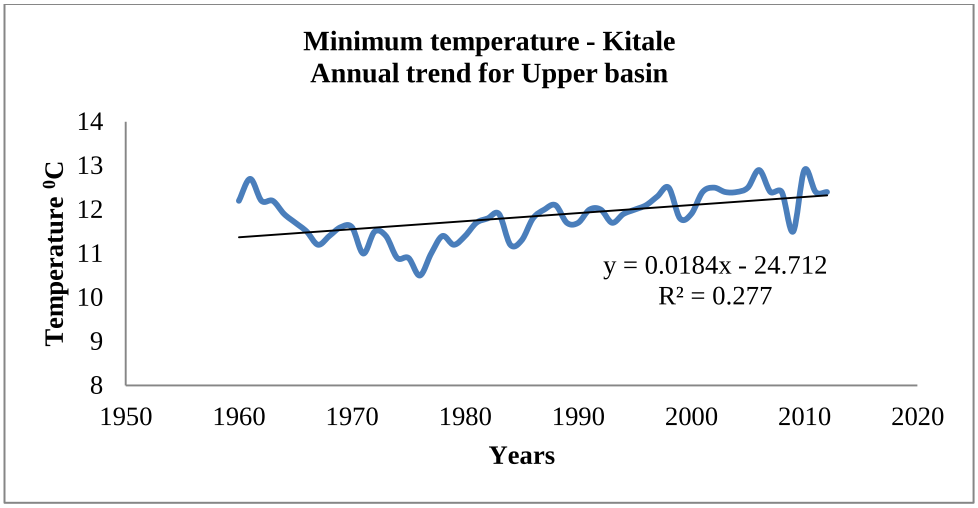


*Fig. 4.27: Annual mean Minimum Temperature for Ki tale* **Source: (KMS, 2011)**

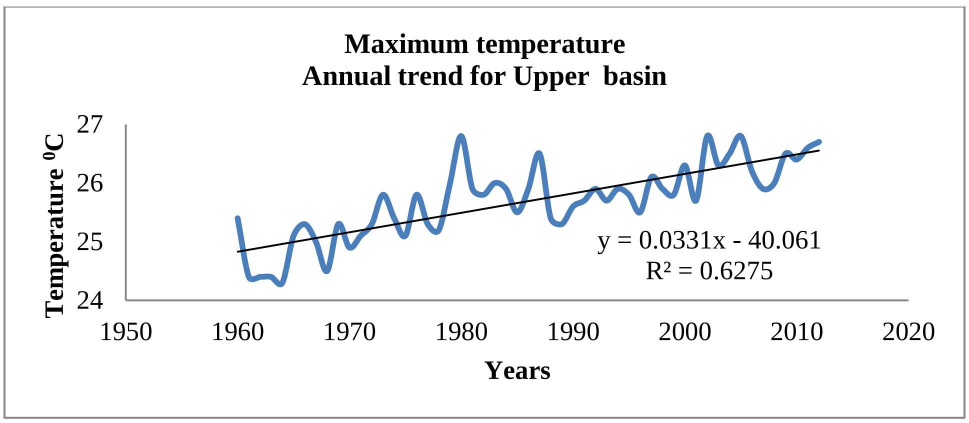


*Fig.4.28: Annual Maximum Temperature for Kitale* **Source: (KMS, 2011)**

As seen from Figures 4.27 and 4.28, the minimum Temperature in the upper basin is incresing at a rate of 0.0184°C annually with and $R^2$ of 0.277while the maximum Temperature is increasing at a rate of 0.033°C annually with an R2 of 0.6275.

### ii) Middle Basin

The mid basin also recorded increasing Temperatures as summarised in Figures 4.29 and 4.30

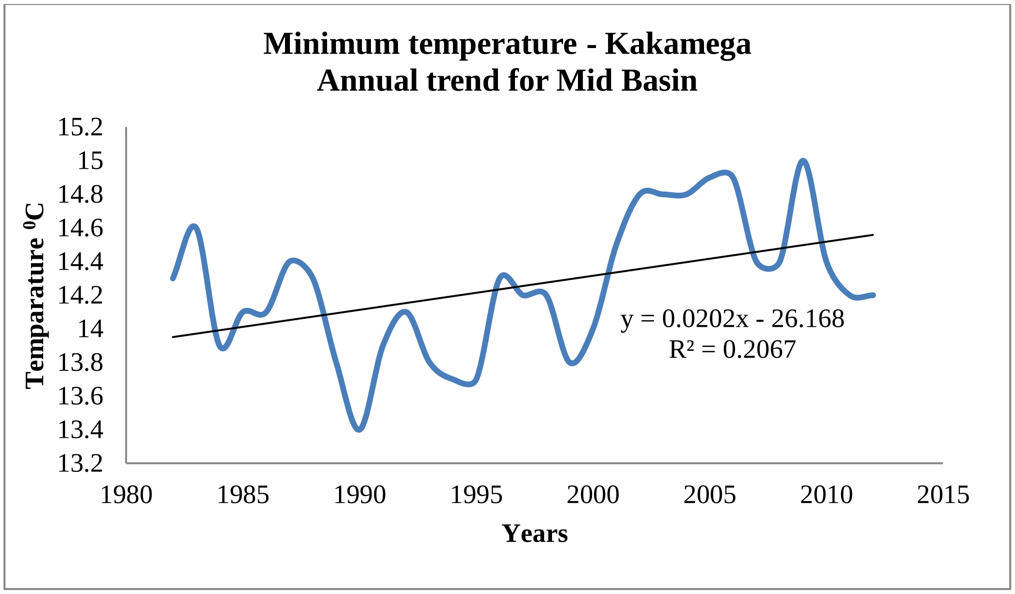


***Fig.4.29:Annual Minimum Temperature forKakamega*** **Source: (KMS, 2011)**

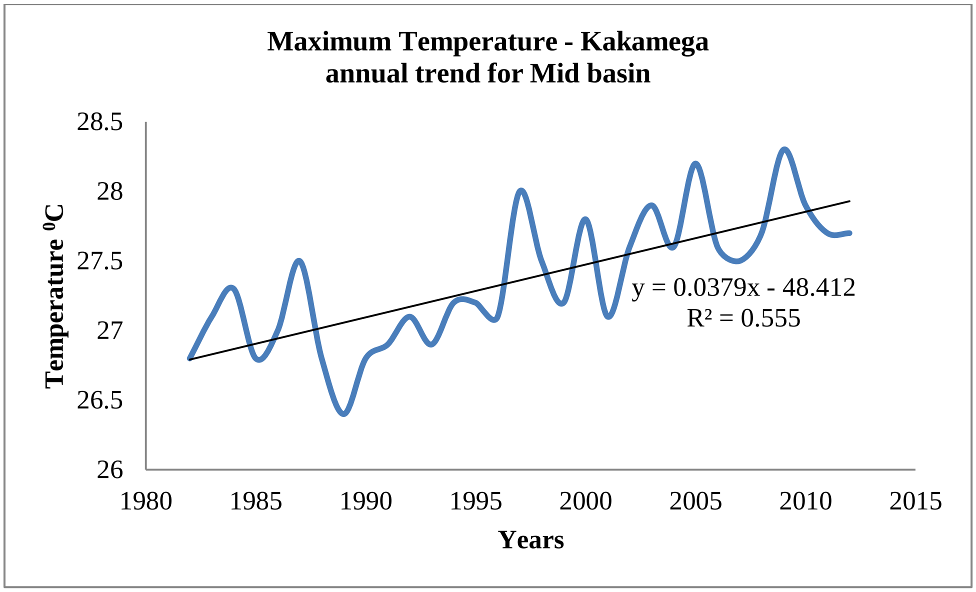


***Fig. 4.30:Annual Maximum Temperature for Kakamega*** **Source: (KMS, 2011)**

The minimum Temperature in the middle basin seemed to be increasing at a rate of 0.02°C annually with an $R^2$ of 0.2067 while the maximum Temperature seems to be increasing at a rate of 0.037°C annually with an $R^2$ of 0.555 as seen from Figures 4.29 and 4.30.

### iii) Lower Basin

The Lower Basin represented by Busia county also recorded increasing Temperatures as summarised in Figures 4.31 and 4.32.

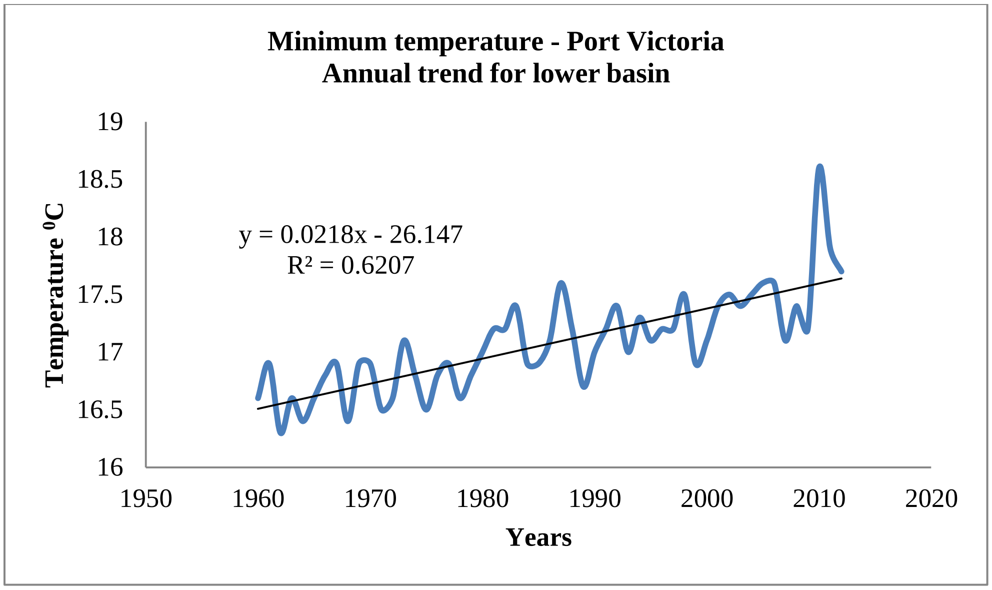


*Fig. 4.31:Annual Minimm Temperature for Port Victoria*

**Source: (KMS, 2011)**

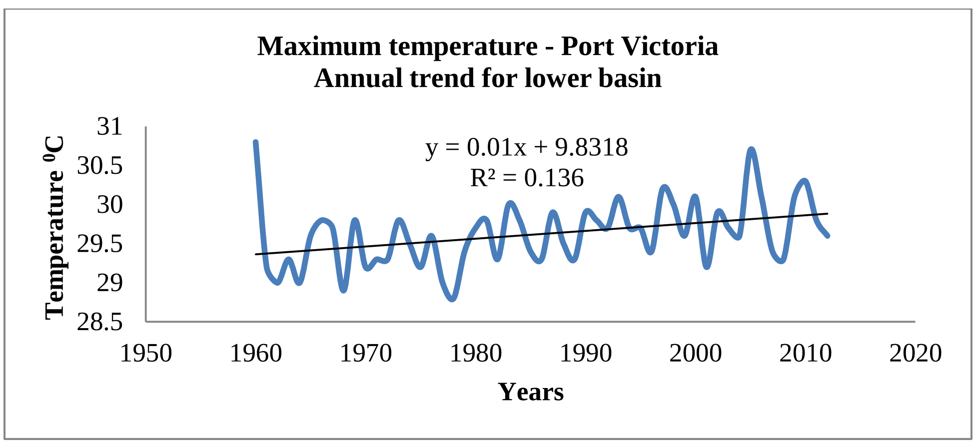


*Fig. 4.32:Annual Maximum temperature for Port Victoria*

**Source: (KMS, 2011)**

As shown in Figures 4.31 and 4.32, the minimum Temperature in the lower basin is also increasing at a rate of 0.022$^{o}$C annually with an $R^2$ of 0.6207 while the maximum Temperature is increasing at a rate of 0.01$^{o}$C with an $R^2$ of 0.136. The temperature variation results established that the annual temperatures in the basin showed a general cooling from 1963 -1977. However, there was a general increase in temperatures from 1980 up to 2010.

This is corroborated by the findings of the (RoK, 2012) which indicated that the mean annual temperatures have increased by one degree in Kenya. Since 1960, an average rate of 0.21 $^{0}$C per decade has been observed. This increase in temperature has been most rapid in MAM where the rate has been 0.29 $^{0}$ C per decade, and slowest in JJAS 0.19$^{0}$ C per decade. Recent reports from the IPCC confirm that there is a general warming across Africa in the range of 0.2 $^{0}$C -0.5 $^{0}$C per decade (Hulme et al 2001, IPCC (2001).

This is also corroborated by the General circulation models which indicated that there would be an increase in the mean annual temperature of 2.5-5$^{0}$C. (McSweeney, New and Lizcano, 2007) also showed that the increase in temperature would be most rapid in MAM season at a rate of 0.29 $^{0}$ C per decade.

**Table 4.5: T-Test for Minimum temperatures**

| **Two-Sample Assuming Equal Variances** | **Trans Nzoia West** | **Kakmega** | **Busia** |
|---|---|---|---|
| Mean | 12.09032258 | 14.25483871 | 17.31612903 |
| Variance | 0.171569892 | 0.163892473 | 0.129397849 |
| Observations | 31 | 31 | 31 |
| Pooled Variance | | 0.167731183 | 0.150483871 |
| Hypothesized Mean Difference | | 0 | 0 |
| Df | | 60 | 60 |
| t Stat | | -20.80749364 | -53.03641896 |
| P(T<=t) two-tail | | 3.96895E-29 | 4.07929E-52 |
| t Critical two-tail | | 2.000297804 | 2.000297804 |

**Source: (KMS, 2011)**

**Table 4.6: T-test for Maximum temperatures**

| t-Test: Two-Sample Assuming Equal Variances | | | |
|---|---|---|---|
| | **Trans Nzoia West** | **Kakamega** | **Busia** |
| Mean | 26.02903226 | 27.36129032 | 29.75483871 |
| Variance | 0.173462366 | 0.214451613 | 0.123892473 |
| Observations | 31 | 31 | 31 |
| Pooled Variance | | 0.193956989 | 0.148677419 |
| Hypothesized Mean Difference | | 0 | 0 |
| Df | | 60 | 60 |
| t Stat | | -11.90971832 | -38.0420255 |
| P(T<=t) two-tail | | 1.90096E-17 | 1.0448E-43 |
| t Critical two-tail | | 2.000297804 | 2.000297804 |

**Source: (Author, 2011)**

### 4.3.4 Perception of farmers on temperatures trends in the Nzoia River basin

When the farmers in the basin were interviewed on their perception of the trend of the temperatures in the basin, they indicated that they had noticed a general increase in the temperatures in the basin. The results were as shown in Table 4.7 where 62% of the farmers in the Trans Nzoia West, 46% in Kakamega County and 57% in Busia indicated they had noticed an increase in the MAM season temperatures.

*Table 4.7: Perception of the farmers on MAM temperatures*

| | Trans Nzoia West | | Kakamega | | Busia | |
|---|---|---|---|---|---|---|
| | Frequency | % | Frequency | % | Frequency | % |
| Increase in temperature | 31 | 62 | 17 | 46 | 13 | 57 |
| Decrease in temperature | 7 | 14 | 12 | 32 | 8 | 35 |
| Normal temperature | 10 | 20 | 7 | 19 | 2 | 9 |
| Unpredictable | 2 | 4 | 1 | 3 | 0 | 0 |
| **Total** | **50** | **100** | **37** | **100** | **23** | **100** |

**Source: (KMS, 2011)**

Perception of farmers on the temperature changes in the JJAS season showed varied results. 66% of the farmers in Trans Nzoia West, which is the upper part of the basin and 69 % of the farmers in Kakamega, indicated that the JJAS temperatures had decreased. However, 77% of the farmers interviewed in Busia indicated that the temperatures had increased over the years as shown in Table 4.8 below. The JJAs season is primarily the reproductive stage where flowering, pollination and cobbing occur mostly.

**Table 4.8: Perception of farmers on JJAS season for the basin**

| | Trans Nzoia West | | Kakamega | | Busia | |
|---|---|---|---|---|---|---|
| | Frequency | % | Frequency | % | Frequency | % |
| Increase in Temperature | 7 | 18 | 6 | 17 | 17 | 77 |
| Decrease in Temperature | 24 | 62 | 24 | 69 | 5 | 23 |
| Normal Temperature | 7 | 18 | 5 | 14 | 0 | 0 |
| Unpredictable | 1 | 2 | 0 | 0 | 0 | 0 |
| **Total** | **39** | **100** | **35** | **100** | **22** | **100** |

**Source: (KMS, 2011)**

A further analysis of the OND temperatures in the upper part of the basin showed that the temperatures were increasing. 45% of the respondents in Trans Nzoia West indicated the temperatures were increasing and 40 % also indicated the temperatures were decreasing as shown in Table 4.9. However, 87% of respondents in Kakamega and 86% in Busia indicated the temperatures were increasing.

**Table 4.9: Perception of farmers on OND temperature changes**

| | **Trans Nzoia West** | | **Kakamega** | | **Busia** | |
|---|---|---|---|---|---|---|
| | Frequency | % | Frequency | % | Frequency | % |
| Increase in temperature | 9 | 45 | 13 | 87 | 6 | 86 |
| Decrease in temperature | 8 | 40 | 0 | 0 | 0 | 0 |
| Normal temperatures | 3 | 15 | 2 | 13 | 1 | 14 |
| **Total** | **20** | **100** | **15** | **100** | **7** | **100** |

**Source: (Author, 2011)**

From the analysis, Maximum temperatures in the MAM season seemed to have the highest temperature rise compared to the minimum temperature of the same season. The minimum temperatures have increased by 0.5 $^0$C for the MAM season. The JJAS seasonal temperatures are the least in warming up only 0.5$^0$C and 0.4$^0$C for the maximum and minimum temperatures respectively. The OND seasons have also warmed up over the years by 1$^0$C, both for the maximum and minimum temperatures. The results indicate that seasonal temperatures, especially the JJAS were decreasing between 1960 to about 1975 and thereafter seem to be rising up to 2012.

The mean temperature in Kenya follows a strong bimodal seasonal pattern. The temperature trends have given clear signal of climate change with the trend being a rise in temperature over land ( Ogallo, 1996;Andressen et al,2008).This is corroborated by the findings of the (RoK, 2012) which indicated that the mean annual temperatures have increased by one degree in Kenya. Since 1960, an average rate of 0.21 $^0$C per decade has been observed. This increase in temperature has been most rapid in MAM where the rate has been 0.29 $^0$ C per decade, and slowest in JJAS 0.19$^0$ C per decade. Recent reports from the IPCC confirm that there is a general warming across Africa in the range of 0.2 $^0$C -0.5 $^0$C per decade (Hulme et al 2001, IPCC (2001). This is also corroborated by the General circulation models which indicated that there would be an increase in the mean annual temperature of 2.5-5$^0$C. (McSweeney, New and Lizcano,2007) also showed that the increase in temperature would be most rapid in MAM season at a rate of 0.29 $^0$ C per decade.

### 4. 4. Effects of climate change on maize Yield in the Basin

### 4.4.1 Maize cultivation trend in the Nzoia Basin

The results of linear regression between area cultivated area under maize production -and time in years showed that the polynomial regression model yielded the equation:

$$Y = -0.4324x^5 + 4307.6x^4 - 2E+07x^3 + 3E+10x^2 - 3E+13x + 1E+16$$

The $R^2$ of 0.7996 suggested that the predictive power of the regression trend was at eighty percent (80%).

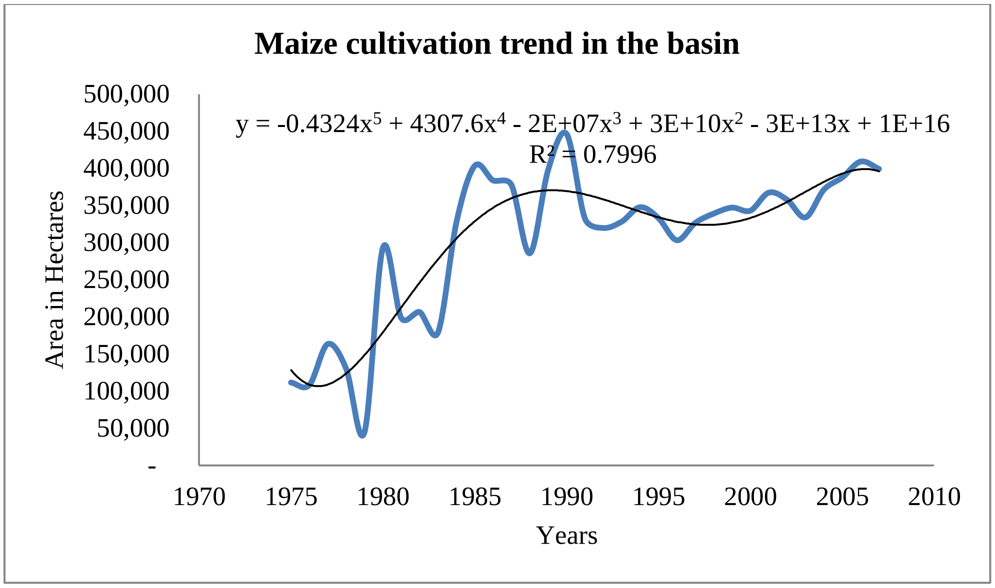


***Fig.4.33. Maize cultivation trend in hectares in the basin***

**Source: (Ministry of Agriculture, 2011)**

Figure 4.33 shows an increase in the area under maize production from 1977 up to about 1984. There was then a sharp decline in the cultivation of maize up to about 1995 when the acreage was very low. From there on, there was a slightly continuous increase in cultivation up to about 2004, from when there was accelerated or very significant increase in the area under maize production.

### 4.4.2 Effects of rainfall variation on Maize yield trend in the Nzoia River Basin

The results from polynomial modelling were as shown in Figure 4.34

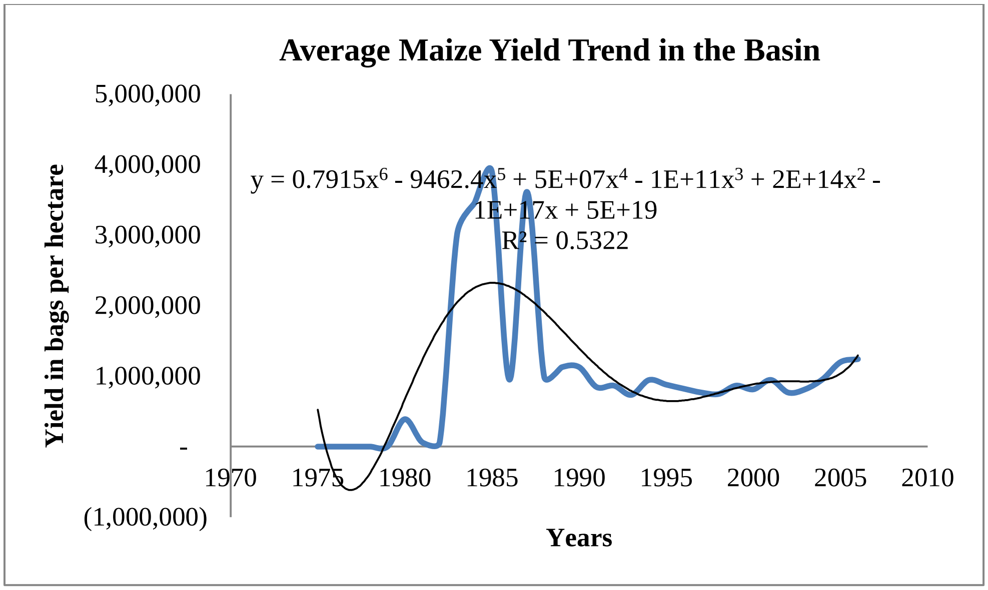


***Fig 4.34: Trend of maize yield over the study period for the Basin.***

**Source: (Ministry of Agriculture, 2011)**

Figure 4.34 yielded the equation:

$$Y = 0.7915x^6 - 9462.4x^5 + 5E{+}07x^4 - 1E{+}11x^3 + 2E{+}14x^2 - 1E{+}17x + 5E{+}19$$

The $R^2$ was 0.5322 suggesting that the predictive power of the regression trend was fair.

