ASSESSMENT OF VULNERABILITY OF WATER RESOURCES TO CLIMATE VARIABILITY IN MARA RIVER BASIN, KENYA

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree or any other award in any other University.

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DEDICATION

I dedicate this thesis to two people whom I hold dear to my daughter Tiana Wanjiru Kamau and my wife Jane Nzomo, their love keeps me going every day.

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Finally, the culmination of a journey that started with a single step and gradually developed into one mighty task. My joy and sense of fulfilment would not be complete without making mention of everyone who offered help and support, in one way or another, during the entire period of this master's study. The brevity of this acknowledgement does not in any way downplay the support I have received from anyone mentioned, or not mentioned, herein. Firstly, I am sincerely grateful to Mr and Mrs Lawrence Waithaka and East Africa office - Global Water for Sustainability (GLOWS) for their financial support in form of tuition and scholarship to undertake this study. I thank my workmates Mr. Aron Kecha and Mr. Griffins Ochieng who gave me time to concentrate on my studies at the expense of work the office.

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ACRONYMS AND ABBREVIATIONS

ALRMP	Arid Lands Resource Management Programme
AOI	Area of Interest
ASALs	Arid and Semi-Arid Lands
ENSO	El Nino Southern Oscillations
ESARO	East and Southern Africa Regional Office
ETM	Enhanced Thematic Mapper
EWS	Early Warning systems
GCM	Global Circulation Models
GIS	Geographical Information Systems
GPS	Global Positioning Systems
IIRR	International Institute for Rural Reconstruction
IPCC	Intergovernmental Panel on Climate Change
IR	Infra-Red
KMD	Kenya Meteorological Department
LANDSAT	Land Satellite
LULC	Land Use Land Cover
LVB	Lake Victoria Basin
MDGs	Millennium Development Goals
MK	Mann Kendall
MMNR	Maasai Mara National Reserve
MRB