Analysis of the annual rainfall in the basin indicated that the average amount of rainfall reduced over the study period as shown in figure 4.8. Table 4.3 showed that 35% of the respondents in Trans Nzoia County, 28% in the Kakamega and 11 % in Busia indicated that the rains had reduced in density. All this led to reduced amount of rainfall density over the study period. Although the rainfall shows a decreasing trend, the average rainfall of about 1257 mm per year was enough to sustain optimal yield according to Table 2.1 showing Agro climatological crop list for western Kenya. This indicates that if the average rainfall of 1257 mm per year received is well distributed throughout the growing period, the farmers would realize optimum yield as indicated in the Table 2.1.

However, a further analysis of the seasonal rainfall showed a lot of variability. For example, in Kitale the MAM season showed a significant decrease in the average amount of rainfall as shown in fig. 4.10.The average amount of JJAS rainfall showed a relative increase as shown in fig. 4.11.The OND rainfall season was increasing as indicated in Figure 4.12. The farmers in the Basin indicated that they had noticed changes in the rainfall pattern as indicated in Table 4.3. 16% of the farmers in Trans Nzoia West, 33% in Kakamega and 57% in Busia indicated that they had noticed a delay in the onset of the rainfall. A delay in the onset of the rains affects the planting calendar of the farmers. Some farmers plant early, others late and others on time depending on their judgement. The farmers who planted their crop in such a time that their crop does not get optimum rainfall requirement at critical stages of development are likely to realize poor yield per unit area.

Analysis of the rainfall figures in the Basin, information from the County Directors of agriculture working in the Basin and the farmers indicated a decrease in the amount of rainfall which affects the planting calendar and the length of growing period. The delay in the onset of the rains affects the planting and harvesting calendar of the farmers. From 1971 to 2011, the onset of rainfall has shifted from February to Mid-March when the majority of farmers plant their maize and in the same way the harvesting period has also shifted as indicated in table 4.4 and figure 4.36 respectively.

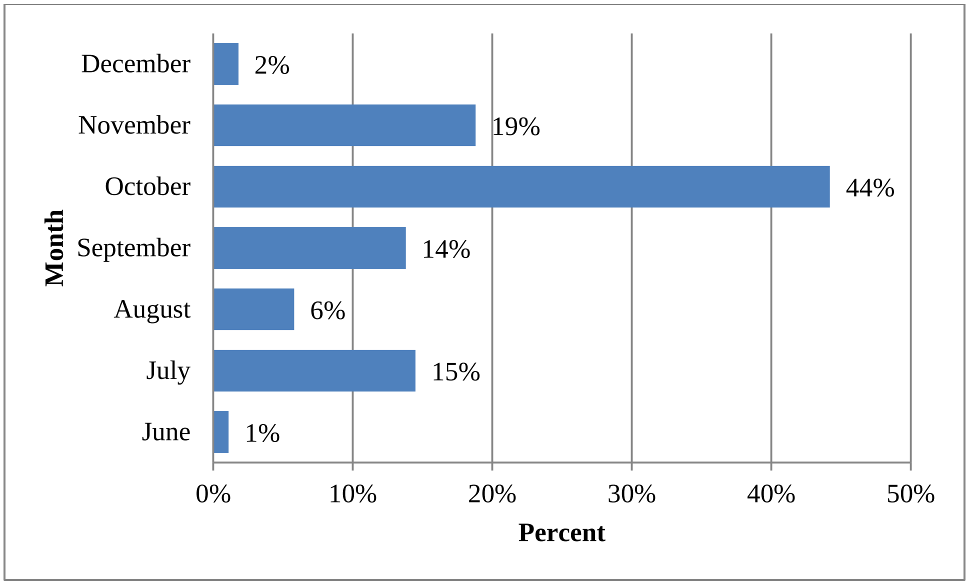


***Figure 4.35: Harvesting dates*** **Source: (Author, 2011)**

However, for farmers who plant early expecting early rains in mid- February up to early March, they are likely to experience poor germination.77% of the farmers in the Kitale County indicated that one of the effects of rainfall variability is poor germination. The agricultural officer indicated that a field with 50% germination would be recommended for reploughing and replanting. Poor germination leads to low maize plant population which does not give optimal yield even when there is optimal maize growing conditions.

The farmers indicated that they plant on the onset of the rains; therefore a delay in the onset of the rains will lead to late planting. There will be reduced yield if the rains cease earlier than the maize growing period or if the rains disappear at critical growing periods. Delayed onset of the rains causes disruption in the timing and planning of the maize growing activities. Some farmers plant early in anticipation of the rains, others wait until the rains have set, yet others, plant much later when the rains are almost over. All this will affect the yield if the crop does not receive well distributed rainfall in the growing period.

From the discussions with the County agricultural officers, they indicated that in 1971, the onset of rainfall was in February and peaked in March. The onset has since shifted to March in the Mid 1980s and further again shifted to Mid-March in 2000s.This was corroborated by the farmers who indicated that they had noticed a shift in the onset and cessation of the rains over the study period. A discussion with the Agricultural officers in the upper basin revealed that though the onset of the rains may delay, but fall consistently once it sets, farmers can still observe their normal harvest if they plant on the onset of the rains.

The erratic pattern of rainfall received in the upper part of the basin poses a challenge to the maize production activities. 18% of the farmers in the upper part of the Basin indicated that they had noticed an unpredictable pattern of rainfall as indicated in Table 4.3. The rains are unpredictable such that they can disappear at critical stages of development of the maize which then affects the yield. Sometimes the rains disappear before germination process is complete leading to uneven germination. Uneven germination leads to a low plant population per unit area which does not give optimal yield even when the growing conditions are optimal as shown in Plate 4.1 below.

***Plate 4.1: Uneven germination of maize crop*** **Source: (Author, 2011)**

Farmers in the basin indicated that they had noticed an unpredictable pattern of rainfall distribution.18% of the farmers in Trans Nzoia West indicated that they had noticed an unpredictable pattern of rainfall. They also indicated that the rains were poorly distributed over the growing season. 10% of the farmers in Kakamega indicated that they had noticed poor rainfall distribution over the growing period as shown in Table 4. 3.

When the germination rate is less than 50%, it's recommended that the field should be ploughed and replanted afresh. This increases the cost of production for the farmer but worse still, the replanting may be done when the rains are almost subsiding and therefore the replanted crop does not enjoy the full benefit of the rainfall season. The rains may, again disappear at critical stage of development still giving poor yields.

The erratic pattern is occasionally accompanied by periods of droughts. At times the dry periods are prolonged causing water stress to the crop. At times the rains at the onset are not enough to sustain germination leading to poor germination of the crop. The rains can disappear altogether leading to wilting of the crop. If the wilting occurs at the vegetative stage of maize development, the crop can survive on the resumption of the rains. Wilting of the crop at the reproductive stage of flowering, tasseling and cobbing leads to low yields per unit area. The crop will not give a good yield leading to low yield per unit area. Table 4.10 shows the effects of rainfall variations on the growing crop of maize.

**Table 4.10: Effect of MAM Rainfall variability on maize production**

| | **Trans Nzoia West** | | **Kakamega** | | **Busia** | |
|---|---|---|---|---|---|---|
| | **Frequency** | **%** | **Frequency** | **%** | **Frequency** | **%** |
| Late Planting | 3 | 3 | 5 | 7 | 3 | 7 |
| Poor Germination | 67 | 77 | 42 | 61 | 1 | 2 |
| Stunted growth | 5 | 6 | 6 | 9 | 24 | 52 |
| Increased pests and diseases | 4 | 5 | 2 | 3 | 0 | 0 |
| Withering | 3 | 3 | 1 | 1 | 0 | 0 |
| Reduced yield | 3 | 3 | 5 | 7 | 17 | 37 |
| Unpredictable yield | 1 | 1 | 0 | 0 | 0 | 0 |
| Good growth | 1 | 1 | 5 | 7 | 0 | 0 |
| Good Germination | 0 | 0 | 3 | 4 | 1 | 2 |
| | **87** | **100** | **69** | **100** | **46** | **100** |

**Source: (Author, 2011)**

The agricultural officer indicated that the Climatic variability is the principle source of fluctuations in global as well as developing country’s food production. Climatic factors such as temperature, precipitation, moisture and pressure affect the development of plants either alone or by interacting with other factors. (Chi-chung, 2004) reported that precipitation and temperatures have opposing effects on yield levels and variability on maize. Global warming is expected to increase difficulty in food production and scarcity (WMO, 2008). Reduced water resource availability would pose greater problems in agriculture and food production.

In Kenya annual rainfall follows a strong bimodal seasonal pattern (RoK). The long rains occur in March to May while the short rains occur between October-December with variations. Results from Figure 4.8 shows a decreasing amount of rainfall received over the years of study and analysis of the seasonal variations revealed different patterns of behaviour in the rainfall trends. In Trans Nzoia West, further analysis revealed a decreasing pattern in the MAM season as shown in Figure.4.10. The decrease in the MAM amounts of rainfall is as a result of delayed onset of rainfall which reduces the average mean of the total amount of rainfall received over the MAM season.

The delayed onset and erratic pattern causes disruption in planting calendar leading to poor timing. Some crops are planted either too early of too late hence leading to poor germination. 77 % of the farmers interviewed in Trans Nzoia indicated that MAM rainfall variations resulted to poor germination as shown in Table 4.7. In addition the erratic pattern causes poor vegetative growth leading to poor crop that does not yield optimally. More so, the erratic pattern of rainfall coupled with rising temperatures as shown in Figure 4.28 result to a conducive environment that can cause high pests and disease incidences at the vegetative stage reducing further the potential yield of the crop.

The JJAS rainfall amount showed a slight increase in the amount of rainfall received over the years of study as shown by Figure 4.11.This could be as a result of the delayed onset of rains, which pushes the peak into the JJAS season. In this way there is no clear demarcation when the MAM rains stop and when the JJAS season starts. This is also indicated in the way the farmers keep planting the maize crop up to early April. 13% of the farmers in the basin planted maize in Early April and 5.8 % in late April as shown in Table 4.4 showing the cross tabulation of the planting dates in the basin.  In addition increase of JJAs rainfall is good for the crop because it coincides with the vegetative and reproductive stage of maize development that require adequate amount of rainfall for optimal yields. However only maize that was planted early in such a way that their development stage coincides with increased rainfall will benefit from the increase in rainfall. When the JJAS season rainfall was analysed, the rainfall amount for Trans Nzoia West was found to be slightly increasing as shown in figure 4.11.This is as result of the changes in the onset of the rains. There is a delay in the onset of the rains pushes the peak into the JJAS season and thus increasing the JJAS rainfall mean. Whenever there is such a pattern, the farmers are most likely to enjoy a normal harvest or increased maize harvest depending on other favourable non climatic conditions.  This is because although the rains delay, once they set they are well distributed through the growing period in amounts that can support optimal performance of maize. But there are years when the rains delay in starting and only fall for a short time that cannot support optimal performance of the maize crop. The rains may disappear at critical stages such as germination, vegetative stage or reproduction stage which greatly affects the yield as also indicated in Table 4.11.

**Table 4.11: Effect of JJAS rainfall variability on maize production**

| | Trans Nzoia West | | Kakamega | | Busia | |
|---|---|---|---|---|---|---|
| | **Frequency** | **%** | **Frequency** | **%** | **Frequency** | **%** |
| Poor flowering | 14 | 26 | 9 | 18 | 0 | 0 |
| Poor Cobbing | 13 | 25 | 20 | 39 | 0 | 0 |
| Increase in Pests and Diseases | 6 | 11 | 8 | 16 | 1 | 6 |
| Stunted growth | 9 | 17 | 4 | 8 | 0 | 0 |
| Premature ripening | 0 | 0 | 0 | 0 | 2 | 11 |
| Reduced Yield | 8 | 15 | 7 | 14 | 13 | 72 |
| Withering | 2 | 4 | 1 | 2 | 1 | 6 |
| Normal yield | 1 | 2 | 2 | 4 | 1 | 6 |
| | 53 | 100 | 51 | 100 | 18 | 100 |

**Source: (Author, 2011)**

In addition, the crop that had uneven germination resulting to a low plant population will do well because of the increased rainfall, however, the yield per unit area will below.

**Table 4.12: Effect of OND rainfall variability on maize production**

| | **Trans Nzoia West** | | **Kakamega** | | **Busia** | |
|---|---|---|---|---|---|---|
| | Frequency | % | Frequency | % | Frequency | % |
| Reduced Yield | 8 | 15 | 6 | 30 | 16 | 89 |
| Normal | 3 | 6 | 1 | 5 | 2 | 11 |
| Increased Yield | 1 | 2 | 0 | 0 | 0 | 0 |
| Maize Rot | 41 | 77 | 13 | 65 | 0 | 0 |
| | **53** | **100** | **20** | **100** | **18** | **100** |

**Source: (Author, 2011)**

Figure 4.12 on the rainfall trend for OND rainfall showed an increasing pattern. This coincides with the harvesting season of maize as shown in Figure 4.36 showing the harvesting dates. 44 % of the farmers in the basin harvest their crop in October and 18% in November. An increase in rainfall during harvest causes rotting due to poor drying and storage before the maize reach the recommended moisture content. This may reduce the quality and quantity of maize affecting the final yield of the crop.

The County Director of Agriculture corroborated the facts that there are variations in the amount of rainfall in the basin. He indicated that there had been a decreasing trend over the years. He indicated that there are occasional periods of droughts. The prolonged dry spells cause water stress which affect the maize crop negatively. At times, the rains at the onset are not enough to sustain uniform germination or the rains disappear soon after germination leading to wilting of the crop. The County Director of Agriculture also indicated that the intermittent falling of rainfall and droughts coupled with increasing temperatures provide a conducive environment for increased pests and diseases incidences as shown in plate 4.2 and 4.3.

***Plate 4.2: Immature maize cob attacked by stock borers due to a spell of drought at the beginning of the reproductive stage*** **(Source: Author 2011)**

***Plate 4.3: Damaged maize stock due to stock borers during dry period of weather***

**Source: (Author, 2011)**

The pests include aphids, stock borers and whiteflies, which attack and affect the optimal performance of the crop reducing the yield. Analysis of rainfall in the lower basin revealed that there is very insignificant variation in the annual rainfall over the study period as shown in Figure 4.17.

Oseri and Masarirambi (2011) indicated that rainfall trend showed significant variations in spatial and temporal patterns of both total annual and planting season which affects crop production. This includes maize which is mostly rainfall dependent, the study also showed that maize production has been on the decline due to the erratic rainfall variability and reduction in the area under maize crop production in response to the erratic rainfall and anticipated drought occurrence. It also confirmed the risk associated with climate variability of maize production depending on the stage of growth and development of the maize crop when the weather aberrations occur.

As far back as 1974, Maize was the most important cereal crop in the District with an average production of 36 bags per hectare, (RoK 1974). However the maize production in Trans Nzoia basin has been declining due to reduced rainfall and also due to the rising cost of inputs and the unavailability of certain farm inputs such as fertilizer at the right time (ROK, 1974).

In the 1980’s especially 1981, the district received more than average rainfall. The average rainfall for that period was normally 1200 mm per year but the total rainfall received was 1709 mm compared to 944.5 mm received in the previous year of 1980.The better rainfall, that was well distributed throughout the season favored good crop production in 1981. Besides the weather, the seasonal crop insurance scheme gave loans to farmers to buy seeds and fertilizer for planting and top dressing which really helped to boost the farmers’ crop production.

The following year, 1982 was characterized by a drop in the maize production due to reduced hectares, attack by army worms, lodging and prolonged rains which lead to rotting of maize while still in the field (RoK, 1982). The drop was also caused by a drop in the number of approvals and financial commitments as a result of strict measures that had been introduced to address defaulters of the seasonal crop credit scheme for the past years. All the defaulters had their accounts closed and therefore they could not access funds to purchase top dressing fertilizer, which really affected the maize production RoK, (1982).

The 1994 was very wet compared to 1993, and as a result, there was good production. An average of 43 bags per hectare was realized. However, a higher yield could not be realized, even with the good rains due to water logging in the lowlands. According to FAOSTAT, 2000, waterlogging at certain critical period of maize development, especially during flowering can reduce maize yield by 50 % or more. This waterlogging could be as a result of increase rainfall during the JJAS season which coincides with the flowering stage of maize. The year 1996 was generally drier than 1995. The rains delayed in coming with the onset of the coming rains around May of the same year. This led to a 14% reduction of land under maize cultivation in 1996.

(Oseri and Masarirambi 2011) indicated that rainfall trend showed significant variations in spatial and temporal patterns of both total annual and planting seasons rainfall which affect crop production including maize which is mostly rainfall dependent. The study also showed that maize production has been on the decline due to erratic rainfall variability and reduction in the area under maize crop production in response to the erratic rainfall and anticipated drought occurrence. It also confirmed the risk associated with climate variability of maize production dependent on the growth stage of the maize crop when the weather aberration occurs.

The timing of the rains is very critical. Although maize appears to be tolerant to water deficit during the vegetative and ripening periods, greatest decrease in grain yield occurs when water deficit occurs during flowering period, including tasselling, silking and pollination, which causes a reduction in grain number per cob. This effect is less pronounced when in the preceding vegetative period, the plant has suffered water deficit. Severe water deficit during the yield formation period may lead to reduced yield due to reduction in grain size. Water deficit during the ripening period has little effect on grain yield.

### 4.4.3 Effects of temperature on Maize yield trends in the Nzoia River Basin

Temperature influences growth and development of plants in such a way that the higher the temperature, the faster the plant grows and matures. However, there is a limit or threshold beyond which the temperature becomes critical or destructive in the growth of the plants. Figure 4.27 shows the long term shift in temperature in the Basin.

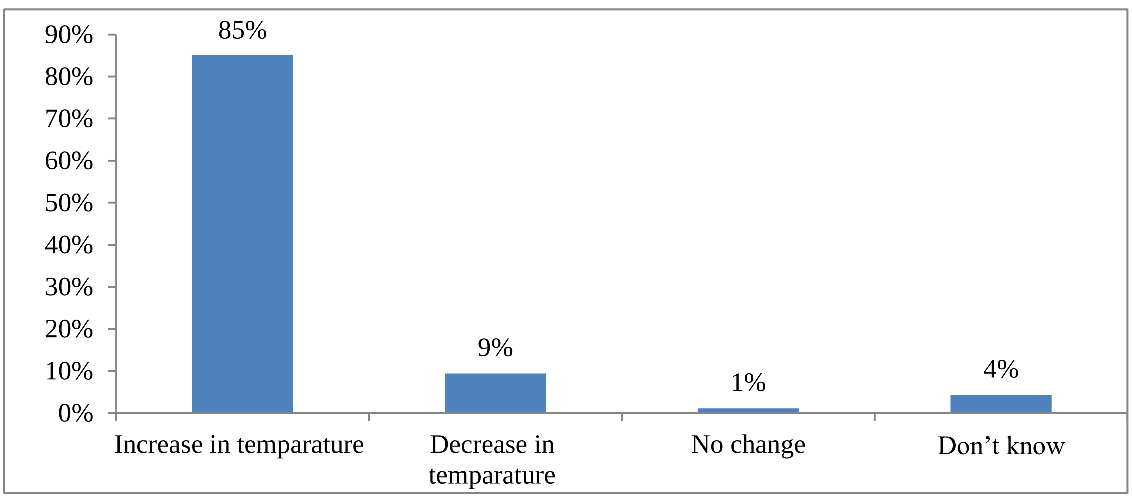


***Fig.4.36:Long term shift in temperatures in the Basin*** **Source: (Author, 2011)**

### 4.4.4 Perception of farmers on temperature changes

Many of the interviewed respondents indicated that they had noticed a shift in temperatures in the farms. Eighty point four percent 80.4% of the respondents indicated that they had noticed the long term shift in temperatures whereas only 19.6% did not agree with the fact that there has been a shift in temperature. In fact eighty five point one percent (85.1 %) indicated that the temperatures had increased over the study period as shown in figure 4.37.

Increase in temperature will also result in increase in atmospheric evaporative demand and hence increased demand and competition for available water for plant growth. When moisture is not limiting, higher temperature and higher carbon dioxide concentration will lead to increased crop yield (Nyabundi & Njoka, 1991). In addition, increase in temperature, increase mineralization of organic matter thus reducing organic matter content of the soils. These leads to reduced soil fertility and poor soil structure for maize production. Increased temperatures will have the impact of increasing post-harvest spoilage of crops. High temperatures coupled with high atmospheric humidity also favours development of animal and crop pests and diseases and which will accentuate the problem of agricultural losses.

Fig 4.24 indicated that temperatures in all the seasons of MAM, JJAS, and OND were increasing. All these seasons are characterized by different agronomic activities on maize. Increasing temperatures will affect these activities. For example MAM is characterized by planting, and the vegetative stage of maize development. Table 4.13shows the effects of increasing MAM temperatures on maize production.

***Table 4.13: Effect of increasing MAM temperatures on maize production***

| | **Trans Nzoia West** | | **Kakamega** | | **Busia** | |
|---|---|---|---|---|---|---|
| | **Frequency** | **%** | **Frequency** | **%** | **Frequency** | **%** |
| Increase in Pest infestation | 4 | 12 | 2 | 11 | 1 | 4 |
| Poor germination | 10 | 29 | 4 | 21 | 3 | 11 |
| Wilting | 7 | 21 | 6 | 32 | 9 | 33 |
| Stunted Growth | 4 | 12 | 1 | 5 | 1 | 4 |
| Fast growth | 4 | 12 | 0 | 0 | 0 | 0 |
| Reduced yield | 1 | 3 | 2 | 11 | 9 | 33 |
| Good germination | 4 | 12 | 4 | 21 | 0 | 0 |
| Normal growth | 0 | 0 | 0 | 0 | 4 | 15 |
| | **34** | **100%** | **19** | **100%** | **27** | **100%** |

**Source: (Author, 2011)**

From Table 4.31, 29% of respondents in the Trans Nzoia West and 21% of respondents in Kakamega County indicated that there was poor maize germination caused by increasing temperatures at the planting stage. Poor germination leads to low plant population per unit area hence reducing the yield per unit area. However 32% of respondents in Kakamega County and 33% of respondents in Busia indicated that there was wilting of the maize crop as a result of increase in temperatures. The wilting arises because of the intermittent dry periods occasioned by erratic rainfall and high temperatures which affect the performance of the crop.

When the JJAS season temperatures were analysed, they were also found to be increasing. This season is characterized by the vegetative and reproductive stage of maize development. Increasing temperatures at the reproductive stage affects the yield greatly. Table 4.14 shows some of the resultant effects of increasing the JJAS temperatures.

**Table 4.14: Effect of increased JJAS temperatures on maize yield**

| | **Trans Nzoia West** | | **Kakamega** | | **Busia** | |
|---|---|---|---|---|---|---|
| | **Frequency** | **%** | **Frequency** | **%** | **Frequency** | **%** |
| Stunted growth | 3 | 11 | 4 | 33 | 0 | 0 |
| Premature Ripening | 2 | 7 | 0 | 0 | 3 | 33 |
| Increase pests and disease incidences | 5 | 19 | 2 | 17 | 0 | 0 |
| Poor flowering and tarselling | 9 | 33 | 5 | 42 | 0 | 0 |
| Poor cobbing | 1 | 4 | 0 | 0 | 0 | 0 |
| Reduced yield | 0 | 0 | 0 | 0 | 3 | 33 |
| Wilting | 5 | 19 | 1 | 8 | 3 | 33 |
| Good flowering | 2 | 7 | 0 | 0 | 0 | 0 |
| | **27** | **100** | **12** | **100** | **9** | **100** |

**Source: (Author, 2011)**

From the table, 33% of respondents in the Kakamega indicated, they observed stunted growth in their crops.  33% of the farmers in Busia indicate premature ripening as a result of increase in the JJAs temperatures. Further, 33% of respondents in Busia also indicated that they noticed wilting of the crop due to increasing JJAS temperatures. Farmers in this region plant short season crops and they plant in early February, therefore, their crops are at the cobbing stage during the JJAS season. From Figure 4.19 showing rainfall in the Busia, the rainfall is very poor and this cause premature ripening leading to small grains and hence poor yield. A combination of reducing rainfall and increasing temperatures causes poor yield.

19% of respondent in Kakamega and 17 % of respondents in the lower indicated that increasing JJAS temperatures cause pests and disease incidences that require pesticides for control. If the pests and diseases are not controlled, they affect the yield of the crop. There are very few farmers who use chemicals to control pests in maize. 33% of the respondents in Trans Nzoia West and 42% of the respondents in the Kakamega indicated that increasing the JJAS temperatures cause poor flowering and tarselling of the maize crop. The high temperatures cause the drying of the silk thus affecting maize pollination and hence reduced number of grains per cob.

Further analysis of the OND temperatures indicated that the temperatures were rising according to Figure 4.26. This is the season when the maize is harvested. 80% of the farmers in the Trans Nzoia West indicated that the increasing temperatures were good for drying maize. But in Busia, 25 % of the respondents indicated that the increased temperatures cause wilting or premature drying of maize. This is because, the farmers plant maze during the OND season. Similarly, 50 % of respondents in Busia indicated that the increased MAM temperatures cause reduction in yield as indicated in Table 4.15.

**Table 4.15 Effect of increasing OND Temperatures on maize production**

| | Trans Nzoia West | | Kakamega | | Busia | |
|---|---|---|---|---|---|---|
| | **Frequency** | **%** | **Frequency** | **%** | **Frequency** | **%** |
| Premature drying | 2 | 20 | 1 | 13 | 1 | 25 |
| Good for maize drying | 8 | 80 | 4 | 50 | 0 | 0 |
| Increase in pests and diseases | 0 | 0 | 1 | 13 | 0 | 0 |
| Reduced yield | 0 | 0 | 1 | 13 | 2 | 50 |
| No effect | 0 | 0 | 1 | 13 | 1 | 25 |
| | **10** | **100** | **8** | **100** | **4** | **100** |

**Source: (Author, 2011)**

In considering the effect of increasing carbon dioxide on maize production, (Nyambundi & Njoka, 1991) indicated that if unchecked, carbon dioxide will double by 2050 and the joint effect of all the greenhouse gases will lead to a rise in global temperature. Carbon dioxide is a primary substrate of photosynthesis and therefore it is expected that increasing $CO_2$ will raise productivity and yield of agricultural plant products. The study also showed that increase in $CO_2$ will also boost growth of weeds, many of which grow more rapidly than crop plants even at current $CO_2$ levels. Increase growth rate of plants will lead to rapid exploitation of soil nutrients and water necessitating application of higher levels of fertilizer.

Considering that most of our African farmers, including those in Kenya, operate at low input levels, crop yields may drop. In addition, in areas with low rainfall the rapid growth of weeds in the early season may utilize much of the soil water so that there is little left for reproductive growth of plants later in the season. The study also showed that plants grown under high $CO_2$ concentration tend to be of low quality, leaves are relatively richer in carbohydrate but poorer in nitrogen. Pests feeding on such plants tend to eat more in order to gain enough nitrogen hence it is expected that there will be increased pest damage with increased atmospheric carbon dioxide concentration.

Other non- climatic factors such as lack of suitable hybrids and lack of machinery such as planters at the planting time also contributed to reduced yield (RoK 1994). In 1995, there was a drop in the hectares of maize because there was a problem of marketing of the previous year's crop. This meant farmer could not afford to plough the expected hectare and also use the optimal farm inputs and all this contributed to a lower yield per unit area in 1995. Most farmers who hired land for growing of commercial maize ,which normally contributed to 30% of the total crop decreased dramatically and all this contributed to reduced yield of maize for that year (RoK,1995).

Some of the land that was previously under maize was left fallow and some other land was put under wheat production. Very low yields were realized compared to the previous year's such as 1995. The low yields were due to a myriad of contributing factors including: late planting where majority of the farmers planted in May and early June, due to the late onset of rains: incidence of stock borers due to late planting: low use of the optimum farm inputs such as application of low dosage of fertilizer due to the high cost of the same; erratic weather conditions such as delayed onset of the rain and also use of non-certified seeds due to financial constraints. All this was attributed to the poor maize marketing that made farmers to incur losses and turn to other enterprises such as wheat farming. This trend has continued over the years of maize production in the Trans Nzoia basin, where the maize production has been fairly stable.

### 4.4.4 Relationship between Maize yield and climate

To examine the nature of relationship between production and the climate within the basin, Pearson's product-moment correlations were generated for both temperatures and rainfall in relation to production. The statistics generated were as shown in Table 4.16 and 4.17.

**(i) Upper basin**

**Table 4.16: Correlation statistics on the variables of maize production in the Upper basin**

| Variable | Coefficient (r) |
|---|---|
| Maize production | 1.00000000 |
| Area Cultivated | 0.47525145 |
| Annual -Rainfall | 0.48877646 |
| Annual - Min Temperature | 0.20784183 |
| Annual- Max Temperature | -0.00858293 |
| MAM - Min Temperature | 0.01365448 |
| JJAS - Min temperature | 0.48927758 |
| OND - Min temperature | -0.06524460 |
| MAM - Max temperature | 0.08840580 |
| JJAS- Max temperature | -0.12061151 |
| OND- max temperature | 0.20983210 |
| MAM- rainfall | 0.07837326 |
| JJAS- rainfall | 0.65870923 |
| OND -rainfall | -0.23001432 |

**Source: (Author, 2011)**

Results from Table 4.16 indicates that JJAS rainfall was substantially correlated to maize production while Area Cultivated, Annual –Rainfall and JJAS - min temperature were moderately correlated. The results of the regression model were as summarized in table 4.17 below and Appendix VI.

**Table 4.17: Regression statistics on the variables of maize production in the Upper basin**

**SUMMARY OUTPUT**

| **Regression Statistics** | |
|---|---|
| Multiple R | 0.939351 |
| R Square | 0.88238 |
| Adjusted R Square | 0.729475 |
| Standard Error | 50531.11 |
| Observations | 24 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 13 | 1.91555E+11 | 14734988293 | 5.770748168 | 0.004415463 |
| Residual | 10 | 25533930548 | 2553393055 | | |
| Total | 23 | 2.17089E+11 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* |
|---|---|---|---|---|---|---|
| Intercept | -45447 | 1178561.283 | -0.038561452 | 0.969999010 | -2671445.218 | 2580551 |
| Area Cultivated | 5.096046 | 1.211814315 | 4.205302689 | 0.001813378 | 2.395955441 | 7.796137 |
| Annual –Rainfall | 179.6849 | 500.758264 | 0.358825714 | 0.727185668 | -936.0740019 | 1295.444 |
| Annual - Min Temperature | -138941 | 158915.1031 | -0.874311093 | 0.402458245 | -493026.1529 | 215143.7 |
| Annual- Max Temperature | 222084.8 | 180538.9914 | 1.230121039 | 0.246804833 | -180181.1293 | 624350.8 |
| MAM - min temperature | -73001.8 | 69854.80912 | -1.045050513 | 0.320603385 | -228648.0183 | 82644.41 |
| JJAS - min temperature | 132982.1 | 78591.5026 | 1.692066862 | 0.121506275 | -42130.70317 | 308094.9 |
| OND - min temperature | -27900.1 | 53451.81853 | -0.521968063 | 0.613057551 | -146998.2157 | 91197.93 |
| MAM - max temperature | -101579 | 35809.5076 | -2.836645026 | 0.017649638 | -181367.4167 | -21790.3 |
| JJAS- max temperature | -45657.8 | 121944.9074 | -0.37441328 | 0.715914124 | -317367.9786 | 226052.4 |
| OND- max temperature | -26132.6 | 56585.92842 | -0.461822065 | 0.654092275 | -152213.9359 | 99948.68 |
| MAM- rainfall | -199.736 | 407.5830799 | -0.490049571 | 0.634671795 | -1107.887609 | 708.4158 |
| JJAS- rainfall | -134.929 | 642.7275458 | -0.209931415 | 0.837936599 | -1567.014919 | 1297.158 |
| OND –rainfall | -91.3482 | 472.5204512 | -0.193321179 | 0.850577568 | -1144.189387 | 961.493 |

**Source: (Author 2011)**

The coefficient of determinant ($R^2$) was 0.882 suggesting that the explanatory power of the independent variables over the dependent variable was 88.2% with the remaining 11.8% of the variation being taken care of by the error term. Based on the ranking of the coefficients provided by Best and Kahn (1998), the results shows that the JJAS rainfall had a significant effect on the maize yield in the upper basin. This is also the season that coincides with the reproductive stage of maize development where any change in the rainfall affects maize yield. This corroborates the findings in section 4.4.2 on the effects of rainfall variability on Maize yield.

The ANOVA statistics suggests that the P-value<0.05 (significance = 0.004415463) implying that the independent variables selected were significant in predicting maize production in the upper basin. From the coefficients table it was established that the most critical independent variables for the variations (P-value<0.05) in the dependent variable were Area Cultivated and MAM - maximum temperatures.

**(ii) MID BASIN**

**Table 4.18: Correlation statistics on the determinants of maize production in the mid basin**

| **Variable** | **Coefficient (r)** |
|---|---|
| Production | 1.000000 |
| Area cultivated | 0.541508 |
| Annual -rainfall | 0.028025 |
| Annual - min temperature | -0.011521 |
| Annual- max temperature | -0.125572 |
| MAM - min temperature | 0.105866 |
| JJAS - min temperature | -0.059945 |
| OND - min temperature | -0.015154 |
| MAM - max temperature | 0.007698 |
| JJAS- max temperature | -0.096252 |
| OND- max temperature | -0.010393 |
| MAM- rainfall | 0.140582 |
| JJAS- rainfall | -0.006874 |
| OND -rainfall | -0.101423 |

**Source: (Author, 2011)**

The results of the regression model were as summarized in Table 4.19 and Appendix VII

**Table 4.19: Regression statistics on the determinants of maize production in the mid basin**

**SUMMARY OUTPUT**

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.935977 |
| R Square | 0.876053 |
| Adjusted R Square | 0.741777 |
| Standard Error | 45994.06 |
| Observations | 26 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 13 | 1.79424E+11 | 13801823426 | 6.524287 | 0.001295 |
| Residual | 12 | 25385439165 | 2115453264 | | |
| Total | 25 | 2.04809E+11 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* |
|---|---|---|---|---|---|---|
| Intercept | 1112888 | 1048968.627 | 1.060935071 | 0.309606 | -1172619 | 3398394 |
| Area cultivated | 1.508577 | 0.370402997 | 4.072798834 | 0.001546 | 0.701538 | 2.315616 |
| Annual –rainfall | -583.457 | 226.4278816 | -2.576791001 | 0.024241 | -1076.8 | -90.1134 |
| Annual - min temperatures | 52178.67 | 151369.3793 | 0.344710889 | 0.736278 | -277627 | 381984.2 |
| Annual- max temperatures | -170768 | 102732.2224 | -1.662260125 | 0.122343 | -394602 | 53066.61 |
| MAM - min temperatures | -31277.2 | 74562.39973 | -0.419477083 | 0.682279 | -193735 | 131180.3 |
| JJAS - min temperatures | -10422.9 | 71942.97277 | -0.144876807 | 0.887213 | -167173 | 146327.4 |
| OND - min temperatures | -40110.3 | 41988.03334 | -0.955280443 | 0.358285 | -131594 | 51373.72 |
| MAM - max temperatures | 43148.39 | 26872.36185 | 1.605679274 | 0.134323 | -15401.5 | 101698.2 |
| JJAS- max temperatures | 99263 | 58796.89696 | 1.688235308 | 0.117161 | -28844.4 | 227370.4 |
| OND- max temperatures | 9653.155 | 32493.50359 | 0.297079539 | 0.771486 | -61144.1 | 80450.42 |
| MAM- rainfall | 874.6515 | 246.3074224 | 3.551056292 | 0.003989 | 337.9937 | 1411.309 |
| JJAS- rainfall | 628.5599 | 217.8444887 | 2.88536042 | 0.013694 | 153.9175 | 1103.202 |
| OND –rainfall | 184.334 | 251.2068648 | 0.733793688 | 0.477167 | -362.999 | 731.6668 |

The coefficient of determinant ($R^2$) was 0.876 suggesting that the explanatory power of the independent variables over the dependent variable was 87.6 percent with the remaining 12.4 percent of the variation being taken care of by the error term. Based on the ranking the coefficients provided by Best and Kahn (1998), this is a “very good” predictive model for maize production in the mid basin.

The ANOVA statistics suggests that the P-value<0.05 (significance = 0.001295) implying that the independent variables selected were significant in predicting maize production in the upper basin. From the coefficients table it was established that the most critical independent variables for the variations (P-value<0.05) in the dependent variable were area cultivated, annual –rainfall mam- rainfall, and JJAS- rainfall. These two seasons coincide with two important stages of maize development. The MAM season is the stage of planting and germination. The results indicated section indicated that poor germination reduces the plant population per unit area hence reduces yield. In addition poor rains in the JJAS season coincides with the reproductive stage of maize development hence poor grain setting and development therefore reduces the yield per unit area

**LOWER BASIN**

**Table 4.20: Correlation statistics on the determinants of maize production in the Lower Basin**

| Variable | Coefficient (r) |
|---|---|
| Production | 1.000000 |
| Area cultivated | 0.071074 |
| Annual -rainfall | 0.428405 |
| Annual - min temperatures | -0.47012 |
| Annual- max temperatures | -0.3573 |
| MAM - min temperatures | -0.25849 |
| JJAS - min temperatures | -0.53623 |
| OND - min temperatures | -0.37974 |
| MAM - max temperatures | -0.43251 |
| JJAS- max temperatures | -0.00228 |
| OND- max temperatures | -0.03338 |
| MAM- rainfall | 0.365579 |
| JJAS- rainfall | 0.112972 |
| OND -rainfall | 0.002257 |

**Source: (Author, 2011)**

It was established that the MAM - max temperature, JJASs - min temperature, annual – rainfall and annual - min temperature were moderately correlated to maize yield in the lower basin while all the other variables had between low and negligible correlation. The results showed that the temperatures was inversely correlated to maize yield in the lower basin suggesting that increases in both minimum and maximum temperatures in the region negatively affected maize production. On the other hand, rainfall was positively correlated implying that an increase in rainfall positively influenced maize yield. The results of the regression model were as summarized in Table 4.21 and Appendix VIII

**Table 4.21: Regression statistics on the determinants of maize production in the lower basin**

**SUMMARY OUTPUT**

| **Regression Statistics** | |
|---|---|
| Multiple R | 0.804461 |
| R Square | 0.647157 |
| Adjusted R Square | 0.188462 |
| Standard Error | 2985.027 |
| Observations | 24 |

**ANOVA**

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 13 | 163427534 | 12571349 | 1.410865 | 0.296498 |
| Residual | 10 | 89103835.8 | 8910384 | | |
| Total | 23 | 252531369 | | | |

| | **Coefficients** | **Standard Error** | **t Stat** | **P-value** | **Lower 95%** | **Upper 95%** |
|---|---|---|---|---|---|---|
| Intercept | 178674.1 | 90762.0928 | 1.968598 | 0.077324 | -23556.4 | 380904.6 |
| Area cultivated | 0.025613 | 0.02047114 | 1.251181 | 0.239347 | -0.02 | 0.071226 |
| Annual –rainfall | -6.63837 | 13.4423889 | -0.49384 | 0.632086 | -36.5899 | 23.31313 |
| Annual - min temperature | -11192.6 | 11233.5456 | -0.99636 | 0.342575 | -36222.5 | 13837.28 |
| Annual- max temperature | -5584.2 | 4187.6104 | -1.33351 | 0.211944 | -14914.8 | 3746.375 |
| MAM - min temperature | 6352.12 | 5931.02728 | 1.070998 | 0.309338 | -6863.03 | 19567.27 |
| JJAS - min temperature | 18.94742 | 4304.65436 | 0.004402 | 0.996575 | -9572.42 | 9610.315 |
| OND - min temperature | -1343.41 | 3488.69185 | -0.38508 | 0.708244 | -9116.7 | 6429.875 |
| MAM - max temperature | -1558.24 | 1869.34409 | -0.83357 | 0.423984 | -5723.4 | 2606.921 |
| JJAS- max temperature | 3344.032 | 2276.54492 | 1.468907 | 0.01726 | -1728.43 | 8416.49 |
| OND- max temperature | 1542.13 | 1894.29549 | 0.814092 | 0.43455 | -2678.62 | 5762.883 |
| MAM- rainfall | 13.16277 | 15.3586096 | 0.857029 | 0.411497 | -21.0583 | 47.38388 |
| JJAS- rainfall | 8.648251 | 23.4406506 | 0.368942 | 0.719862 | -43.5808 | 60.87728 |
| OND –rainfall | 17.50881 | 17.4972302 | 1.000662 | 0.340588 | -21.4775 | 56.49506 |

**Source: (Author, 2011)**

The coefficient of determinant ($R^2$) was 0.647 suggesting that the explanatory power of the independent variables over the dependent variable was 64.7 percent with the remaining 25.3 percent of the variation being taken care of by the error term. Based on the ranking the coefficients provided by Best and Kahn, (1998), this is a “fair” predictive model for maize production in the lower basin. A little caution needs to be exercised when dealing with the model because 25.3 percent of the variations in the production of maize in the lower basin are explained by variables outside the model. Further investigation is therefore necessary to identify the remaining factors responsible for the variation.

The results show that maize production was not only depended on rainfall and temperatures. While the years that had the highest amount of rainfall showed high yields realized per unit area, it is also evident that there were other factors that played a big role in realizing optimum maize yield. The rains should be received at the right time and be well distributed throughout the growing period. If the rains were received late, they gave rise to the pest incidence such as the maize stock borers which eventually reduce the yield of maize. At times the rains come but at the wrong time for example when heavy rains are received at harvesting time, there is much loss due to the rot that occurs in the field.

Whenever there was a very dry period like in 1996, and the rains were delayed, then the yield was very low. However, there are other non-climatic factors that also affect the farmers in the Basin. For example the years that the farmers had the seasonal crop credit scheme running, and all the farmers had access to timely land preparation, seed acquisition and timely and optimal top dressing, they harvested the crop well. But when they did not have all the farm inputs, they planted late, others used non certified seeds which reduced the yields altogether. The results show that while the rainfall and temperature play a key role in maize production, there are other non-climatic factors that need to be addressed for optimal crop production.

## 4.5 Practices and Technologies related to Climate Change adaptation, mitigation and agricultural production among the communities in the Nzoia River Basin

The results in 4.2.1 indicated that the rainfall pattern in the basin showed variability as characterized by the change in rainfall intensity, delay in the onset and ceasation. This is a major threat to food production in the basin. In view of the changing patterns, stakeholders of agriculture in the basin had various responses to these changing patterns of rainfall and its impact on agriculture. The farmers and policy makers interviewed had various ways in which they were responding to these changes in the climatic patterns. The responses from the respondents were summarized in the Table 4.18 below.

*Table 4.22 : Measures to adapt to changing and erratic rainfall patterns*

| | Trans Nzoia West | | Kakamega | | Busia | |
|---|---|---|---|---|---|---|
| | **Frequency** | **%** | **Frequency** | **%** | **Frequency** | **%** |
| Plant on onset of rainfall | 28 | 28 | | 23 | 7 | 23 |
| Diversify to other enterprises | 16 | 15 | 6 | 9 | 3 | 10 |
| Diversify to other crops | 32 | 30 | 21 | 32 | 14 | 47 |
| Plant Early maturing varieties | 22 | 21 | 15 | 23 | 4 | 13 |
| Promote sustainable land management practices | 6 | 6 | 3 | 5 | 2 | 7 |
| Use of pesticides | 1 | 1 | 2 | 3 | 0 | 0 |
| Seek assistance from Ministry of Agriculture | 0 | 0 | 1 | 2 | 0 | 0 |
| Done Nothing | 0 | 0 | 3 | 5 | 0 | 0 |
| **Total** | **105** | **100** | **66** | **100** | **30** | **100** |

**Source: (Author, 2011)**

### 4.5.1 Integrated Farming

The study showed that farmers had diversified their crop enterprises to cope with the changing climate patterns. Many farmers had changed from monoculture to mixed crop enterprises, where they plant maize and other crops such as long rotation crops like fruit trees that are more resilient to erratic rainfall. 47% of the farmers in Busia interviewed indicated that they have diversified their enterprises on the farms to grow other crops as insurance to maize crop failure. This reduced the acrearage under maize production and subsequently reduced the yield of maize from the basin. Planting both long and short rotation crops helps farmers fulfill long and short term needs. Clearly, farmers need also to be trained to use marginal land and temporal gaps through intercropping and agro forestry. Farmers also keep dairy animals and poultry. Some of the land that used to be under maize is now used for production of high yielding grass for making hay.

***Plate 4.4: A Maize farmer practicing integrated farming***

**Source (Author, 2011)**

***Plate 4.5 :The same farmer Farmer also practicing Dairy and fruit Farming***

**Source: (Author,2011)**

***Plate 4.6: Maize Intercropped with Tomatoes, bananas, and kales. He also makes bricks for a living in Kakamega County*** **Source: (Author, 2011)**

### 4.5.2 Planting on the onset of the rains

Planting early following the first effective rainfall of the season ensures even germination and maximum use of available rainfall water. The study established that agricultural extension officers used to advice farmers to plant their maize during the dry season preceding the start of the rains because it was almost certain that the rains would start on the fifteenth day of March of every year. However, due to the changing and unreliable rainfall patterns, farmers, especially those who are financially able, prepare their fields, procure farm inputs early and wait for the onset of rains before they sow their seed. They plant when they are sure the soils are wet enough to sustain germination. They no longer plant during the dry season in anticipation for the start of the rains. However, farmers who wait for rains before they start their land preparations are disadvantaged. From the household interviews, twenty eight per cent (28%) of the farmers recommended planting on the onset of the rains as an adaptation measure to address negative effects arising from erratic rainfall pattern. Farmers across the basin indicated that they had noticed changes in the rainfall pattern as shown in table 4.3 on perception of farmers on observed changes on rainfall pattern in the basin.16% in Trans Nzoia County,33% in Kakamega County and 57% in Busia indicated that they had noticed reduced rainfall trend. 10% in Kakamega County indicated that they had noticed poor distribution and 18% in Trans Nzoia County indicated that they had noticed an unpredictable pattern of rainfall.

Figure 4.8 on Annual rainfall trends of the Nzoia River Basin indicated a reducing trend of rainfall over the study period. The MAM seasonal rainfall trend, when planting occurs also indicated that the rainfall had reduced over the study period in the upper, middle and lower basin as indicated in Figure 4.10, Figure 4.14,and 4.18 respectively and Table 4.2 on Perception of Farmers on trends of rainfall patterns.

Further, there is a general increase in temperature in the basin especially the MAM season temperatures when planting takes place as shown in figure 4.23 and figure 4.26 showing the seasonal temperature variations, and Table 4.7 on Perception of farmers on MAM temperatures.

### 4.5.3: Planting in the Long and short season

Planting both long and short season crops will help farmers fulfill long and short term needs.  Traditionally, farmers only utilize the long rains to grow maize and leave their farms fallow till the next season. There is need for farmers to take advantage of this increase in short season rains and plant short season maize for domestic consumption and sale.

### 4.5.4: Early maturing and Drought tolerant Maize varieties

Twenty one percent 21% of the farmers in Trans Nzoia West and 23% of farmers in Kakamega who were interviewed indicated that they had shifted towards planting early maturing maize varieties. Some farmers were planting both early maturing and long maturing varieties to spread the risk. However, early maturing varieties do not yield as much as late maturing varieties as shown in Table 2.1. Six percent (6%) of the farmers indicated that they plant twice a year to compensate for the low yield from the early maturing varieties. They plant in March and harvest in June –July and plant the second crop in July -August and harvest in November December.

***Plate 4.7: Water stressed maize crop in Trans Nzoia West*** **Source: (Author, 2011)**

Maize crop is grown in climates ranging from temperate to tropic during the period when mean daily temperatures are above 15 $^{0}$C and frost free. Successful cultivation depends on the right choice of varieties so that the length of growing period of the crop matches the length of the growing season and the purpose for which the crop is to be grown. When average daily temperatures are below 20 $^{0}$C, early grain varieties take approximately 80-110 days and medium varieties take 110-140 days to mature. When mean daily temperatures are below 20$^{0}$C, there is an extension in days to maturity of 10-20 days for each 0.5$^{0}$C decrease depending on varieties and at 1.5$^{0}$C maize grain crop takes 200-300 days to mature. With mean daily temperature of 10-15 $^{0}$C the maize mostly grown as forage because of the problem of seed set and grain maturity under cool conditions. The crop is very sensitive to frost, particularly in the seeding stage but it tolerates hot and dry atmospheric conditions as long as sufficient water is available to the plant and temperatures are below 45$^{o}$C.

Climate change has an impact on the maize phenology because temperature changes influences the schedule of maize sowing, flowering and grain filling. Spatially, the sowing date of maize will slightly advance in future due to the warming trend. Phonologically, the early sowing helps to prolong the maturity season of the current early maize cultivar. Figure 4.34 indicated that the planting dates in the basin has shifted and farmers are planting from mid -March up to early April as opposed to early 1980s when they were planting in mid –February.

### 4.5.5 Promotion of sustainable agricultural land use management

Table 4.19 shows measures undertaken by farmers to mitigate the adverse impacts of rising temperatures due to climate change. Promotion of sustainable land management practices will help to address the problem of mineralization and hence improve the soil structure and soil fertility.

***Table 4.23: Measures to mitigate and adapt to the rising temperatures***

| | **Trans Nzoia West** | | **Kakamega** | | **Busia** | |
|---|---|---|---|---|---|---|
| | Frequency | % | Frequency | % | Frequency | % |
| Plant trees around the farm | 2 | 15 | 11 | 73 | 1 | 1 |
| Plant short season varieties | 3 | 23 | 0 | 0 | 0 | 0 |
| Plant cover crops | 0 | 0 | 2 | 13 | 1 | 50 |
| Promote sustainable land management practices | 1 | 8 | 1 | 7 | 0 | 0 |
| Use of pesticides | 6 | 46 | 1 | 7 | 0 | 0 |
| Plant on onset of rain | 1 | 8 | 0 | 0 | 0 | 0 |
| **Total** | **13** | **100** | **15** | **100** | **2** | **100** |

**Source: (Author, 2011)**

From Table 4.19, showing measures to mitigate and adapt to the rising temperatures, fifteen 15% of the farmers in Trans Nzoia and 73 % of the farmers in Kakamega County indicated that they planted trees as a way of mitigating against the high temperatures in the farms. Trees are known to change the micro climate of an area as well as attracting the convectional rainfall. One farmer who had established a thirty acre forest in Trans Nzoia indicated that sometimes he gets rainfall on his farm and the surrounding areas when there is no rain in other parts of the County.

### 4.5.6: Small-scale irrigation along the existing rivers

A few of the farmers, especially those leaving close to the Nzoia River practice growing maize under irrigation using diesel pumps. They mainly target the green maize market which seems to fetch better prices in the market, hence worth the struggle. Some of the farmers said they were willing to grow maize under irrigation but they did not have the requisite infrastructure to do so. They did not have the capacity to set up an irrigation system in their farms however much they understood the potential that existed in using the Nzoia River for irrigation. A few of them preferred to irrigate horticultural crops which seemed to fetch more money in the market in comparison to maize.

Green house farming promotes crop production under controlled conditions. Many farmers have turned to greenhouse farming, especially for high value horticultural crops such as tomatoes other than growing maize.

***Plate 4.8: Greenhouse for high value horticultural crops production***

**Source: (Author, 2011)**

### 4.5.7: Enhancing Household adaptive Capacity

Other measures undertaken by other stakeholders include enhancing the household adaptive capacity of the farmers. From the results, farmers who work closely with extension services providers seemed to be better equipped to cope with climatic changes than those who did not. Seventy two per cent (72%) of the farmers interviewed indicated that they receive information and advice from extension workers whereas twenty eight percent did not get any extension services. The frequency of visitation varied greatly for different farmers as shown in figure 4.38. Most of the farmers, thirty eight point eight per cent (38.8 %) were only visited twice a year for dissemination of agricultural messages.

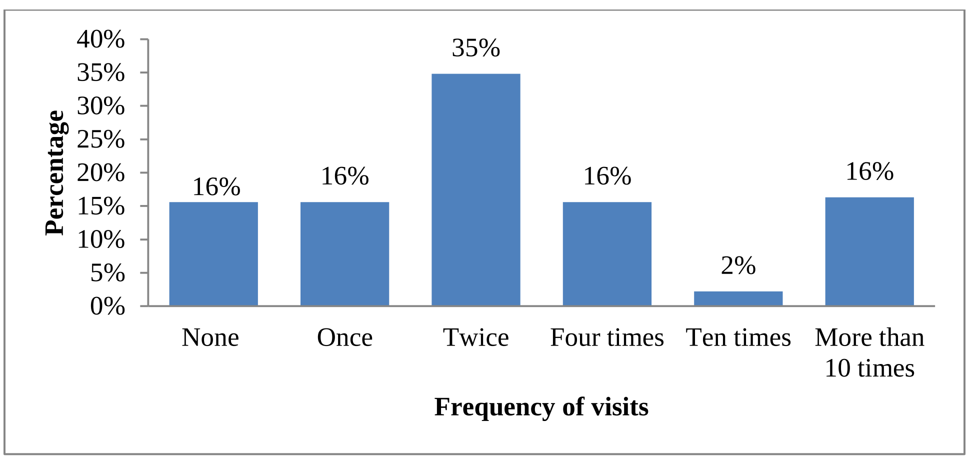


***Fig.4.37: Frequency with which farmers are visited Source*** **Source: (Author, 2011)**

The farmers also indicated that they received agricultural extension messages from various sources but mainly the Government agricultural extension officers and Non-Governmental organizations working in the Basin. From the figure 4.39 below, 71 % per cent of the extension service providers are government agencies whereas twenty two percent (22%) are from NGOs.

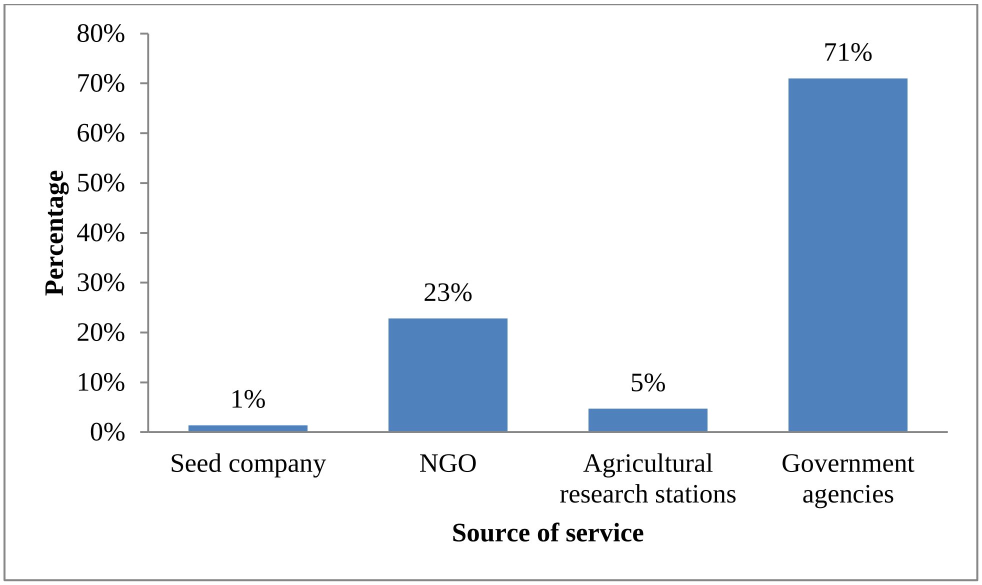


***Fig. 4.38: Extension service providers in Trans Nzoia River Basin Source***

**Source: (Author, 2011)**

Some of the farmers also indicated that they received climate information on rainfall and temperature from the extension service providers. Of this, fifty six percent (56 %) indicated they received climate information from the extension workers whereas 44% percent did not receive climate information from the extension workers, who visited them. The main source of climate information is the media including the radio and daily newspaper as shown in the figure 4.40 below.

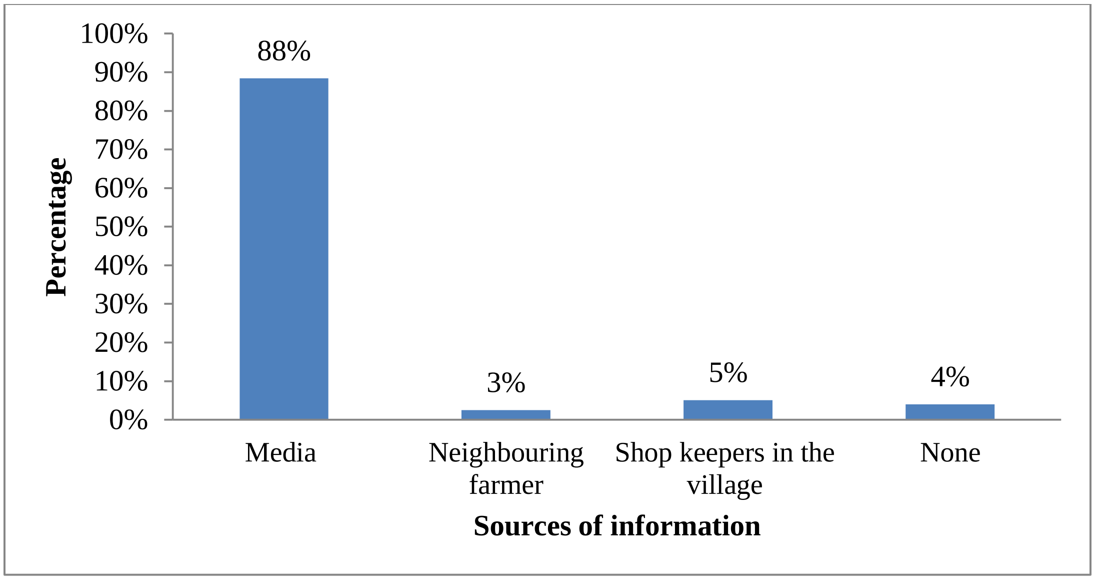


***Fig.4.39: Other sources of climate information*** **Source: (Author, 2011)**

From Figure 4.40 indicates that farmers rely a lot on the media for climate change information especially on the rainfall forecasting. Given that most farmers have access to some form of media, especially the radio, there is need to develop effective programmes tailored towards addressing the climate change issues and use these media effectively to reach out to the farmers.

**4.5.8: Community based weather monitoring**

The community based weather monitoring is practiced in the lower part of the Basin, where monitoring of the lower Nzoia River is key in flood warning. This same weather data can be used for modeling to predict the behavior of climate and its effect on food production.

### 4.5.9: Local Traditional knowledge

The most widely relied upon indicators are the timing, intensity and duration of cold temperatures during the winter season. Timing of fruiting by certain local trees, the water level in streams and ponds, the nesting behavour of birds and insects in rubbish heaps. Some farmers carefully observe the changing pattern of the winds and movement of the clouds, developing specialization in local meteorological patterns. Others speculate on the past cold season, and the relationship between cold winters and good rainfall or the pattern of good bad season per the years. Some of the farmers, who live close to Mt Elgon, indicated that they make their predictions following the cloud cover on Mt. Elgon as an indication on the intensity of the rains. All these local knowledge can be integrated with the current technological advancement in weather monitoring to help the local farmers to be well prepared against the adverse impacts of climate change.

### 4.5.10: Provision of credit facilities and subsidized inputs

Apart from the unreliable rainfall pattern and increasing temperatures in the Basin, one of the challenges that farmers grapple with is the acquisition of the agricultural inputs on time. Sometimes even when the rains comes on time, the farmers do not have ready farm inputs, they therefore still plant late and realize poor yields. There is need therefore, to , develop programmes to help the farmer to be ready in terms of land preparation and acquisition of farm inputs when the rains come, so that the farmers plant early for the maize crop to utilize the rains to the optimum.

### 4.5.11: Weather and crop insurance

The study established that Kilimo Salama Plus insurance which is a product of a partnership between Syngeta, MEA Limited and UAP Insurance insures the full farm investment where in case of droughts or excess rain, the farmer gets compensation. The insurance covers investment in farm inputs and outputs values. The input costs includes labour, costs of seed and crop fertilizer and crop protection costs, whereas the value of harvest includes an estimate of the expected harvest values in terms of Kenya shillings (Syngeta, 2008).

The Kilimo plus insurance protects the farmer against extreme weather events such as droughts and excess rain at the end of the season while the crop is in the field. However, this insurance does not cover river flooding, poor drainage, causing water logging, localised storms, pest and disease, hail storms, frost and poor farm management. The pay-out for this insurance is based on how bad the weather is as measured by the weather station near your farm. The weather station chosen must be near your farm and must have similar weather to your farm. The pay-out is calculated based on the actual amount and distribution of rainfall over the crop season and not necessarily based on the actual visiting of your farm. The compensation is easy and fast because it’s paid through M-Pesa, two weeks after the end of the contract. In addition, personal farming advice is offered through a free helpline and via the short messaging services (SMS). The crops covered under this insurance include maize, beans, sorghum and wheat.

### 4.5.12 Research and Development

Re-invigorating agricultural research and development (R&D) to produce crop varieties that can withstand projected climate variability. Specific agricultural research areas that address climate change need to be undertaken; and creation of functional linkages with development partners for technology enterprise initiatives.

### 4.5.13: Climate modeling and crop modeling

Climate modeling is a means of simulating the processes and interactions within the climate system in order to draw conclusions about the future status and trends of climate based on assumptions about the concentration of greenhouse gases or change in the amount of solar energy.

Climatic variations, continuous increase in population pressure and market infrastructure are driving forces that reduce agricultural productivity. Changes in climatic scenarios are of vital importance for rain fed agriculture as a change in one climatic variable alters other variables which include temperature, precipitation and solar radiation. Associated impact of increasing temperature, changing rainfall pattern and intensity has led to reduced agricultural productivity and yield over the world. There is need to adopt climate modeling and crop modeling as a means of finding the best option and mimic climatic degradation are two key factors under contemplation in agronomic research to enhance crop productivity. Crop simulation models proved to be efficient substitute for agricultural systems under diverse climatic conditions. These models aid in decision making tools and sustainable agriculture.

Crop simulation models consider the complex interactions between weather, soil properties and management factors which influence crop performance. Crop simulation models have been developed over many years in recital with advances in crop physiology, crop ecology, and computing technology. Modeling performance has been envisaged with several opportunities in future including scientific investigation, decision making by crop managers and key contributor in understanding and advancing the genetic regulation of plant performance and plant improvement.

Agricultural system models have a long history in assisting scientists and land managers to understand their systems and the ways in which they can be managed. These models can be used to explore management decisions at the field, farm and enterprise level for landholders facing complex management decisions arising from climatic variations, continuous increase in population pressure and market infrastructure.

## 4.6 Enabling Policy and Legislative Framework

The study established that though the constitution of Kenya, Vision 2030 and EMCA provide a legal and institutional framework and foundation for climate change management, more specific policy and legislative instruments are required to effectively address the potential impacts of climate change on maize and provide appropriate responses.

The results indicated that the Vision 2030 acknowledges the importance of the environment in development. However, it does not adequately recognize the threats and opportunities presented by climate change in Agriculture and more so maize production. Integrating climate change response considerations into Kenya's Development planning process will ensure the threats and opportunities presented by climate change are considered and addressed adequately.

The results indicated that the national environment policy aims to provide a holistic framework to guide the management of the environment and natural resources in Kenya. This will ensure that the linkage between environment and poverty reduction is integrated in all government processes and institutions in order to facilitate and realize sustainable development at all levels in the context of green economy.

The National environment policy recognizes that climate change is a reality and that human activities are largely responsible for increasing concentration of GHG in the earth's atmosphere. The policy proposes two approaches of addressing climate change; mitigation measures aimed at tackling both the causes of climate (GHG) emissions and the adaptations measures to cope with the impacts of climate change. Agriculture production, industrial processing manufacturing, tourism, infrastructure and public health are impacted the most. It is expected that with climate change the frequency and intensity of extreme weather events such as floods and droughts will increase RoK C. However the policy does not explicitly outline the mitigation and adaptation measures to address the effects of climate change in agriculture and more so in maize production.

The RoK, 2010 indicated that Rain-fed agriculture is the second largest contributor to the country's GDP, with tea, coffee and horticulture contributing greatly to the country's foreign exchange earnings. However, given its reliance on weather, agricultural production bears the brunt of climate variability and change. The (RoK, 2010) also recognises that in Kenya, the most vulnerable sectors include agriculture, tourism, infrastructure, health, and natural resources especially biodiversity. The report proposed some interventions in the sector including : Support for community-based adaptation, diversifying rural economies, with the aim of reducing reliance on climate-sensitive agricultural practices; creation of functional linkages with development partners for technology enterprise initiatives; Re-invigorating agricultural research and development to produce crop varieties that can withstand projected climate variability. Specific agricultural research areas that address climate change need to be undertaken; Developing an innovative Insurance Scheme – low premium micro-insurance policy which together with low interest loans will insure farmers against crop failure due to droughts, pests or floods; Enhancing agricultural extension services to train farmers on how to better cope with climate variability and change; Strengthening integrated and environmental friendly pest management systems to cope with increased threats from insects, pathogens, and weeds, and developing proper food storage facilities to cater for surplus harvest while promoting traditional and modern food preservation methods. Another strategy is building or enhancing systems for conveying climate information to rural populations are very important.

The Government and development partners need to provide support to the Kenya Meteorological Department's (KMD's) Early Warning Systems to facilitate the timely dissemination of projected and downscaled weather information to farmers. This will enhance farmers' resilience to the impacts of climate change, e.g. through altering the timing of planting dates to adapt to changing conditions, promoting irrigated agriculture by developing irrigation schemes along river basins, construction of water basins and pans, but also reconfiguring irrigated production systems to use water more efficiently and to accommodate the use of marginal quality water, addressing land degradation by building soil and stone bunds, creating grass strips and contour levelling as well as incorporating trees or hedgerows. These measures will increase rain-water infiltration, reduce run-off during floods, reduce soil erosion, and help trap sediments including dead plant matter, promoting conservation agriculture (CA), whose aim is to achieve sustainable and profitable agriculture and ultimately improve farmers' livelihoods through the application of the three Conservation Agriculture principles: minimal soil disturbance, permanent soil cover and crop rotations.

The Agricultural Sector Development Strategy was another Government's commitment to the farmers and rural people of Kenya. It positioned the agricultural sector as a key driver for delivering the ten (10) per cent annual economic growth rate envisaged under the economic pillar of the Vision 2030. It provided a guide for the public and private sector's effort with regard to the development challenges facing the agricultural sector, (RoK, 2009). As the backbone of our economy, the sector's Vision of "Food Secure and Prosperous Nation" was not only appropriate, but also in tandem with the Vision 2030 of 'A Globally Competitive and Prosperous Nation'. Besides ensuring food security and nutrition for all Kenyans, the sector was also expected to generate income and employment especially in the rural areas.

Less than twenty per cent 20% of Kenya's land mass has high to medium agricultural potential supporting about seventy five per cent 75% of the population. The remaining over eighty per cent (80%) lies in the ASALs, where sustainable rain-fed production of crops is limited by water deficits. This clearly showed that there was pressure on land with agricultural potential and population migration to the ASALs was likely to increase. Moreover, it was an indication that the country is poorly endowed with potential for rain-fed agriculture. This meant that rain-fed agriculture alone could not meet the challenge of achieving food security.

African Governments, regional bodies, development partners, and agricultural and other stakeholders meeting in Maputo in 2003 identified irrigation as a priority area for investment to accelerate agricultural growth. Maputo declaration 2003 recommended 10% of Government expenditure to agriculture sector. Projected budgetary support for the sector currently is only 4%. Clearly, this is not adequate to support the outlined programmes for poverty and hunger reduction. Concentration of resources is required to bridge the enormous budgetary deficit. In view of the foregoing, water resources management and development cannot be viewed in isolation, but as an integral part of the resources of watersheds. Properly managed and developed watersheds can contribute to sustainable flow and availability of water (blue and green in the form of soil moisture, groundwater and surface water). Therefore, managing water resources in an ecologically sustainable manner by taking into consideration proper land use and an integrated development of resources that involves agriculture (livestock, crop, fishery and agro-forestry), natural resources (forest, range, wildlife), environment and human resources is critical.

Food security is a major water resource related issue in southern-Saharan Africa, where about one third of the population is living in drought prone areas, with a growing season that is too short to support reliable rain-fed agricultural production. In the past, African farmers had developed traditional agriculture systems with high levels of resilience not only to climatic variability but also to change in the political and economic conditions. Current growth in food production is only about half of what is accessible to low – income sectors.

The public and decision makers have become aware that responses to climate change are of utmost urgency. They want to know what they can do now. Even without this new pressure, policy makers operate on shorter decision horizons than researchers do. Few think farther ahead than 8 years at most. There is need for the research community to lay out longer-term agendas and needs. Pragmatically, researchers can accommodate this discrepancy by offering short-term messages. That doesn’t mean abandoning longer-term analysis and planning, rather, it means interacting with the public on practical and effective terms. Yet climate is an unprecedented policy challenge and will require public institutions to change the way they do business and at the same time, there is a longer-term need to develop in-depth, rigorously tested research on vulnerability, impacts, and adaptation, including model comparisons and large-scale comparative studies. Especially for that longer-term need, the rigor of vulnerability, impacts, and adaptation research needs sharpening, Not necessarily through the use of quantitative models, but through enhanced data collection, availability, and analysis, and a spectrum of research methods that can continue to address uncertainties.

# CHAPTER FIVE

# DISCUSSION OF RESULTS

## 5.1. Changes in the Climate change patterns in the Nzoia River Basin.

### 5.1.1 Changes in the Rainfall trends in the Nzoia River Basin.

Analysis of the annual rainfall indicated a general decrease of the rainfall pattern over the study period. Analysis of the rainfall in the upper basin indicated that there was a decrease in the amount of rainfall over the MAM season over the years of study. Analysis of the JJAS rainfall showed a slight increase in the amount of rainfall received by 1.4133 mm per annum. However, the OND rainfall amount increased at the rate of 4.05 mm per annum. Therefore, OND was the likely amount of rainfall causing the increase in the annual averages in the basin. However, the slight increase in annual rainfall was because the OND rainfall amount was the lowest amount of rainfall received in the course of the year. Therefore a slight increase in the OND rainfall would not cause significant changes.

The decrease in the amount of rainfall for MAM was as result of the delay on the onset of the rainfall as indicated by 73% of the farmers who indicated that they had observed a decrease in the rainfall pattern as shown in Table 4.2. The onset of the rainfall used to be mid-February but over time it had changed to Mid-March. Sometimes it starts late in March and peak in April thus giving rise to very low MAM rainfall amount but increasing the JJAS rainfall amount. This was also corroborated with the instrumental data from KMD analysed in Fig 4.9 on the rainfall trend in the upper basin. The delay in the onset of the rains lead to reduced cumulative amount of rainfall recorded over the

MAM season. The agricultural experts in the upper basin indicated that they had observed a reduction in the amount of MAM rainfall and attributed it to the delay in the onset of the rains.

Farmers indicated that they had observed a light density of the MAM rainfall season which further contributes to the reduced amount of rainfall recorded. This is because the delay in the rainfall season pushes the peak of the long rains further into April as opposed to the peak of the rains being in March which further reduces the cumulative amount of rainfall received over the MAM season and also increases the amount of rainfall received in the JJAS rainfall season.

The farmers indicated that there was a delay in the onset of the rains. The delay of onset of the rainfall and the unpredictable pattern of rainfall disrupts the farming calendar of activities of the farmers. It also affects the kind of maize varieties the farmers may want to plant. If there is a delay in the onset of the rainfall, the growing season becomes short and therefore the farmer needs to be advised to plant short season varieties instead of the long maturing varieties to take advantage of the short rainfall season occasioned by delayed onset of the rains.

This calls for a closer collaboration between the farmers, agricultural extension staff and the forecasting department of the Meteorological department. Farmers need to use the agro-climatological information to make informed decisions on when to plant their crop and what type of crop and variety to plant depending on the expected amount of rainfall as indicated in Table 2.1 showing the Agro climatological crop list for western Kenya.

Analysis of the JJAS rainfall season in the upper part of the basin indicated that rainfall was increasing at a rate of 1.41 mm per annum over the study period. The increase of the JJAS rainfall season could be as a result of the delay in the onset of the rains in Mid-March which causes the rainfall to extend and peak into JJAS season causing a slight increase in the amount of rainfall received. The increase of the amount of rainfall in JJAS rainfall has makes some of the farmers to plant twice a year. With good timing and good choice of a medium yielding variety, some of the farmers take advantage of this increase in JJAS rainfall amount to grow and harvest maize twice a year in the upper and middle basin.

The JJAS is usually the season when maize is in the vegetative and reproductive stage. Therefore, increase in the amount of rainfall is good for optimum maize production when other production factors are supplied at optimum level. However, 18% of the farmers in the upper Basin indicated that they had observed an erratic pattern of rainfall in the JJAS rainfall season as indicated in Table 4.3. Poor rainfall at the reproductive stage of flowering and tasseling reduces the yield. Water stress caused by poor rainfall causes drying of the silk thus causing poor fertilization. Poor fertilization causes by poor grain formation and setting. If the crop receives consistent rainfall at this stage, the poorly formed grains will grow to normal maturity. However the yield per unit will not be optimum due to the few grains formed per cob. However, if the crop does not receive rains, the poorly formed grains will be small in size hence resulting to low yield per unit area. Although the rains have been observed to increase over the JJAS season, they will only benefit the crop if they are received consistently and sufficiently over the growing period and more critically at the reproductive stage of flowering, tasseling and cobbing for the farmers to realize an optimum yield.

Analysis of the OND rainfall season indicated that the rainfall for the upper part of the basin was increasing at the rate of 4.05 mm per annum as shown in Fig. 4. 12. This is the amount of rainfall influencing the average annual increase of rainfall in the upper basin. This is also the season when most farmers harvest their crop. The increased rainfall coincides with the physiologically mature maize which is normally either still in the field or stacked ready for harvesting. Increasing rainfall causes losses due to rotting as a result of increased moisture content in the maize and also high temperatures typical of the OND season as shown from the results.

Analysis of the rainfall in the Middle basin showed a different behavour to the rainfall pattern in the upper basin. Analysis indicated that the average rainfall was decreasing at a rate of 2.87 mm per annum over the middle Basin. The analysis of MAM season indicated a decreasing pattern of 0.6 mm per annum as shown in Figure 4.15. This increasing pattern was negligible. This average amount of rainfall was within the average amount required to support a good crop as per the table 2.1 on the crop List for Western Kenya was. However the challenge was how the rainfall was not well distributed over the growing period. JJAs analysis also indicated a decreasing pattern of rainfall at the rate of 0.21mm per annum. The OND rainfall for Kakamega recorded over the years was decreasing over the study period as shown in Figure 4.16.

Analysis of the rainfall in the Lower Basin indicated that the annual rainfall trend for the lower basin was low over the study period. For the, Lower Basin the MAM rainfall season showed a significant decrease in rainfall amounts received over the study period. The rainfall was decreasing at the rate of 2.95 mm per annum. However the JJAS rainfall season showed a relative increase over the study period at the rate of 2.03 mm per annum as shown in Figure 4.19. OND for the Lower Basin also showed an increase in amount of rainfall over the study period as shown in figure 4.20. OND rainfall was increasing at a rate of 3.16 mm per annum.

Analysis of the farmer’s perception indicated that 13% of the farmers in the Lower basin indicated that the rainfall had reduced over the study period. Only 5% of the farmers interviewed indicated that they had noticed changes in the onset of the rains as shown in Table 4.2. 57% indicated that there was a delay in the onset of the rains. The delay in the onset of MAM rainfall season causes an extension of the rains into the JJAS rainfall season thus causing the rainfall to increase slightly. Table 4.4 showing the planting dates indicated that most of the farmers plant their crops in early March and Mid-March which is also the onset of the rains. Due to the average rainfall amount received of about 800 mm, the Medium maize Varieties are commonly grown in the lower part of the Basin as indicated by Table 2.1 and Fig 4.21.

### 5.1.2 Discussions on Temperature Trends in Nzoia River Basin

The results of the study indicated that the temperature trends of the Basin were decreasing from 1960 to 1979; thereafter the temperatures started increasing as indicated in Figure 4.24 and 4.25 respectively. The seasonal temperatures of MAM, JJAS and OND also depicted the same trend as shown in Figure 4.26.

Analysis of the upper Basin indicated that the temperatures were increasing at a rate of 0.0184 $^0$C for Minimum temperatures, whereas 0.033 $^0$C for Maximum temperatures. The Middle Basin also recorded an increase in temperatures. The Minimum temperatures increased at the rate of 0.037 $^0$C annually as indicated in Figure 4.29 and 4.30 respectively.

The Minimum temperatures in the Lower Basin also increased by 0.022 0C per annum whereas the Maximum temperatures increased by 0.01 $^0$C temperatures. The minimum temperatures for the basin were 17$^0$C while the Maximum temperatures were 29.7 $^0$C. Whereas the minimum and maximum temperatures of the lower basin were increasing, as shown in Figure 4.31 and 4.32, the annual rainfall amounts for the same lower basin were decreasing at the rate of 2.95 mm per annum. The decrease is more prevalent in the MAM rainfall season, which was also the planting season. From Table 4.4 on planting dates, the farmers in the Lower basin plant between early March and Mid- March which is the end of the MAM season.

The average rainfall of the Lower Basin was also about 800 mm per annum. The results show that there are high temperatures 29.7 $^0$C for maximum, with low rainfall and a very short window within which the rainfall is received and within which the farmers must plant their crop.

The JJAS rainfalls have an average of 500 mm. Although the rainfall trend shows an increasing trend, the average amount of rainfall were very low. However the average temperatures were about 26.5 $^0$C and they have also recorded the highest rate of increase over the study period. This therefore means that the maize planted in March will have to grow through a low rainfall and warmer than normal temperature conditions. The maize variety grown must be one that can grow fast and also tolerate the low moisture and high temperature growing period.

Analysis of the OND minimum and maximum temperatures were found to be increasing over the study period. OND also recorded the lowest rainfall amount of about 400 mm per annum and average temperatures of about 17.32$^0$C and 29.75 $^0$C for Minimum and maximum temperatures respectively as shown in Table 4.5 and 4.6 respectively. Though Maize is known to be drought tolerant, this condition cannot support optimal growing of maize. The increase of temperatures over the basin was corroborated by the farmers when 86% of those interviewed indicated that they had noticed an increase in temperature.

This finding s of the study corroborates the findings of Ogallo, 1996, Andressen et all, 2008 indicated that the temperature trends had given clear signals of climate change with the trend being a rise in temperature over land. In addition, it was corroborated by the findings of (RoK, 2012), which indicated that the mean annual temperatures had increased by one degree in Kenya. The findings also indicated that the increase in temperature had been most rapid in MAM where the rate had been 0.29$^0$C per decade and slowest in JJAS where the rate had been 0.19 $^0$C per decade.

Hulme et al, 2001 and IPCC, 2001 indicated that there had been a general warming across Africa in the average of $0.2^0$C – 0.5 $^0$C per decade. This was also corroborated by the general circulation models which indicated that there would be an increase in the mean annual temperatures of 2.5-5 $^0$C (Sweeney, New and Liz can, 2007) also showed that the increase in temperature would be most rapid in MAM season at a rate of $0.29^0$C per decade.

The rapid increase of MAM temperatures and reduced amount of rainfall over MAM rainfall season and the delay in the onset of the rainfall requires farmers to adjust their planting calendars to dates that will help them to utilize the available rainfall. There is need to develop drought tolerant and early maturing varieties that can withstand the increased temperatures and reduced rainfall over the growing period. There is also need for a closer collaboration with the relevant government agencies including KMS and the Ministry of Agriculture to provide information on the rainfall predictions and provide early warning to help farmers' preparedness of any upcoming season and help them to adjust accordingly.

The results indicated 71% of extension service providers are government agencies and also 90 % of farmers get information from the media. These tools should be employed to help farmer's preparedness in addressing the changes in climate by having them disseminate information on the climate predictions and appropriate messages such as the kind of maize varieties to plant and when to plant.

### 5.2 Effects of changes in rainfall pattern on Maize Yield

The results showed that although the rainfall trend for the Basin was reducing, average rainfall was 1257 mm per annum. According to table 2.1 showing the Crop List for Western Kenya, this amount of rainfall could sustain most of the medium varieties of maize if the rainfall is received in a consistent manner and well distributed over the growing period and when other growing conditions are optimal. However, the results have shown a lot of seasonal variations where there was delay on the onset of the MAM rainfall which causes the delay in the planting of maize by farmers. Over time, the planting season has moved from Mid-February to Early march and at the time of the study most farmers were planting in Mid-March. Some were even planting by early April depending on the onset of the rainfall season especially in the upper and middle basin. Fifteen percent (15% and Fifteen percent (19%) of the farmers in the upper and middle Basin respectively indicated they planted their crop in early April. This was clearly demonstrated by Table 4.4 showing the planting dates and figure 4.36 showing the harvesting dates. The delayed onset of the rains affects the planting calendar of the farmers.

The results also showed the decreasing amount of rainfall over the study period. The decrease in amount of rainfall for MAM caused by the late onset shortens the growing period for maize. The Upper basin is suitable for growing the late maturing varieties, however over time the decrease in the amount of rainfall over the growing period has caused farmers to resort to growing short season and medium varieties. The medium and short season varieties are not as high yielding as the late maturing varieties as indicated in Table 2.1.This coupled with the erratic manner in which the reduced rainfall is received causes poor germination hence reducing the plant population per unit area and reduces yield of maize per unit area in the Basin. Discussions with the Agricultural officer indicated that a field with 50% germination should be reploughed and replanted afresh. This is an increased cost to the farmer and also risky because the replanted crop may not receive enough and consistent rainfall to produce optimal yield. The agricultural experts also indicated that even though the rainfall may delay, the farmers could still harvest optimal yield, if the rainfall is received consistently over the growing period of maize.

Further, the experts indicated that variations in rainfall at critical stages of development affect maize growing. Maize crop that experiences water stress at the vegetative state may recover and yield optimally once the maize receives rainfall and other growing conditions are optimum. However, water stress at the reproductive stage affects the optimal yield of maize. This calls for farmers to be well prepared to plant on the onset of the rains to ensure the crop utilizes the available rainfall for maize growing. There is need for accurate prediction of when the rains will be expected so that farmers are advised on when to plant.

### 5.3 Effect of changes in Temperature on Maize yield

Results from section indicated that the temperatures in the Basin have increased over time. The increase in temperatures causes increased atmospheric evaporation demand and competition for available water for the plant. The results also indicated that these temperatures have been increasing in the highest in the MAM season. This is also the sowing season for maize. Decreasing rainfall as discussed in section 5.3, and increasing temperatures cause poor germination and wilting of the crop due to water stress.

The JJAS temperatures were also found to increasing as shown in Fig 4.26. The JJAS season is characterized by the vegetative and reproductive stage of maize development. Increasing temperatures cause wilting and stunted growth of the maize crop hence affecting production. The crop can survive and produce normally if wilting occurs at the vegetative stage and the rains resume before the crop has not reached the wilting point.

The reproductive stage of maize development, especially in the upper part of the basin occurs in the JJAS season. Increasing temperatures as observed in Fig 4. 26 cause poor flowering and tasseling and hence poor cobbing. Reduced rainfall further reduces the grain size of the maize causing further reduction of the maize yield. The erratic rainfall and increase in temperatures causes favourable conditions for pests and disease occurrence. The maize stock borers and aphids are known to attack maize in such growing conditions as shown in Plate 4.2 and 4.3.

Harvesting maize is carried out in the OND season. This occurs mainly in the upper basin and middle part of the basin where most farmers harvest their crop in the OND season. An increase in temperature is known to promote maize drying and reduce spoilage due to rotting occasioned by increased rainfall. However analysis of the OND rainfall season for the upper Basin indicated an increase in the amount of rainfall as shown by fig. 4.12. This increase in temperature and increase in rainfall causes the physiologically mature maize in the farms to rot. These increases the post-harvest losses due to the high moisture contend in the harvested maize and high temperature causing condusive environment for fungal growth. With poor sunlight, the maize may not dry to the required moisture content for storage leading to further postharvest losses and reduction in the quality of maize.

## 5.4 Practices and technologies adopted to mitigate and adapt to changes in climate and their effect on maize Yield

The goal of adaptation is to develop flexible and resilient societies and economies that have the capacity to address both challenges and opportunities presented by the changing climatic conditions. Resource poor farmers and communities use a variety of coping and adaptive mechanisms to ensure food security and suitable livelihoods in the face of climate change and variability (Pulwarty et al, (http:www.nap.edu/catalog/12545.html).

### 5.4.1 Integrated Farming

Increasing agricultural biodiversity has proved to be a key livelihood strategy for coping with changing and more challenging environmental conditions in other drought prone parts of Nzoia River Basin**.** This finding corroborates the findings of other studies which proposed diversification of the crop enterprises as a way of coping with climatic changes. Wang et al., 2011 and Oseri and Masarirambi, 2011 indicated that diversification from traditional maize crops to other types of crops such as millet, sorghum, which can withstand drought and higher temperatures can help farmers to cope with the changing climatic patterns. The respondents across the Basin indicated that they had diversified their crop enterprises. 30% in the upper Basin, 32% in the Middle Basin and 47% in the

Lower Basin indicated that they had diversified to other crop enterprises as an a way of reducing the risks of maize crop failure. They no longer grow maize alone but have ventured into other enterprises on their farms as indicated in Plates 4.4, 4.5 and 4.6. They plant both short season crops such as kales and long season crops like fruit trees on their farms.

### 5.4.2 Plant on the onset of the rains

The results indicated that there are changes in the rainfall and temperature patterns, as indicated the decreasing annual and variation seasonal rainfall pattern and increasing temperatures changes. When the farmers were interviewed on their perception of the changes in rainfall and temperature, they indicated that there were changes as indicated by table 4.3 on perception on rainfall changes and table 4.7, 4.8 and 4.9 on temperature changes in the Basin. Table 4.4 also indicated different planting dates due to different times when the rains are received. Due to variations in the on the onset of the rains, farmers plant their crops on the onset of the rains to ensure that the crop utilizes all the available rainfall received within the given season for optimum maize growth. In addition Wang et al., 2011 and Oseri and Masarirambi, 2011 proposed that changing the sowing schedules in response to future climate such as shifting to an earlier sowing date may alleviate the negative effect of increasing temperature.

Maize is an efficient user of water in terms of total dry matter production among the cereals. For maximum production, medium maturity grain crops requires between 500-800 mm of water depending on climate. Maize is relatively tolerant to water deficit during the vegetative and ripening periods. Greatest decrease in grain yields is caused by water deficit during the flowering period including tasselling, silking and pollination, mainly due to reduction in the number of grains per cob as discussed in section 4.3. This effect is less pronounced when in the preceding vegetative period, the plant has suffered water deficit. Severe water deficit during flowering period, particularly at the silking and pollination stage may result to little or no grain yield due to drying of silk. Water deficit during the yield formation may lead to reduced yield due to reduction in grain size. Water deficit during the ripening period has little effect on the grain yield. The table 2.1 shows the Agro climatological crop list for Western Province showing the climatic requirement of growing different varieties of maize in the Basin.

Maize flourishes on well drained soils, therefore, waterlogging should be avoided particularly during flowering and yield formation period. Waterlogging during flowering can reduce grain yield by 50% or more. When rainfall is low and irrigation water supply is restricted, irrigation scheduling should be based on avoiding water deficit during flowering period, followed by yield formation period.

Chi-Chung et al., 2011 indicated that climate variability affects maize yield and various crop processes and activities of maize production. The study showed that the risk associated with climate variability of maize production in general depended mainly on the growth stage of the maize crop, when the weather aberration occurs. However other factors such as poor accessibility to inputs partly due to increased prices may have also contributed to decline in maize yield. It is therefore important for the farmer to plan in such a way that the maize seed is sown on the onset of the rains so that the crop can utilize the available amount of rainfall.

### 5.4.3 Plant early maturing and drought tolerant crops

Temperatures influence growth and development of plants. The higher the temperature, the faster plants grow and mature. High temperatures can however result in increase in atmospheric evaporation demand and result to high rate of evaporation and can limit dry land farming especially in the lower part of the basin. Changing the maize variety to plant drought tolerant or early maturing varieties is one way of addressing the adverse impacts of climate change as indicated by Oseri and Masarirambi, 2011.However this must be accompanied by other strategies such as provision of timely and accurate information on the seasonal weather prediction

### 5.4.4 Promotion of sustainable agricultural land use management

These are improved technologies and practices that mitigate land degradation and greenhouse gas emissions and facilitate households to adapt to climate change. They include the use of improved crop varieties, crop cover and green manure, crop rotation, intercropping, mulching and conservation agriculture. Tree felling both for domestic and commercial purposes is widespread in the Basin. However, there are efforts targeted at improving the state of natural resources, particularly forests which include orientation training, exposure visits, workshops and meetings to promote attitude and behavior change. Support for woodlot and tree nurseries establishment and restoration of degraded land as well as controlled grazing and browsing is encouraged to promote natural forest regeneration**.** Promotion of agro forestry, ground cover to enhance soil fertility and conservation agriculture to promote minimum tillage is also encouraged. The extension officers use schools to promote planting of more trees through such projects as Greening schools. The Ministry of Agriculture gazetted farm forestry rules to promote and maintain farm forest cover of at least ten percent (10%) of every farm holding. This will preserve and sustain the environment and help to reduce the adverse impacts of climate change.

### 5.4.5 Small scale irrigation along existing rivers

The need for optimized water use efficiency by improving irrigation facilities and bringing more agricultural land under irrigation to maize production and introducing water saving techniques was also proposed by Oseri and Masarirambi, 2011. The changes in dryness and length of grain filling are the two main reasons why the future maize yield may decline. Therefore potential adaptation can be achieved by improving irrigation efficiency.

### 5.4.6 Enhancing Household adaptive Capacity

The results indicate that farmers rely a lot on the media for climate change information especially on the rainfall forecasting. Given that most farmers have access to some form of media, especially the radio, there is need to develop effective programmes tailored towards addressing the climate change issues and use these media effectively to reach out to the farmers. There is need, therefore for building the capacity of farmers in the basin by establishing a closer working relationship with extension service providers. There is also need to build the capacity of the farmers in other areas such as livestock keeping, marketing development; grazing management; production of small grains (sorghum and millet); conservation farming; environmental education; community based seed banking; entreupreurship development (targeting especially women); postharvest storage and processing development ;sustainable use of wetlands and social networks (safety nets ) to help communities to be well equipped for against climate change. Such enterprises act as safety nets for the farmers.

### 5.4.7 Community based weather monitoring

There is need to provide uniformly distributed whether stations in the basin to give more accurate weather updates. To understand changes in local weather patterns, simple weather stations could be established, preferably in local secondary schools. This will provide information on daily minimum and maximum temperature, rainfall and humidity. The data will help the community understand how local weather patterns are changing over time. This information can then be used to model the climate patterns and make predictions that are more focused and locally relevant this same weather data can be used to model and predict the behavior of climate and its effect on food production. In a few years, communities will be able to draw concrete conclusions regarding the changing climate. At the national level, there is need to allocate adequate resources to the Kenya Meteorological Department to procure latest equipment and build capacity for climate data collection, storage, analysis and forecast.

### 5.4.8 Provision of credit facilities and subsidized inputs

There have been efforts by the Government to help the farmers to access agricultural credit from facilities such as the Agricultural Finance Corporation (AFC) and other commercial banks. The Ministry of Agriculture through the Kilimo Biashara initiative disbursed money to the commercial banks including Equity Bank, Cooperative Bank, Family Finance and Kenya Women Finance Trust Bank which was released to farmers.

Other initiatives by the Ministry included the distribution of seeds to the small scale farmers through the National Accelerated Agricultural Input Access programs (NAAIAP) RoK, 2013. Such initiatives help the farmers to be well equipped and access farm inputs and plant on the onset of the rains.

### 5.4.9Weather and crop insurance

Crop insurance is purchased by agricultural producers, including farmers, ranchers, and others to protect themselves against either the loss of their crops due to natural disasters, such as hail, drought, and floods, or the loss of revenue due to decline in the prices of agricultural commodities. Providing appropriate crop insurance coverage to maize farmers helps to reduce the risks associated with reduced maize production and yield losses caused by climate variability. AIC, 2008 indicates that crop insurance does not only stabilize the farm incomes but also helps the farmers to initiate production activities after a bad agricultural year. It cushions the shock of crop losses by providing farmers with a minimum amount of protection (Rachu and Chand, 2008). However providers of weather insurance products must know the kind of climatic conditions that impact crop yields. From these conditions, weather indices can be defined. Evidently, these conditions will vary across crops, crop varieties soil types and management practices.

Crop insurance also helps to facilitate adoption of improved technologies, encourages higher investments resulting in higher agricultural production. Crop credit insurance also reduces the risk of becoming defaulters of institutional credit. The reimbursement of indemnities in the case of crop failure enables the farmers to repay his debts and thus, his credit line with the formal financial institution is maintained intact.

There is need of designing and implementing a crop insurance programme that can protect vulnerable small and marginalized farmers from hardships arising from weather aberrations. This will bring in stability in the farm incomes and increase the farmer production (Bhende, 2002). Insured household are known to invest more on agriculture inputs leading to higher outputs and income per unit area. The risk bearing capacity of an average farmer in the semi-arid tropics is very limited. A wealthy farmer is able to spread risk over time and space in several ways. He can use stored grains or saving during bad years, he can diversify his crop production across different plots; he can opt for higher average yield or profits over a period of time even if it is achieved at the cost of high annual variability on output (Hazell, 1992).

Insurance companies must ensure that the set of indices they use captures the site specific crop vulnerability situations of their clients. Establishing the details of this vulnerabilities situation requires collection of a host of site specific factors, including most important data about crop yields as well as detailed description of crop varieties. Kilimo Salama Plus insurance is a product of a partnership between Syngeta, MEA Limited and UAP Insurance. The insurance insures the full farm investment where in case of droughts or excess rain, the farmer gets compensation. The insurance covers investment in farm inputs and outputs values (Syngeta, 2008).

The Kilimo plus insurance protects the farmer against extreme weather events such as droughts and excess rain at the end of the season while the crop is in the field. However, this insurance does not cover river flooding, poor drainage, causing water logging, localised storms, pest and disease, hail storms, frost and poor farm management. The pay-out for this insurance is based on how bad the weather is as measured by the weather station near your farm. The weather station chosen must be near your farm and must have similar weather to your farm. The pay-out is calculated based on the actual amount and distribution of rainfall over the crop season and not necessarily based on the actual visiting of your farm. The compensation is easy and fast because it’s paid through M-Pesa, two weeks after the end of the contract. In addition, personal farming advice is offered through a free helpline and via the short messaging services (SMS). The crops covered under this insurance include maize, beans, sorghum and wheat. The farmers in the Basin will therefore require an appropriate insurance scheme designed to protect them against the loss or reduction of maize crop yield due to climate change.

### 5.4.10 Local Traditional knowledge

Farmers use knowledge of weather systems such as rainfall, thunderstorms, windstorms and sunshine to prepare for future weather. Elderly male farmers formulate hypothesis about seasonal rainfall by observing natural phenomena, such as the appearance of certain birds, mating of certain animals and flowering of certain plants, while cultural and ritual specialist draw predictions from divinations, vision or dreams (Ron coli et al 2001). This provides a basis for development of more effective adaptation strategies that are cost effective, participatory and sustainable.

There is need to promote the local traditional knowledge that can provide a basis for development of more effective adaptation strategies that are cost effective, participatory and sustainable. Farmers have over time acquired knowledge of weather systems such as rainfall, thunderstorms, windstorms and sunshine that can help to prepare for future weather. Elderly farmers should be encouraged to formulate hypothesis about seasonal rainfall by observing natural phenomena and other indicators such as timing, intensity and duration of cold temperatures to make predictions that can help local farmers. Some farmers carefully observe the changing pattern of the winds and movement of the clouds, developing specialization in local meteorological patterns. Such knowledge should be harnessed and used to make informed decisions by farmers.

### 5.4.11 Research and Development

There is need to re-invigorate agricultural research and development (R7D) to produce crop varieties that can withstand projected climate variability. Specific agricultural research areas that address climate change need to be undertaken. There is need also to create functional linkages with development partners for technology enterprise initiatives.

### 5.4.12 Improve climate change data collection, dissemination and analysis

Climate change will have dramatic consequences for agriculture. However substantial uncertainty remains about where the effects will be greatest. These uncertainties make it challenging to move forward on policies to combat the effects of climate change. Global efforts to collect and disseminate data on the spatial nature of agriculture need to be strengthened. Regular, repeated observations of the surface of the earth via remote sensing are critical. Funding for national statistical programmes should be increased so that they can fulfill the task of monitoring climate change. Understanding agriculture – climate interactions well enough to support adaptation and mitigation activities based on land use requires major improvements in data collection, dissemination, and analysis.

Crop and livestock productivity, market access, and the effects of climate all are extremely location specific. International development agencies and national governments should work to ensure that technical, financial, and capacity –building support reaches local communities. They should also encourage community participation in national adaptation planning process. Community-based adaptation strategies can help rural communities strengthen their capacities to cope with disasters, improve their land management skills, and diversify their livelihoods. While national adaptation policies and strategies are important, the implementation of these strategies at local levels will be the ultimate test of the effectiveness of adaptation.

Various studies indicate that Agriculture in developing countries is one of the most vulnerable sectors of the global economy to climate change (Rosenweig and Parry 1994, Kurukulasuriya et al, 2006, Seo and Mendelson, 2008c). Farmers will be hard hit if they do not adjust at all to the new climate. Farmers are also observed to make management decisions on their farms to maximize profit. Through generations of learning by doing, farmers know what choices work best on their farms.

Climate change results from increased emissions and subsequent concentration of greenhouse gases in the atmosphere. Increased concentration of these gases in the atmosphere causes global warming which is accompanied by a shift in rainfall patterns, sea level rise and hence a shift in food production, water resources, health and human settlement. The rapid change in the composition of the ecosystem may benefit some species whereas others who do not adapt may become extinct. Land presently unavailable for agriculture could with increased temperatures and rainfall support crops. In other areas, droughts may become more frequent, whereas other areas could have increased incidences of pests and diseases. These impacts of climate change could create serious social, political and economic problems. Farmers in developing countries and more so in the Nzoia River Basin are likely to be hard hit if they do not adjust to new climates. They need to embrace different measures depending on their initial climate conditions. The economy of the Nzoia River Basin is largely rural, and the population earns its living from agriculture especially maize and livestock. Maize, therefore, doubles up as a food crop as well as cash crop for farmers to sell and earn a living.

Adaptation to climate change is deemed to be taking place. There are numerous programmes and activities to reduce climate-related risks and increase resilience at national and local levels. However, few climate change adaptation initiatives have been evaluated and evaluation criteria have not been established and hence the effectiveness of reducing vulnerability to the range of climate projection is unknown especially in the Nzoia River Basin.

Scoones, et al., (2008) showed that resource poor farmers and communities use a variety of coping and adaptive mechanisms to ensure food security and suitable livelihoods in the face of climate change and variability. Adaptive capacity and choices, however, are based on a variety of complex causal mechanisms, crop choices, elements of social capital (such as associations, networks and levels of trust) are important determinants of social resilience and responses to climate change.

Pulwarty, at www.nap.edu, indicated that coping with or managing climate variability and change in maize production systems requires a combination of adaptation and mitigation measures that involve the choice of maize practices and understanding of the science of climate by agricultural experts and the community. Wang et al. and Masarirambi proposed a range of possible strategies such as adjusting the cropping calendar to synchronize crop planting and growing period with soil moisture availability based on season–climate and rainfall focus.

## 5.5 Policy Implications

The study established that in recognition of the serious threats posed by climate change, the Government of Kenya has taken and continues to take measures to secure the Country's development against the risks and impacts of climate change.

This first national policy to recognize the reality of climate change, (RoK, 2010) provided the evidence of climate impacts on different sectors of the economy and proposed mitigation and adaptation strategies to address the same. A series of observed climate trends in Kenya, including general warming over land locations. However the strategy did not articulate the impacts of climate change on maize production which this study has addressed. This study confirmed that there is a general warming of the basin as indicated by fig 4.23 and results in section 3.3 and 4. 4

The other national policy RoK, 2011, sought to take the adaptation and mitigation efforts to the next level of implementation by guiding actions to respond to climate change challenges. The plan outlined long-term integrated strategies for achieving climate change goals including identification of low carbon development in the agriculture sector.

The study established that stakeholders in the basin have adopted various technologies and practices in response to the changing climate patterns.

Low carbon and climate resilient development require access to, diffusion and transfer of environmentally sound technologies(EST). (RoK,2015).This report indicated that Kenya does not have adequate technological capacity to effectively mitigate climate change in Kenya and therefore needs to transfer, develop, and adapt appropriate technologies for climate change mitigation and adaptation. Some of the technologies identified in this study include adoption of early maturing or drought tolerant maize, promotion of sustainable land management, conservation tillage.

### 5.6. Integrated Maize Production Management Plan

The study demonstrated that there is indeed an increasing trend in the climatic patterns and climatic variability in the basin as indicated by the increasing temperatures and the erratic rainfall patterns. Senelwa, 2012, indicated that for given crop, the yield will increase with temperature up to a threshold and then start declining. Temperature and rainfall are important climatic elements in maize production, especially for rain fed maize production which solely depends on natural rainfall and temperature. Therefore, the observed increase in temperature and erratic pattern of rainfall in Nzoia River Basin will have either a negative or positive impact on maize production in the basin and the country as whole. There is need therefore to develop an integrated maize production and management plan to address the adverse impacts of climate variability and climate change that may affect maize production in the basin.

The stakeholders on maize production in the Basin suggested a number of measures to address the adverse impacts of climate change as discussed in section 5.5 and 5.6. The measures included the behavioral, technological and policy measures that have to be adopted by relevant stakeholders. The plan suggests concerted measures to be taken by each stakeholder to address these impacts and reduce the negative effects to the farmer.

**Table 5.1: Integrated Maize Production Management Plan**

| **Issue** | **Strategy** | **Implementing Institution** | **Source of Funding** |
|---|---|---|---|
| Erratic Rainfall Pattern | • Promote integrated Farming<br>• Early warning system<br>• Promote community based weather monitoring<br>• Plant on the onset of rains<br>• Establishment of well distributed and well equipped, weather stations in the basin<br>• Increase climate change data collection ,analysis and dissemination | • Kenya Meteorological Service<br>• KALRO,<br>• KEFRI,<br>• NGOs/CBOs<br>• Residents<br>• Ministry of Agriculture | Go<br>Development partners<br>NGOS/CBOs |
| Delay in the onset of the rain | • Planting on the onset of rains<br>• Enhance Household adaptive Capacity<br>• Promote Community based weather monitoring<br>• Promote sustainable land use management | • Ministry of Agriculture<br>• Kenya Meteorological Service<br>• NGOs/CBOs | GoK<br>Development Partners<br>Private Sector |
| Reduced duration and intensity of the | • Plant, early maturing and drought tolerant varieties | • KALRO<br>• Seed | GoK<br>Donor<br>Funding |

| | | | |
|---|---|---|---|
| rains | • Promote research and development<br>• Promote Community based weather monitoring<br>• Enhance Household adaptive Capacity | Companies<br>• Fertilizer Companies<br>• Ministry of Agriculture<br>• Kenya Meteorological Service<br>• KALRO | NGOs/CBOs |
| Extreme weather events such as droughts ,flooding | • Promote small scale water harvesting and irrigation along the existing rivers<br>• Local traditional knowledge<br>• Promote Community based weather monitoring<br>• Promote weather and crop Insurance<br>• Establish small irrigation projects on existing rivers and the tributaries | • National Irrigation Board<br>• Ministry of environment, Water and Natural Resources<br>• Kenya Meteorological Department | Private sector<br>GoK |
| Increasing Temperature | • Early maturing and Drought tolerant and varieties<br>• Enhance Household adaptive capacity<br>• Research and development of drought tolerant and early maturing varieties | • KALRO<br>• Ministry of Environment, Water and Natural Resources<br>• NEMA | GoK<br>NGOs/CBOs<br>Development Partners |
| Increased disease and pest incidences (Armyworms, aphids, stock borers) | • Research and development of disease resistant crops<br>• Support community based adaptations | KALRO<br>Ministry of Agriculture | GoK<br>Development Partners |
| Water deficit at critical stages of maize development | • Promote weather and crop insurance<br>• Promote small scale irrigation<br>• Integrated Farming | Insurance Companies<br>Lending institutions – Banks and Micro-financing Institutions | Private Sector<br>Development Partners<br>GoK |

| | | | |
|---|---|---|---|
| Increased cost of production due to Re-ploughing and replanting in the event of crop failure | • Provision of credit facilities for farm inputs<br>• Provision of weather and crop insurance<br>• Early warning system<br>• Enhance household adaptive capacity<br>• Raise awareness on climate change by providing climate change related information<br>• Development of an insurance scheme | Lending institutions – Banks and Micro-financing Institutions | GoK<br>Development Partners |
| Increased atmospheric evaporative demand | • Promote drought tolerant and early maturing varieties<br>• Promote sustainable agricultural land use management practices | Ministry of Agriculture<br>NGOs/CBOs<br>Farmer groups | GoK<br>NGOs/CBOs |
| Increased competition for available water | • Promote sustainable agricultural land use management practices | Ministry of agriculture | GoK<br>NGOs/CBOs |
| Increased mineralization of organic matter | • Promote sustainable l land use management | Ministry of Agriculture<br>NGOs<br>Farmer groups | Private Sector<br>GOK<br>NGOs/CBOs |

**Source: (Author, 2011)**

# CHAPTER SIX

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Introduction

This chapter presents the summary of the findings, conclusions and recommendations including suggested areas of further research.

## 6.2 Summary of key findings

The study established that annual rainfall shows strong seasonality with bi-modal distribution patterns (Ogallo, 1992) and RoK, 2012. The long rains occur in the month of March to May, while short rains occur in the month of October to December with variations. The third rainfall peak of June, July-August is experienced in the Western highlands due to the incursions of moist air masses from Atlantic ocean and the forested basin of the Democratic Republic of Congo during the Northern hemisphere summer season (Ogallo,1997). The study showed a decreasing pattern in annual average rainfall in the basin over the study period. The average rainfall pattern in the upper zone showed a general increase over the study period. However the MAM rainfall pattern for the upper basin showed a decreasing pattern. In addition the JJAS and OND rainfall pattern showed an increasing pattern over the study period.

The pattern of the annual average rainfall for the Middle Basin indicated a decreasing pattern of rainfall. The rainfall pattern for the MAM, JJAS and OND also indicated a decreasing pattern over the study period. The annual average rainfall for the Lower basin showed a decreasing pattern of rainfall. The average MAM rainfall indicated a decreasing pattern of rainfall in the Lower basin. However, the JJAS and OND seasonal rainfall pattern showed an increasing pattern of rainfall in the Lower Basin. The respondents indicated that they had noticed a decrease in the rainfall over the years of study. They indicated that they had noticed a delay in the onset of the rainfall. They also indicated that the rainfall was erratic over the study period and was characterized with unpredictable and poorly distributed rains over the growing period.

Analysis of the temperature trends over the study period indicated that the temperatures were falling from 1960-1979, from when the temperatures started rising again up to 2012.The average seasonal temperature variations for MAM, JJAS, and OND depicted the same increasing trend over the study period.

However the analysis of the temperatures for the upper Basin indicated an increasing trend for both the Minimum and Maximum temperatures over the study period. This trend was also observed for the Middle and Lower basin for both the minimum and maximum temperatures. The maximum temperatures for MAM season have the highest temperature rise compared to the minimum temperatures of the same season. The JJAS season temperatures are the least in warming up. The mean temperature trend in the basin has given a clear signal of climate change with trend being a rise in temperature over land. The respondents in the whole Basin indicated that they had noticed a general increase in the temperatures in the Basin.

The results of the temperature and rainfall variations showed a decrease in rainfall and an increase in temperature over the study period. Analysis of the rainfall pattern indicated that there is a delay on the onset of the rainfall. The delay on the onset affects the planting calendar of the farmers in the Basin. This is characterized by some farmers planting early whereas others plant late depending on their judgment. The maize crop that is planted too early or too late may not get optimum rainfall for it to have optimum yield. The onset of the long rainfall has shifted to mid-March. This is also when most farmers are planting their crop. For farmers who plant earlier than mid-March, the crop experiences poor germination due to erratic rainfall at the germination stage. This reduces the plant population per unit area and therefore reduced the yield of maize. There was an increase in the amount of rainfall received over the JJAS season. This season is characterized by the reproductive stage of maize development. An increase in the rainfall amount promotes good silking, tasselling and cobbing.

However the Middle basin showed a decreasing pattern of the JJAS rainfall. The temperatures over this season showed an increasing pattern. This had a negative impact such that the reduced rainfall and increased temperatures causes the drying of the silk and poor tasselling leading to poor grain setting hence reducing the yield per unit area. Inadequate rainfall caused by poor rains or erratic rainfall at the critical stage of reproduction causes poor yield of maize. The erratic rainfall accompanied by the prolonged period of drought causes water stress to the crop leading to wilting and sometimes drying of the crop before physiological maturity. Waterlogging at flowering reduces yield, which normally occurs during the month of JJAS and coincides with the flowering stage of maize development. Climate factors such as temperature, precipitation, moisture affect development of plants either alone or by interacting with other factors. Global warming therefore is expected to increase difficulty in food production and scarcity. Reduced water resource availability pose a great challenge to agriculture and food production.

Reduced rainfall and increase in temperatures provide a favourable environment for increase in pests and disease incidences which causes yield reduction. Erratic rainfall causes poor germination that can lead to reploughing and replanting hence increasing the cost of production and lowering gross margins for farmers. Other effects of the rainfall variability will include: reduced area under maize production caused by farmers switching to other crop enterprises as means of reducing the risk of maize crop failure. The OND rainfall season showed an increasing trend of rainfall. The prolonged OND rains occur when the maize, especially in the upper basin has reached physiological maturity and are ready for harvesting. The prolonged rains lead to rotting of maize while still in the field; and also at storage due to the high moisture content at harvesting and poor drying conditions due to lack of sunshine. Provision of solar driers in strategic areas will help the farmers not to lose their crop due to increase in the OND rainfall.

The results showed an increase in temperature over the study period. Increase in temperature results in an increase in atmospheric evaporative demand and hence increase demand and competition for water available for plant growth. When moisture is not limiting, high temperatures and higher carbon dioxide concentration leads to increased crop yield. The intensity of rainfall received in the basin has changed over the years. Sometimes the rains at the onset, when most farmers are expected to plant are not enough to sustain uniform germination. The poor germination results to low density in the maize population. When the maize plant population is below fifty percent, the farmers are advised to replough and replant again. Sometimes, the rains are not well distributed in the growing season causing drying and wilting of the maize crop. This increases the cost of production but more so leads to poor harvest at the end of the growing season.

However, the study also noted that there are numerous non-climatic factors that cause low yields including lack of suitable maize seed at planting, poor prices for previous season hence farmers cannot afford to perform the agronomic practices as requires. These results to late planting, farms being left fallow, farmers turning to other enterprises which are less rainfall depended.

The farmers and other stakeholders had various responses to the changing rainfall and temperature patterns to reduce climate –related risks and increase resilience of the farmers both at the local and national levels. The farmers indicated that they use various coping and adaptation mechanisms to ensure food security and suitable livelihoods in the face of climate change and variability. The various coping and adaptation mechanisms are based on complex causal mechanisms, crop choices, elements of social capital to help them respond to climate change.

This choices included, Integrated farming where farmers have diversified their crop enterprises to include fruit tree farming, horticulture crops ,as an insurance to crop failure. The farmers also plant long and short season crops to take care of their long term and short term needs. Farmers plant on the onset of the rains when they are sure that the rainfall is enough to support uniform germination Farmers are advised by the agricultural extension farmers to acquire the farm inputs, prepare the field and wait for the onset of the rains. This is a measure to address poor germination arising from the delayed onset of the rains and the erratic pattern of rainfall experienced in the Basin. Farmers also indicated that they have switched to plant early maturing and drought tolerant maize. Some farmers plant both varieties of the early maturing and long maturing varieties to spread the risk of crop failure when they plant only late maturing varieties.

Promotion of sustainable land management practices to address the problem of mineralization hence poor soil structure and fertility arising from increase in temperature. Other measures include enhancing household adaptive capacity, use of local based traditional knowledge, provision of credit facilities and subsidized inputs and provision of weather and crop insurances.

## 6.3 Conclusions

The results showed that the annual rainfall in the basin showed a decreasing pattern over the study period. The reduced rainfall affects the type of maize varieties grown. The late maturing varieties grown in the upper part of the basin may no longer be suitable due to the reduced amount of rainfall over the growing period. This will require the adoption of early maturing and drought tolerant varieties. However, the early maturing varieties are not as high yielding as the late maturing varieties. This will reduce the yield of maize harvested per unit area. The early maturing varieties take a short time to mature and therefore farmers plant twice in both the long and short season. This helps the farmers to utilize the increased JJAS rainfall season for crop production.

The delay in the onset of the rainfall reduces the cumulative amount of rainfall received over the MAM period. This delay also affects the planting calendar of activities for the farmer. A delay in the onset of the rains will also delay the planting activities for the farmer. Analysis of the planting dates over the study period revealed that they have shifted from mid-February in the 1980’s to mid- March. The delay on the onset of the rains makes farmers to plant at different times depending on their judgment. Some of the crop is planted at such a time that the crop does not get optimal moisture at the critical stages of development such as the reproductive stage and this reduces yield per unit area. The farmers who plant early experience poor germination due to poor rainfall received at the beginning of the season this reduces the plant population per unit area hence the yield. In the same way farmers who plant late due to the delayed onset may not have optimal moisture at the critical stage of maize development leading to poor yield. Sometimes farmers have poor judgment on when the rains will start and therefore will require support and access to the accurately predicted climate change information. There is need to enhance household adaptive capacity by agricultural extension officers working closely with farmers and providing them with the right information on predicted climate and how they can respond by planting the right varieties for the predicted season.

The unpredictable pattern of rainfall is sometimes accompanied by the prolonged periods of droughts causing water stress to the maize crop. When the crop wilts at the vegetative stage, it can survive when the rains resume and have normal yields. .However, the crop is adversely affected if wilting occurs at the reproductive stage of maize development. This is as a result of the high temperatures causing the drying of the silk thus affecting flowering, tasselling and grain setting. Waterlogging at certain critical stages of maize development such as the reproductive stage can reduce maize yield by 50% or more. For crops planted on time, the vegetative and reproductive stage of maize development that requires optimum rainfall coincides with the increased rainfall in the JJAS leading to optimal yield when all other production factors are well supplied.

Though maize is tolerant to water deficit during the vegetative and ripening stage, deficit during flowering, tasselling, silking and pollination causes yield reduction due to reduced number of grains per cob and also reduced grain size. In addition, waterlogging at flowering can greatly reduce maize yield. Prolonged rains during ripening stage of maize will cause rotting of the maize while still in the field and hence reduce the yields further.

The temperature analysis showed that there had been a general cooling of the temperature between 1963 to about 1987. Since then there has been a steady warming up in the basin. The rising temperatures have been most rapid during the MAM where the rate was $0.29^0$C per decade and slowest in JJAS. Both the maximum and minimum temperatures for the upper, middle and lower part of the basin have been rising. However, the maximum temperature rise for the MAM season seems to be higher than the minimum temperatures. The OND temperatures have risen by $1^0$C for both the maximum and minimum temperatures.

Increasing temperatures results to increase in atmospheric evaporative demand and hence increase demand and competition for available water for plant growth. Increasing temperature also increase mineralization of the organic matter content of the soils leading to reduced soil fertility and poor soil structure.

Increase in temperatures coupled with high atmospheric humidity favours development of crop pests and diseases which accentuate the problem of yield losses. The high temperatures in OND season and the increase in the rainfall amount causes rotting to the harvested crop due to the high moisture content of maize at harvesting and also due to poor drying conditions due to lack of sunshine.

The results showed that there has been a general increase of hectare of maize. However, further analysis showed that there was increase in growing of maize from 1977 to 1990 and then there was a drop in the hectare up to 1995. Since then, the hectare increased again up to 2004.This shows that the area under maize cultivation has been fluctuating.

Farmers are known to be the best researchers and they always seem to come up with trials before other scientists have answers. The study revealed that farmers had already started adaptations to the changing climate. Most farmers wait for the onset of rainfall before they plant their maize. This is to avoid poor germination caused by the erratic pattern of rains. They now have to wait until the soils had enough moisture to sustain germination before planting their maize. They prepare the land, buy the farm inputs and wait for sufficient rains before planting the maize seed. Some indicated that they now plant two types of maize varieties, the medium maturing and the early maturing seed types so that they can reduce the risk of total crop failure.

The farmers have diversified their crop enterprises to have safety net measures against adverse impacts of climate change in case of crop failure. Most farmers especially in the lower part of the basin plant millet and sorghum which can withstand drought and high temperatures

## 6.4 Recommendations

There is need, therefore for the Government to:

1. Promote integrated farming

2. Advise farmers to plant on the onset of the rains
3. Promote planting of early maturing and drought tolerant varieties
4. Provide accurate and timely weather focus for the basin to help farmer's preparedness and decision making in maize growing activities
5. Promote sustainable land management practices.
6. Enhance household adaptive capacity by creating awareness on the impacts of climate change and the available adaptation measures.
7. Provide weather and crop insurance

## 6.5 Areas of further study

1. Evaluate the adaptation measures practiced by farmers to identify the most effective adaptation measures that can address the adverse effects of climate change on maize production.
2. Assessing how different management methods will affect maize production under the changing climate changes in the Basin.
3. One of the challenge or knowledge gap is that the yield of maize may increase or decrease depending on the management method, the natural prerequisite, and agricultural policy and therefore climate change scenarios may be difficult to interpret.

## REFERENCES

Agatsiva, J. L. & Situma, C.A. (2006) *Long Rains Maize and Wheat Production in Kenya.* DRSRS Technical Report No. 166

Ahmed, M., & Hassan, F. (2011). *APSIM and DSSAT as Decision Support Tools:* Rawalpindi, Pakistan: Department of Agronomy, PMAS Arid Agriculture University.

Akintola, J.O., (2001). Comparative analysis of the distribution of rainy days in different ecological zones in Nigeria agriculture. *J. Environ. Ext., 2*(1)*, 31-48*

Al Gore, *An Inconvenient Truth, The Planetary Emergency of Global Warming and What We Can Do About It* (Rodale Books, 2006).

Anderson, J.R. & Hazell, P.B.R. (1987). *Variability in corn yields: Implications for agricultural research and policy in developing countries.* Published for The International Food Policy Research Institute. Baltimore and London: The John Hopkins University Press.Workshop.

Andressen, J., Olson, Massawa and Maitima. (2008). *The Effects of Climate change and Land Use Changes on Climate and Agricultural Systems in Kenya.* Nairobi: Clip Policy Workshop.

Appelgren, B. & Burch, S. (1995). *African Water Resources: Challenges and opportunities for sustainable development.* Working paper No. 1 Water Resources Policy reform: Issues and effects in the Agriculture sector, FAO, World Bank.

Bancy, M.M. (2000). The influence of climate change on maize production in semi-humid and semi-arid areas of Kenya.*J. Arid Environ., 46*(4), 333-334.

Bast, L., J.(2013). *Seven Theories of Climate Change*. The Hear land Institute. www.heartland.org

Best, J.W.& Kahn J.M. 91998) Education Research .USA *www.abacon.com*

Chi-Chung, C., McCarl, B.A. & Schimmelpfennig, D. (2004). Yield Variability as Influenced by Climate: A Statistical Investigation. *Climatic Change, 66*, 239-261.

Department of Environment Food and Rural Affairs (2014). *Draft River Basin Planning Guidance* www.defra.gov.uk

FAO (1995). FAOCLIM 1.2, *Worldwide Agro climatic Data.FAO Agro- meteorology* Working Paper Series No. 11. FAO, ROME. 1 CD-ROM and 66P EWSNET.

FAO (2010). *Climate Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation.* Rome, Italy:Vile delleTerme di Caracalla.

FEWSNET (2010). *A Climate Trend analysis of Kenya –August 2010*. Nairobi: FEWSNET.

Gikungu, D. (2013). *Weather and Climate.* A paper in the Bulletin of the Kenya Meteorological Society, June- August 2013.

GOK (1974). *Trans Nzoia District Annual Report- Ministry of Agriculture* (Unpublished)

GOK (1981). *Trans Nzoia District Annual Report—Ministry of Agriculture* (Unpublished)

Gonzalez, A. (2012). Driscol, J. and Maguira, Padraig (2012). *Implementation of River Basin Management Plans: Current issues and future needs. www.iclrd.org*

ICRAF (2008). *Baseline Report on Yala and Nzoia River Basin*. WELIEMP Findings and solutions

Intergovernmental Panel on Climate Change, Climate Change 2007: *The Physical Science Basis* (Cambridge University Press, 2007). http://www.ipcc.ch/

International commission for the protection of the Danube River(2008). *ICPDR Strategy on Adaptation to climate change*

IPCC (1992). *The Supplementary Report to the IPCC Scientific Assessment*. J.T. Houghton, B.A. Callandar and S.K. Varney, (Eds.). Cambridge: Cambridge University Press.

IPCC, (2007) *Climate Change 2007: Impacts, Adaptations and Vulnerability*. Cambridge: Cambridge University Press.

Jayne, T.S., & Argwings-Kodhek, G. (1997). Consumer Response to Maize Market Liberalization in Urban Kenya. *Food Policy*, 22(5).

Jayne, T.S., Yamano, T., Nyoro, J., &Awour, T. (2001). *Do Farmers Really Benefit From High Food Prices Balance Rural Interests in Kenya's Maize Pricing and Marketing Policy*. Working Paper 2b, Tegemeo Institute, Nairobi, Kenya

Jha, A. K., Barensten, D. J., Phelps, M. P., Dittent, S., (2010). *Guiding Principles for Environmental Planning: Safer Homes: Safer Homes Stronger Communities.* World Bank www.housingreconstruction.org

Kabuko –Mariara, J. & Karanja, F.K. (2007). *The Economic Impact of Climate Change on Kenyan Crop Agriculture: A Ricadian Approach* "World Bank Policy Research Working Paper 4334.1-40

Karanja, D. D. & Oketch, A. G. O. (1992). *The Impact of Maize Research in Kenya.* In Proceedings of a Workshop. Review of the National Maize Research Program. KALRO/ISNAR. Management Training Linkage Project. 100pg.

Karanja, D.D. (1996). *An Institutional and Economic Analysis of Maize Research in Kenya.* MSU International Development Working Paper, No.57, East Lansing: Michigan State University.

Karanja, D.D., Thomas, S., Jayne, & Strasberg, P. (1998). *Maize Productivity and Impact of Market Liberalization in Kenya*, Tegemeo Working Paper.

Kenya Meteorological Service (2013). *Weather and Climate Change; Bulletin of the Kenya Meteorological Society June –August 2013.*

Kenya National Bureau of Statistics (KNBS) (2010).*The Kenya Population and Housing Census Report, 2009*. Nairobi: Government Printer.

King'uyu, S. (2013). *Are there benefits in climate change, or is it all negative*. A Science Feature in the Kenya Meteorological Society Bulletin.

Krejicie, R.& Morgan D.W(1970). *Determining sample size for research activities.*

Kuhnlein, V.H., Erasmus, B. & Spigelski, D. (2009). *Indigenous Peoples Food Systems: The Many Dimensions of Culture Diversity and environment for Nutrition and Health.* Rome: FAO Centre for Indigenous Peoples Nutrition and Environment.

Lane, M.B. & McDonald, G. (2005). Community-based Environmental Planning: Operational Dillemas, Planning Principles and Possible Remedies. *Journal of Environmental Planning and Management 48*(5), 709-735

Litman, T. (2013). *Planning Principles and Practices.* Victoria Transport Policy Institute.www.vtpi.org

Ludwig-Maximillians-University Munich (2012). *Danube River Basin: Climate Change Adaptation*

Luedeling, E. (2011). *Adaptation to Climate Change and Insurance: Climate Change Impacts on Crop Production in Busia and Homa Bay Counties, Kenya*. World Agroforestry Centre

Madiyazhagan R., Birch, C.J., Carberry, P.S., & Micheal, R. (2004). *Water and high temperature stress effects on maize production.* A Paper Presented at the 4th International Crop Science Congress.

Mugalavai,. M E (2013). Seasonal and Spatial Assessment of Agro-climatic Parameters of crop farming: case of Lake Victoria Basin, Kenya.

Mugenda & Mugenda (1999). *Research Methods: Quantitative and Qualitative Approaches.* Nairobi, Kenya: ACTS Press

Mutimba, S., Mayieko, S., Olum, P., & Wanyama, K., *Climate Vulnerability and adaptation preparedness in Kenya*

Murgor, D.K. (2015). Farmers Access to climate information and weather information and its impacts on maize and wheat production in Uasin Gishu County, Kenya.

Myers L. J., Well, D.A., & Lorch, F. R. (2010). *Research Design and Statistical Analysis* (3rd ed.). Great Britain: Routledge

National Environment Management Authority (NEMA) (2004). *State of Environment Report for Busia District*. Nairobi: Government Printer.

Nyabundi, J.O., & Njoka, T. J. (1991). *Impacts of climate change on Agriculture and forests in Africa*: A paper in a Change in Weather, African Perspective on Climate Change

Nyabundi, J.O., & Njoka.T.J. (1991). *Impacts of climate change on Agriculture and forests in Africa*: A paper in a Change in Weather, African Perspective on Climate Change

Nyoro, J. (2002). *Agriculture and Rural Growth in Kenya*. Tegemeo Working Paper

Okoth-Ogendo, H.W.O. & Ojwang, J.B. (1995). *A Climate for development: climate Change Policy options for Africa.* Nairobi: Acts Press.

Omari, K. (2010). *Climate Change Vulnerability and Adaptation Preparedness in Southern Africa- A case Study of Botswana.* Heinrich Boll Stiftung

Onywere, S.M., Getenga, Z.M., Mwakalia, S.S., Twesigye, C.K., & Nakiranda, J.K. (2011). *Assessing the challenge of settlement in Budalangi and Yala Swamp Area in Western Kenya*, Using Landsat Satellite Imagery. The open Environmental Engineering Journal, 2011, 4, pg. 07-104.

Oseni, T.O. & Masarirambi, M.T. (2011). Effect of Climate Change on Maize (Zea mays) Production and Food Security in Swaziland. *American-Eurasian J. Agric. & Environ. Sci., 11* (3), 385-391.

Parry, M. (1990). *Climate Change and World Agriculture*. London: Earth scans Publications

Peterson, G.A., Westfall, D.G., &. Cole, C. V. (1993). Agro ecosystem approach to soil and crop management research. *Soil society of America Journal, 57,* 1354-1360.

Pielke Sr., R., "Climate Change: The need to consider human forcings besides greenhouse gases," Eos 90: 45, 413 (November 2009).

Rachu, S.S & Chandu, R. (2008). *Agricultural Insurance in India: Problems And Prospect National Centre For Agricultural Economics And Policy Research.* New Delhi: Indian Council of Agricultural Research.

Report WRMA (2011). *Nzoia River Basin Management Initiative: a public private partnership between WRMA and Mumias Sugar Panpaaper Mills*

Republic of Kenya (1996). *Busia District Development Plan 1997-2001*. Nairobi: Government Printer.

Republic of Kenya (1996). *Trans Nzoia District Annual Report – Ministry of Agriculture, Livestock Development and Marketing.* Kitale, Kenya (Unpublished)

Republic of Kenya (2001). *Busia District Development Plan 2002-2008*. Nairobi: Government Printers.

Republic of Kenya (2003). *Economic Recovery Strategy for Wealth and Employment Creation.* Nairobi, Kenya: Government Printers

Republic of Kenya (2004). *Strategy for Revitalizing Agriculture.* Nairobi, Kenya: Government Printers

Republic of Kenya (2006). *Responses to climate Change and opportunities for sustainable development*. Nairobi, Kenya: Government Printers.

Republic of Kenya (2007).*Kenya Vision 2030 – A globally Competitive and Prosperous Kenya.* Nairobi, Kenya: Government Printers

Republic of Kenya (2009). *Agricultural Sector Development Strategy 2009-2020*. Nairobi, Kenya: Government Printers.

Republic of Kenya (2009). *State of Environment Report Kenya, 2006/7-Effects of Climate Change and Coping Mechanisms in Kenya.* Nairobi, Kenya: Government Printers.

Republic of Kenya (2010). *National Climate Change Response Strategy*. Nairobi: Government Printers.

Republic of Kenya (2010a). *State of Environment of Kenya: Effects of Climate Change and Coping mechanisms in Kenya*. Nairobi: Government Printers.

Republic of Kenya (2010b). *The Constitution of Kenya*. Nairobi: Government Printers

Republic of Kenya (2012). *National Accelerated Agricultural Inputs Access programme: Implementation guidelines, work plans and Budgets.* Nairobi: Government Printers.

Republic of Kenya (2013). *Ministry of Agriculture: Economic Review of Agriculture*. Nairobi: Government Printers.

Republic of Kenya (2013a). *Trans Nzoia County Development Profile: Ministry of Devolution and Planning.* Nairobi: Government Printer.

Republic of Kenya (RoK) (2013b). *Kakamega County Development Profile, Ministry of Devolution and Planning.*Nairobi: Government Printers

Republic of Kenya (RoK) (2013c). *Busia County Development Profile, Ministry of Devolution and Planning.*Nairobi: Government Printer

Republic of Kenya *Maize Harvest Forecast for 1984 in Bungoma, Elgeyo Marakwet, Kakamega, Nakuru, Nandi, Trans Nzoia, Uasin Gishu and West Pokot Districts.* Nairobi: Government Printers

Scafetta, N. and West, B. J., "Interpretations of climate-change data," Physics Today, November 2009.

Scafetta, N., "Climate change and its causes: A discussion about some key issues," La Chemical Industrial 1: 70-75 (2010).

Scafetta, N., "Empirical analysis of the solar contribution to global mean air surface temperature change," Journal of Atmospheric and Solar-Terrestrial Physics 71: 1916–1923, doi:10.1016/j.jastp.2009.07.007 (2009).

Sea, S.N. & Mendelsohn, R. (2008c). *A structural Ricardian Analysis of Climate Change Impacts and Adaptations in African Agriculture*. The World Bank Development Research Group

Seo, N., Mendelsohn, R., Kurukulasuriya, P., Dinar, A. & Hassan, R. (2008).*Differential adaptation strategies to Climate Change in African cropland by agro-Ecologies zones*

Situma, C.A. &Agatsiva, J.L. (2006).*Long Rains maize and Wheat production in Kenya 2005*. DRSRS Technical Report No.163

Sperling, F. *et al* (2008).*Transiting to Climate Resilient development perspectives from communities in Peru*

SPREP, (2003).*Climate Variability and Change and Sea level Rise in the Pacific Islands Region.A Resource Book for Policy and Decision Makers, Educators and other Stakeholders*. Japan: Ministry of Environment

Sud, Y.C., Walker, G.K., and Lau, K.-M., "Mechanisms regulating deep moist convection and sea-surface temperatures in the tropics," Geophysical Research Letters 26: (8), 1019-1022 (1999).

Sweeney, C., New, M., & Lizcano, G. (2007).*UND Climate Change Country Profiles-Kenya.* Oxford: University of Oxford. http://country profile.geog.ox.ac.uk

Wang, M., Li, Y., Ye, W., Bornman, J.F., & Yan, X. (2011).Effects of climate change on maize production and potential adaptation measures: a case study in Jilin Province, China. *Journal of Climate Research, 46,* 223–242

Watson, T. R., Marufu, C. Z.& Richard, M. H.(1998). *The Regional Impacts of Climate change: An assessment of Vulnerability.* World Meteorological Centre.

Watt, W.J. (1983). *Economic and Environmental principles and guidelines for water and Related lead resources Implementation studies.*

Williams, A., & Funk, C. (2010). *A Westward Extension of the Pacific Warm Poll leads to March through June drying in Kenya and Ethiopia*. US Geological Survey Open file Report.

World Bank (2007). *World Development Report* -2007. Nairobi: World Bank

World Meteorological Organization (WMO) (2008). Climate Sense: Coping with Climate Variability and Change in Kenya. *WMO Bulletin 57* (1) –April 2008.

World Meteorological Organization (WMO), (1996).*Climate, weather and agriculture*. A paper presented at World Food Summit – Rome, 13 – 17th November.

# APPENDIX I: HOUSEHOLD INTERVIEW SCHEDULEFOR HOUSEHOLDS IN TRANSNZOIA RIVER BASIN

***Preamble***

My name is Catherine Mbaisi. I am a PhD Student in the University of Eldoret carrying out my research entitled: Impacts of Climate Change on Agricultural Production in Kenya: Climate *change mitigation and adaptation strategies in maize production in Nzoia River Basin, Kenya.*

Your responses to these questions will be anonymous and confidential and solely used for academic purpose only.

**Questionnaire No................**

**A: Identification of Respondents**

1. Name of Interviewee (Optional)……………………………………………………

**2. Location**

i). County ..........................................................................................
ii). Division.........................................................................................
iii).Location.........................................................................................
iv). Sub Location...................................................................................

**B. Respondents Characteristics**

**Household Size (of owner of the farm)**

| | **3.Gender** | **4.Age** | **5.Marital status** | **6 Level of Education** | **7.Occupation** |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| | ***Key***<br>1 Male | | ***Key***<br>1 Married | **Key**<br>1)No education | **Key** |

| | | | | | |
|---|---|---|---|---|---|
| | 2Female | | 2 Never Married<br>3 Previously Married (Divorced, Separated, widowed) | 2) Primary<br>3) Secondary<br>4)Tertiary | 1 Yes<br>2 No |

**Land use/ Production**

8. Type of farm entity

   i) Small –scale ii) Medium scale iii) large scales

9. What is the size of your land under farming?

10. What is the size of your land under maize production?

11. System of farming

    i). Shifting cultivation (with long fallow period)

    ii). Continuous cropping (No fallow period)

    iii). Continuous cropping with multiple rotations (includes short fallow period)

    iv). Livestock grazing land

    v). Others (**Please specify**)

12. Type of tenure **(**allow for multiple choice)

    i. Own land and own use
    ii. Own land and rent to others
    iii. Sharecropped land
    iv. Communal lands (Traditional ownership)
    v. Communal lands (Traditional ownership)
    vi. Rented lands
    vii. Borrowed land (Do not pay for usage)
    viii. Others please specify

***13. Information on the Maize crop grown in your farm over the last 12 months. (See Landscape)***

| | 13.1 | 13.2 **Maize farming activities** | 13.3.3 | 13.4 | 13.5 | 13.6 | 13.7 | 13.8 | 13.9 | 13.10 | 20.11 | 20.12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | Planting Date | Harvest Date | %area cultivated with crop | Quantity Harvested Kg | Amount consumed by HH Kg | Amount consumed by Livestock Kg | Amount lost due to disease and pests | Quantity Sold Kg | To whom output is sold | Total value of crops sold | Amount of seeds used | Cost /kg of seeds |
| 1 | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | |

i. Directly to Consumers ii. Middle/wholesale iii. Cereals Board iv.. Others

14. Please Name the Maize variety that you plant on your farm.

i...............................................................
iii...........................................................

ii...............................................................
iv............................................................

15. Please state the average yield of your Maize crop in a normal year (see the landscape table) Normal year average (in terms of Kg/ha……………………………………………

**Access to extension services –All questions concern the last 12 months**

16. Do you get information and advice from extension workers?

*i. Yes; ii. No*

17. How many times do they visit you per year?

i. 1.None
ii. 2. once
iii. Twice
iv. Four
v. ten times
**vi.** More than ten

18. Do you pay for receiving extension advice?

*i. yes; ii. no* (if no, go to 5.1.4

19. If you pay, how much do you pay annually for extension?

20. From which organization are the extension officers from?

*i. Government agency;*
*ii. Agricultural research station*
**iii.** *NGO*
**iv.** *Other (please specify…).*

21. Have extension officers provided information on expected rainfall and precipitation?
*KEY: i yes; ii no*

22. If you get any technical assistance and advice on weather conditions, from other sources apart from official extension workers, from where do you receive the necessary information?

*KEY: i Media; ii Neighbouring farmer; iii Shopkeepers in village; IV Others (please. specify …); v none.*

**C. Climatic Variability and Patterns**

23. How long have you been a farmer?…………………………….. (In number of years)

24. In your own understanding, what is climate change?
.......................................................................................................................
.......................................................................................................................
.......................................................................................................................

25.What is climatic variability
.......................................................................................................................
.......................................................................................................................

26. Have you ever observed any evidence of climate variability in this area?
i. Yes ii. No

27. If yes, what evidence have you observed?
Explain
.......................................................................................................................
......................................................................................................................
.......................................................................................................................

**D. Effects (Impacts) Of Climate Change**

28. Have you noticed any long-term shifts in the mean temperature on your farm?

Yes ☐ No ☐

29. If yes what are the temperature changes on the farm

i. Increase in temperature ii. Decrease in temperature iii. No change iv. Don't know
Please explain..........................................................................................

……………………………………………………………………………….

30. Have you noticed any long-term shifts in the mean rainfall on your farm ?
Yes ☐ No. ☐

31. If Yes, What are the changes in rainfall?
i. Increase in precipitation ii. Decrease in precipitation iii. Changes in onset of the rains iv. Increase in frequency of the droughts. V. No change vi. Don't know
Please explain..........................................................................................

32. In your opinion, how has the temperature variation affected maize production in your farm?
i.........................................................................ii........................................................
...........iii.........................................................................iv.......................................

33. How has the rainfall variation affected maize production in your farm?
i.........................................................................ii........................................................
iii......................................................................iv......................................................

**E. Mitigation and Adaptations Practices to Climate Change**

34 What adjustments have you made to respond to these long-term shifts in temperature in your farm? (Please list below.
i........................................................................ii.........................................................
iii.........................................................................iv....................................................

35. What adjustments have you made to respond to these long-term shifts in Rainfall in your farm?
i................................................................ii.................................................................
iii................................................................iv...........................................................

36. What are the main primary constraints for making the necessary adjustments to climate variations? (E.g. weather effects in terms of temperature and rainfall fluctuations) within and between seasons?
i..................................................................................................................................
ii.................................................................................................................................
iii................................................................................................................................
iv................................................................................................................................
v.................................................................................................................................

37 Have you considered using water from Nzoia River or its tributaries for irrigation as a way of mitigating climate change?

Yes ☐ No. ☐

38. If yes, what exactly are you doing?

**E. Policy recommendations**

39. What, in your opinion should the Government do to address the adverse effects of climate change?

## APPENDIX II: INTERVIEW SCHEDULE FOR MoA

**Preamble**

My name is Catherine Mbaisi. I am a PhD Student in the University of Eldoret carrying out my research entitled: Impacts of Climate Change on Agricultural Production in Kenya: Climate *change mitigation and adaptation strategies in maize production in Nzoia River Basin, Kenya.*

Your responses to these questions will be anonymous and confidential and solely used for academic purpose only.

**General Information**

**Name of Respondent…………………………………………………………………………**

**Designation..............................................................................................**

**County.....................................................................................................**

1 What is the mandate of your institution with regard to climate change?

………………………………………………………………………………

2 Have you experienced any significant climate change signals over time

3 If any, what are these signals………………………………………………

………………………………………………………………………………

4 In your opinion, how do these changes in climate affect agricultural production in the Nzoia Basin?

.........................................................................................................................

………………………………………………………………………………

………………………………………………………………………………

5 What are some of the practices and technologies being adopted to address climate change?

..........................................................................................................................

…………………………………………………………………………………

6 What are the mitigation and adaptation strategies adapted to address the adverse impacts of climate change……………………………………………………………………

…………………………………………………………………………………

7 What are some of the policy recommendations that the government can adopt in order to address the adverse impacts of climate change……………………………………………………………………….

…………………………………………………………………………………

8. Maize Production in bags per ha since 1980

## APPENDIX III: INTERVIEW SCHEDULE FOR THE DIRECTOR KENYA METEOROLOGICAL SERVICE

**Preamble**

My name is Catherine Mbaisi. I am a PhD Student in the University of Eldoret carrying out my research entitled: Impacts of Climate Change on Agricultural Production in Kenya: Climate *change mitigation and adaptation strategies in maize production in Nzoia River Basin, Kenya.*

Your responses to these questions will be anonymous and confidential and solely used for academic purpose only.

**A. General Information**

Name of Respondent.........................................................................................

Designation.........................................................................................................

1. What is the mandate of your institution with regard to climate change?

   ………………………………………………………………………………..

2. Have you experienced any significant climate change signals over time………………………………………………………………………………..

   ………………………………………………………………………………..

3. If any, what are these signals? ………………………………………………..

………………………………………………………………………………………

4. In your opinion, how do these changes in climate affect agricultural production in the Nzoia Basin? …………………………………………………………………

………………………………………………………………………………………

5. What are some of the Practices and technologies being adopted to address climate change? ……………………………………………………………………...

7. What are the mitigation and adaptation strategies adapted to address the adverse impacts of climate change. ……………………………………………………..……...

8. What are some of the policy recommendations that the government can adopt in order to address negative impacts of climate change…………………………

## APPENDIX IV: MONTHLY RAINFALL OF THE BASIN IN MILLIMETER

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1961 | 6.8 | 40.1 | 62.9 | 218.3 | 119.5 | 119.0 | 151.0 | 109.8 | 41.6 | 179.9 | 442.9 | 127.8 |
| 1962 | 14.8 | 40.1 | 54.8 | 184.4 | 216.1 | 40.9 | 87.7 | 83.6 | 49.6 | 88.4 | 140.8 | 49.0 |
| 1963 | 31.4 | 47.2 | 98.4 | 311.8 | 237.3 | 19.0 | 6.1 | 77.0 | 51.3 | 7.6 | 200.4 | 126.2 |
| 1964 | 37.4 | 40.1 | 71.1 | 205.3 | 74.7 | 45.2 | 232.1 | 129.3 | 92.9 | 25.4 | 20.1 | 68.1 |
| 1965 | 10.4 | 22.3 | 34.5 | 146.9 | 40.8 | 29.0 | 91.1 | 59.9 | 14.7 | 115.2 | 113.5 | 52.6 |
| 1966 | 22.1 | 154.4 | 103.6 | 269.5 | 55.8 | 42.6 | 99.0 | 129.4 | 56.2 | 96.3 | 43.1 | 6.1 |
| 1967 | 37.4 | 20.5 | 82.3 | 189.1 | 288.4 | 108.4 | 119.2 | 64.1 | 17.9 | 106.8 | 290.0 | 56.9 |
| 1968 | 37.4 | 168.4 | 87.2 | 136.9 | 81.8 | 38.9 | 68.5 | 201.7 | 29.4 | 189.8 | 225.1 | 86.5 |
| 1969 | 63.9 | 124.9 | 165.6 | 51.4 | 223.4 | 50.6 | 112.9 | 31.7 | 104.4 | 102.3 | 62.2 | 14.2 |
| 1970 | 149.2 | 7.1 | 176.4 | 213.2 | 103.6 | 74.5 | 101.6 | 232.7 | 34.8 | 81.2 | 65.0 | 43.2 |
| 1971 | 38.2 | 5.9 | 19.6 | 166.0 | 131.5 | 106.1 | 72.8 | 116.3 | 73.1 | 86.3 | 52.5 | 117.3 |
| 1972 | 21.6 | 63.4 | 16.9 | 125.1 | 165.1 | 146.1 | 82.1 | 142.2 | 117.0 | 177.0 | 197.2 | 14.5 |
| 1973 | 36.4 | 36.2 | 0.6 | 53.3 | 135.3 | 34.2 | 53.7 | 170.5 | 92.0 | 48.6 | 166.8 | 48.4 |
| 1974 | 9.3 | 1.8 | 201.3 | 112.6 | 75.4 | 111.9 | 140.3 | 135.9 | 23.4 | 67.3 | 63.7 | 13.3 |
| 1975 | 9.3 | 31.0 | 36.4 | 129.6 | 262.4 | 51.5 | 170.8 | 188.3 | 121.7 | 48.6 | 59.0 | 13.0 |
| 1976 | 3.5 | 17.4 | 14.6 | 57.1 | 188.1 | 42.8 | 116.2 | 89.2 | 29.6 | 28.5 | 22.3 | 33.7 |
| 1977 | 45.9 | 11.1 | 18.9 | 400.7 | 160.6 | 76.1 | 103.5 | 156.2 | 52.2 | 192.5 | 321.3 | 14.5 |
| 1978 | 37.4 | 40.1 | 87.4 | 171.0 | 141.9 | 78.3 | 109.9 | 117.2 | 51.3 | 103.4 | 130.6 | 56.9 |
| 1979 | 37.4 | 40.1 | 87.4 | 171.0 | 141.9 | 78.3 | 109.9 | 117.2 | 51.3 | 103.4 | 130.6 | 56.9 |
| 1980 | 16.3 | 2.0 | 20.7 | 153.2 | 200.0 | 27.4 | 38.3 | 63.8 | 24.3 | 43.8 | 141.6 | 6.5 |
| 1981 | 0.9 | 4.5 | 260.1 | 164.4 | 82.5 | 33.4 | 418.7 | 390.8 | 83.4 | 47.7 | 17.7 | 20.8 |
| 1982 | 12.7 | 6.7 | 51.1 | 362.2 | 333.8 | 195.0 | 103.0 | 132.9 | 9.5 | 188.6 | 192.3 | 72.0 |
| 1983 | 6.5 | 81.9 | 87.4 | 101.1 | 114.9 | 79.7 | 38.0 | 117.2 | 51.3 | 103.4 | 130.6 | 56.9 |
| 1984 | 37.4 | 40.1 | 6.0 | 57.6 | 43.0 | 70.0 | 109.9 | 117.2 | 51.3 | 103.4 | 51.6 | 16.6 |
| 1985 | 46.5 | 26.0 | 133.9 | 352.4 | 240.8 | 71.0 | 96.4 | 67.9 | 30.3 | 103.4 | 130.6 | 56.9 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 37.4 | | 117.5 | 221.5 | 107.0 | 155.5 | 109.9 | 61.3 | 34.0 | 103.4 | 130.6 | 56.9 |
| 1987 | 2.4 | 65.1 | 51.0 | 109.3 | 246.9 | 97.2 | 8.8 | 80.0 | 20.1 | 27.2 | 224.0 | 56.9 |
| 1988 | 58.3 | 6.7 | 87.4 | 347.8 | 210.7 | 55.1 | 163.2 | 85.1 | 105.3 | 92.5 | 68.2 | 63.5 |
| 1989 | 37.4 | 44.0 | 90.8 | 186.5 | 150.4 | 23.0 | 84.6 | 117.2 | 51.3 | 103.4 | 130.6 | 56.9 |
| 1990 | 37.4 | 82.9 | 123.7 | 30.4 | 5.5 | 6.4 | 99.1 | 68.1 | 17.8 | 53.5 | 130.6 | 56.9 |
| 1991 | 37.4 | 35.5 | 90.5 | 0.0 | 105.3 | 88.2 | 93.1 | 244.1 | 10.3 | 92.8 | 52.8 | 45.4 |
| 1992 | 37.4 | 13.3 | 33.1 | 178.4 | 76.9 | 103.0 | 70.9 | 98.4 | 60.4 | 180.9 | 92.6 | 77.1 |
| 1993 | 112.3 | 104.5 | 9.4 | 127.6 | 224.4 | 57.8 | 72.5 | 72.3 | 13.2 | 31.5 | 169.0 | 41.6 |
| 1994 | 37.4 | 6.3 | 71.4 | 159.9 | 125.0 | 122.2 | 65.7 | 159.3 | 22.0 | 5.4 | 325.8 | 53.9 |
| 1995 | 37.4 | 29.8 | 70.4 | 174.6 | 12.7 | 41.7 | 97.9 | 94.0 | 55.7 | 103.4 | 51.4 | 44.0 |
| 1996 | 36.9 | 69.0 | 153.8 | 56.1 | 73.6 | 227.9 | 234.9 | 126.6 | 54.2 | 12.2 | 99.8 | 56.9 |
| 1997 | 12.9 | 40.1 | 56.8 | 284.7 | 26.7 | 142.8 | 186.0 | 136.2 | 5.4 | 251.8 | 258.4 | 74.3 |
| 1998 | 37.4 | 40.1 | 87.4 | 171.0 | 141.9 | 78.3 | 109.9 | 117.2 | 51.3 | 103.4 | 130.6 | 56.9 |
| 1999 | 37.4 | 25.0 | 160.2 | 142.1 | 94.5 | 50.2 | 75.2 | 98.1 | 19.5 | 179.1 | 60.3 | 16.7 |
| 2000 | 32.0 | 40.1 | 87.4 | 20.7 | 144.5 | 139.9 | 88.1 | 71.3 | 54.8 | 143.4 | 80.2 | 33.4 |
| 2001 | 116.0 | 4.2 | 170.5 | 188.0 | 124.1 | 42.6 | 100.9 | 168.4 | 39.8 | 102.0 | 169.5 | 8.9 |
| 2002 | 43.4 | 2.5 | 115.8 | 69.9 | 145.0 | 60.1 | 30.5 | 58.8 | 11.9 | 187.4 | 85.0 | 168.1 |
| 2003 | 13.5 | 8.9 | 104.9 | 242.7 | 176.3 | 31.5 | 56.1 | 178.7 | 51.3 | 18.6 | 80.0 | 56.9 |
| 2004 | 49.3 | 10.1 | 29.7 | 265.7 | 87.8 | 72.5 | 118.6 | 141.5 | 92.1 | 154.8 | 224.8 | 62.2 |
| 2005 | 67.1 | 46.2 | 107.3 | 135.9 | 350.2 | 85.7 | 157.0 | 4.5 | 104.9 | 53.6 | 46.0 | 56.9 |
| 2006 | 54.0 | 19.0 | 127.2 | 234.8 | 86.7 | 62.7 | 137.9 | 138.9 | 58.1 | 217.3 | 262.8 | 149.6 |
| 2007 | 18.8 | 72.5 | 27.1 | 187.9 | 185.5 | 239.0 | 154.8 | 110.1 | 83.2 | 36.0 | 5.0 | 56.9 |
| 2008 | 41.2 | 24.1 | 170.2 | 112.5 | 20.2 | 63.2 | 149.1 | 49.5 | 134.6 | 242.0 | 115.6 | 56.9 |
| 2009 | 66.7 | 40.1 | 10.5 | 147.7 | 201.3 | 20.8 | 87.4 | 31.5 | 36.4 | 132.4 | 46.6 | 194.0 |
| 2010 | 37.4 | 63.2 | 325.7 | 250.5 | 111.2 | 78.8 | 87.2 | 104.7 | 74.3 | 103.4 | 77.4 | 13.1 |

**Source: (KMS 2011)**

## APPENDIX V: AVERAGE YIELD, RAINFALL AND TEMPERATURE

| year | Yield(bags/ha) | Rain(mm) | Tmax$^0$C | Tmin$^0$C | Tave$^0$C |
|---|---|---|---|---|---|
| 1984 | 2.700 | 621.6 | 25.8 | 11.9 | 12.5 |
| 1985 | 3.150 | 1079.8 | 24.7 | 11.8 | 12.6 |
| 1986 | 3.520 | 759.2 | 25.0 | 12.3 | 12.6 |
| 1987 | 3.641 | 819.8 | 25.9 | 12.4 | 12.6 |
| 1988 | 3.600 | 791.2 | 24.9 | 12.6 | 12.6 |
| 1989 | 4.050 | 886.4 | 24.8 | 11.9 | 12.6 |
| 1990 | 2.970 | 789.2 | 25.2 | 12.1 | 12.7 |
| 1991 | 3.072 | 921.9 | 25.1 | 12.9 | 12.7 |
| 1992 | 3.870 | 724.8 | 25.5 | 12.5 | 12.7 |
| 1993 | 2.520 | 675.8 | 25.4 | 12.0 | 12.7 |
| 1994 | 3.870 | 777.2 | 25.1 | 12.6 | 12.8 |
| 1995 | 3.600 | 756.6 | 25.5 | 12.5 | 12.8 |
| 1996 | 3.330 | 819.1 | 24.9 | 13.0 | 12.8 |
| 1997 | 2.513 | 898.2 | 25.5 | 12.5 | 12.8 |
| 1998 | 0.351 | 737.8 | 25.8 | 13.0 | 12.8 |
| 1999 | 2.880 | 732.1 | 25.2 | 12.3 | 12.8 |
| 2000 | 2.692 | 698.5 | 26.0 | 12.4 | 12.9 |
| 2001 | 3.063 | 894.7 | 25.2 | 12.9 | 12.9 |
| 2002 | 2.339 | 728.2 | 26.9 | 12.7 | 13.0 |
| 2003 | 2.420 | 1140.4 | 25.6 | 13.1 | 13.0 |
| 2004 | 2.790 | 667.4 | 26.2 | 12.7 | 13.0 |
| 2005 | 4.050 | 694.8 | 26.2 | 13.0 | 13.2 |
| 2006 | 4.115 | 748.5 | 25.7 | 13.4 | 13.4 |

**Source:( KMS, 2011)**

## APPENDIX VI: UPPER BASIN DATA ON YIELD, RAINFALL AND TEMPERATURE

| Year | Pdn | area | annual -rain | annual - min temp | Annual max temp | mam - min temp | jjas - min temp | ond - min temp | mam - max temp | jjas- max temp | ond- max temp | mam- rain | jjas- rain | ond - rain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1984 | 133,655 | 49,502 | 929.7 | 11.2 | 25.9 | 12.6 | 11.1 | 10.9 | 27.4 | 24.4 | 25.4 | 263.8 | 441.5 | 204.9 |
| 1985 | 174,759 | 55,479 | 1331.5 | 11.3 | 25.5 | 12.6 | 10.7 | 10.8 | 25.5 | 24.3 | 26 | 737.3 | 404.7 | 126.8 |
| 1986 | 181,383 | 51,529 | 952.2 | 11.8 | 25.9 | 12.9 | 11.4 | 11.4 | 26.1 | 24.1 | 26.2 | 390.6 | 415.8 | 126.1 |
| 1987 | 173,311 | 47,600 | 1172.3 | 12 | 26.5 | 12.9 | 11.6 | 11.9 | 26.7 | 25.4 | 26.5 | 535.4 | 327.8 | 217.9 |
| 1988 | 245,088 | 68,080 | 1267.6 | 12.1 | 25.4 | 13.3 | 11.9 | 11.2 | 26.1 | 23.9 | 24.9 | 383.6 | 603.1 | 209.9 |
| 1989 | 276,818 | 68,350 | 1313.8 | 11.7 | 25.3 | 12.4 | 11.5 | 12 | 25.5 | 24.3 | 25.3 | 549.6 | 438.3 | 291.7 |
| 1990 | 177,431 | 59,741 | 1186.5 | 11.7 | 25.6 | 13 | 11 | 11.1 | 25.8 | 24.8 | 26 | 500.5 | 340.7 | 169.2 |
| 1991 | 169,535 | 55,186 | 1264.8 | 12 | 25.7 | 13.2 | 12.1 | 11.1 | 26.4 | 24.3 | 25.3 | 410.6 | 557.9 | 214.8 |
| 1992 | 225,195 | 58,190 | 1269.8 | 12 | 25.9 | 13 | 11.8 | 11.6 | 27.2 | 24.1 | 25.5 | 301.9 | 587.8 | 369.5 |
| 1993 | 165,504 | 65,676 | 1157.5 | 11.7 | 25.7 | 12.4 | 11.4 | 11.5 | 26.8 | 24.5 | 26.1 | 361.4 | 430.6 | 161.3 |
| 1994 | 268,191 | 69,300 | 1106.7 | 11.9 | 25.9 | 12.8 | 11.9 | 11.6 | 26.5 | 24.3 | 25.3 | 258 | 547 | 287.8 |
| 1995 | 228,960 | 63,600 | 1249.1 | 12 | 25.8 | 12.9 | 12 | 11.7 | 26.5 | 24.6 | 25.4 | 383.4 | 511.5 | 281 |
| 1996 | 181,152 | 54,400 | 1171.9 | 12.1 | 25.5 | 13.4 | 12.1 | 11.4 | 26 | 24.1 | 26 | 469.8 | 467.8 | 117.4 |
| 1997 | 159,298 | 63,400 | 1247.4 | 12.3 | 26.1 | 12.9 | 11.7 | 13.2 | 26.5 | 25.4 | 24.8 | 501.5 | 405.2 | 332.2 |
| 1998 | 22,640 | 64,500 | 1287.1 | 12.5 | 25.9 | 13.8 | 12 | 11.7 | 27.4 | 24.5 | 26.1 | 328.5 | 492.1 | 243.6 |
| 1999 | 179,424 | 62,300 | 1179.9 | 11.8 | 25.8 | 13.2 | 11.4 | 11.9 | 26.3 | 24.4 | 25.2 | 363 | 443.6 | 363.2 |
| 2000 | 172,260 | 64,000 | 1029.3 | 11.9 | 26.3 | 13 | 11.7 | 12.1 | 27.5 | 24.7 | 25.6 | 294.6 | 492.1 | 223.3 |
| 2001 | 240,408 | 78,500 | 1439.3 | 12.4 | 25.7 | 13.4 | 12.3 | 12.1 | 26.2 | 24.5 | 25.6 | 446.5 | 557.1 | 371.6 |
| 2002 | 208,902 | 89,300 | 1148.3 | 12.5 | 26.8 | 13.4 | 12 | 12.5 | 28.7 | 25.5 | 25.7 | 403.3 | 361.3 | 342 |
| 2003 | 199,605 | 82,491 | 1372.7 | 12.4 | 26.3 | 13.5 | 12.2 | 11.9 | 27 | 24.6 | 26.6 | 597.5 | 615.8 | 131 |
| 2004 | 266,915 | 95,657 | 1124.5 | 12.4 | 26.5 | 13.4 | 11.8 | 12.1 | 27.2 | 25.4 | 26.2 | 388.1 | 336.2 | 344 |
| 2005 | 383,573 | 94,700 | 1076.9 | 12.5 | 26.8 | 13.7 | 12.2 | 12.2 | 27.4 | 25.2 | 26.9 | 360.5 | 466.1 | 187.8 |
| 2006 | 392,574 | 95,400 | 1491.9 | 12.9 | 26.2 | 13.7 | 12.7 | 13 | 26.2 | 25.3 | 25.2 | 474.7 | 495.5 | 442 |
| 2007 | 507,500 | 101,500 | 1568 | 12.4 | 25.9 | 13.1 | 12.9 | 11.5 | 27 | 24.3 | 26.3 | 463.2 | 818.2 | 130.2 |

**Source: (Author, 2011)**

## APPENDIX VII: MID BASIN DATA ON YIELD, RAINFALL AND TEMPERATURE

| Year | Pdn | area | annual -rain | annual - min temp | Annual max temp | mam - min temp | jjas - min temp | ond - min temp | mam - max temp | jjas- max temp | ond- max temp | mam- rain | jjas- rain | ond - rain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | 34,356 | 116,748 | 2244.8 | 14.3 | 26.8 | 15.3 | 13.6 | 14.3 | 27.4 | 26 | 25.9 | 600.3 | 773.5 | 641.8 |
| 1983 | 244,232 | 84,225 | 1920.5 | 14.6 | 27.1 | 15.5 | 14.1 | 14.5 | 28.4 | 25.9 | 26.3 | 625.9 | 739.7 | 414.9 |
| 1984 | 255,000 | 102,000 | 1637.9 | 13.9 | 27.3 | 14.9 | 13.4 | 14.1 | 28.3 | 26.1 | 27 | 626.1 | 609.3 | 328 |
| 1985 | 260,070 | 138,400 | 2210 | 14.1 | 26.8 | 15.1 | 13.2 | 14.2 | 26.6 | 25.7 | 27.7 | 846.7 | 817.2 | 321.5 |
| 1986 | 207,021 | 115,750 | 1785.9 | 14.1 | 27 | 14.8 | 13.5 | 14.3 | 27 | 25.8 | 27.1 | 728.2 | 559.3 | 400.5 |
| 1987 | 273,000 | 137,400 | 2003.2 | 14.4 | 27.5 | 15.1 | 13.8 | 14.5 | 27.5 | 26.8 | 27.5 | 832.9 | 530.9 | 440.2 |
| 1988 | 208,620 | 12,200 | 2608.5 | 14.3 | 26.8 | 15 | 13.7 | 14.2 | 27 | 25.7 | 27 | 957.1 | 1122.4 | 336.2 |
| 1989 | 310,040 | 134,800 | 1996.8 | 13.8 | 26.4 | 14.2 | 13.3 | 14.4 | 26.6 | 25.3 | 26.7 | 672.5 | 724.8 | 499.3 |
| 1990 | 310,500 | 135,000 | 1993.4 | 13.4 | 26.8 | 14.6 | 12.5 | 12.8 | 26.6 | 26.3 | 27.1 | 633.2 | 725.7 | 344.7 |
| 1991 | 187,845 | 73,655 | 2069 | 13.9 | 26.9 | 15 | 13.4 | 13.6 | 27.4 | 25.8 | 26.6 | 868.7 | 516.2 | 450.1 |
| 1992 | 194,360 | 74,754 | 1939.9 | 14.1 | 27.1 | 15.5 | 13.3 | 13.4 | 28.2 | 25.7 | 26.6 | 598 | 907.5 | 322.7 |
| 1993 | 146,330 | 66,514 | 1521.2 | 13.8 | 26.9 | 14.4 | 13.2 | 14 | 27.8 | 25.4 | 28 | 491.3 | 613.6 | 217.6 |
| 1994 | 180,000 | 69,343 | 1938.7 | 13.7 | 27.2 | 14.3 | 13.5 | 13.5 | 27.2 | 25.8 | 27.4 | 798.2 | 608.2 | 450.6 |
| 1995 | 179,179 | 68,915 | 1976.4 | 13.7 | 27.2 | 14.9 | 13.5 | 12.9 | 27.3 | 26.3 | 27.1 | 684.8 | 736.9 | 404.6 |
| 1996 | 67,740 | 27,096 | 2123.2 | 14.3 | 27.1 | 14.8 | 14.1 | 14.4 | 27.3 | 26.1 | 27.3 | 826.5 | 672.6 | 342 |
| 1997 | 65,234 | 30,198 | 1619.5 | 14.2 | 28 | 14.8 | 13.6 | 15 | 28.8 | 27.2 | 26.5 | 581.3 | 471.4 | 520.3 |
| 1998 | 83,202 | 31,108 | 1828 | 14.2 | 27.5 | 15.1 | 13.6 | 13.7 | 28.7 | 26.4 | 27.7 | 683.4 | 523.3 | 325.3 |
| 1999 | 81,746 | 33,005 | 1758.2 | 13.8 | 27.2 | 14.2 | 13.3 | 14.4 | 27 | 26 | 27 | 668.3 | 648.2 | 322.2 |
| 2000 | 54,041 | 30,020 | 1394.3 | 14 | 27.8 | 14.7 | 13.4 | 14.6 | 28.4 | 26.7 | 27 | 371.7 | 560.7 | 392.8 |
| 2001 | 61,071 | 29,500 | 2097.7 | 14.5 | 27.1 | 14.8 | 14.2 | 15 | 27.3 | 26.2 | 27.5 | 700.2 | 765.2 | 404.1 |
| 2002 | 65,026 | 26,008 | 2122.3 | 14.8 | 27.6 | 15.6 | 14 | 15.3 | 28 | 27 | 27.1 | 856.9 | 526.1 | 616.3 |
| 2003 | 76,007 | 24,797 | 2100.3 | 14.8 | 27.9 | 15.6 | 14.3 | 14.9 | 28.4 | 26.3 | 28.1 | 706.5 | 1007.8 | 282.2 |
| 2004 | 58,906 | 29,450 | 1568 | 14.8 | 27.6 | 15.3 | 14 | 14.9 | 28 | 26.8 | 27.4 | 529.9 | 572.1 | 319.2 |
| 2005 | 62,572 | 26,265 | 1707.5 | 14.9 | 28.2 | 15.9 | 14.2 | 14.9 | 28.2 | 26.6 | 28.6 | 562.9 | 729.3 | 271.3 |
| 2006 | 66,746 | 27,050 | 2306.6 | 14.9 | 27.6 | 15.4 | 14.4 | 14.9 | 27.2 | 26.8 | 26.8 | 858.9 | 715.6 | 600.9 |
| 2007 | 74,965 | 17,610 | 2025.1 | 14.4 | 27.5 | 14.7 | 14.3 | 14.3 | 28.6 | 26 | 28 | 529.6 | 999.4 | 384.3 |

**Source: (Author, 2011)**

## APPENDIX VIII: LOWER BASIN DATA ON YIELD, RAINFALL AND TEMPERATURE

| Year | Pdn | area | annual - rain | annual - min temp | Annual max temp | mam - min temp | jjas - min temp | ond - min temp | mam - max temp | jjas- max temp | ond- max temp | mam- rain | jjas- rain | ond - rain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1984 | 13,772 | 22,310 | 839.6 | 16.9 | 29.8 | 18 | 16.4 | 16.8 | 30.6 | 28.9 | 29.6 | 394.3 | 204.2 | 155.7 |
| 1985 | 14,254 | 23,092 | 862 | 16.9 | 29.4 | 17.5 | 15.9 | 17.7 | 28.8 | 28.3 | 30.9 | 415.6 | 189.3 | 121.8 |
| 1986 | 16,393 | 29,506 | 861.4 | 17.1 | 29.3 | 17.7 | 16.3 | 17.2 | 28.6 | 28.9 | 29.7 | 407.7 | 119.8 | 228.8 |
| 1987 | 17,999 | 30,600 | 640.1 | 17.6 | 29.9 | 18.3 | 16.9 | 17.8 | 29 | 29.9 | 30.4 | 278.1 | 107 | 166.1 |
| 1988 | 15,901 | 31,484 | 825.4 | 17.2 | 29.5 | 18 | 16.5 | 16.9 | 28.7 | 28.9 | 30.6 | 255.1 | 190.1 | 122.5 |
| 1989 | 15,901 | 31,484 | 695.8 | 16.7 | 29.3 | 16.8 | 16.2 | 17.2 | 28.9 | 29.3 | 30 | 278.5 | 86.8 | 277.5 |
| 1990 | 15,901 | 31,484 | 874.2 | 17 | 29.9 | 17.6 | 16.3 | 17.2 | 28.9 | 29.9 | 31 | 323.4 | 144.6 | 165 |
| 1991 | 12,069 | 17,001 | 856.1 | 17.2 | 29.8 | 18 | 16.7 | 16.9 | 29.8 | 29 | 29.9 | 548.4 | 64.2 | 91.6 |
| 1992 | 12,069 | 17,001 | 595.1 | 17.4 | 29.7 | 18.1 | 16.7 | 17.1 | 29.4 | 28.5 | 30.1 | 216 | 129.1 | 219.1 |
| 1993 | 13,605 | 18,366 | 692.6 | 17 | 30.1 | 17.7 | 16.4 | 17.7 | 30 | 29.4 | 31.9 | 222.6 | 135.8 | 180 |
| 1994 | 16,957 | 42,731 | 790.8 | 17.3 | 29.7 | 17.9 | 16.5 | 17.3 | 29.1 | 29 | 30.1 | 303.6 | 147.4 | 267.5 |
| 1995 | 15,680 | 28,224 | 754.8 | 17.1 | 29.7 | 17.8 | 17 | 17.1 | 29.6 | 29 | 29.9 | 398.9 | 136.8 | 192.2 |
| 1996 | 15,489 | 34,849 | 870.4 | 17.2 | 29.4 | 17.8 | 16.9 | 17.2 | 29.4 | 28.5 | 30 | 426.3 | 204.6 | 147.8 |
| 1997 | 14,540 | 24,305 | 904.3 | 17.2 | 30.2 | 17.6 | 16.8 | 18 | 30 | 30.5 | 29 | 253.5 | 66.7 | 569.2 |
| 1998 | 13,450 | 31,044 | 785.4 | 17.5 | 30 | 18.5 | 16.6 | 17.5 | 30.4 | 29.3 | 30.8 | 321.7 | 155.1 | 216.1 |
| 1999 | 16,685 | 44,406 | 842.1 | 16.9 | 29.6 | 17.7 | 16.1 | 16.9 | 28.6 | 28.7 | 30 | 416.3 | 189.5 | 152.6 |
| 2000 | 8,117 | 8,935 | 681.1 | 17.1 | 30.1 | 17.3 | 17 | 17.7 | 30.4 | 29.4 | 29.4 | 229.2 | 146.5 | 274.9 |
| 2001 | 10,419 | 14,036 | 701.1 | 17.4 | 29.2 | 17.9 | 16.9 | 17.7 | 29.3 | 28.7 | 29.8 | 257.3 | 227.4 | 147.1 |
| 2002 | 11,327 | 15,319 | 891.6 | 17.5 | 29.9 | 18 | 16.7 | 17.7 | 29.1 | 30 | 29.8 | 310.2 | 148.8 | 361.4 |
| 2003 | 8,443 | 13,467 | 694.8 | 17.4 | 29.7 | 18.2 | 17 | 17.3 | 29.5 | 29.1 | 30.4 | 344.5 | 168.4 | 142.5 |
| 2004 | 7,643 | 12,167 | 515 | 17.5 | 29.6 | 18.2 | 16.8 | 17.5 | 29.5 | 28.8 | 29.8 | 78.1 | 115.7 | 234.7 |
| 2005 | 7,116 | 14,765 | 478 | 17.6 | 30.7 | 18.4 | 16.8 | 17.8 | 29.9 | 29.5 | 32.3 | 245.7 | 113.7 | 77.9 |
| 2006 | 8,505 | 17,784 | 942.6 | 17.6 | 30.1 | 18.2 | 17.1 | 17.9 | 29.1 | 29.6 | 29.4 | 363.4 | 84.2 | 373.5 |
| 2007 | 11,050 | 222,340 | 405.4 | 17.1 | 29.4 | 17.2 | 16.9 | 17.3 | 29.8 | 28.6 | 30.2 | 100.8 | 125 | 82.3 |

**Source: (Author, 2011)**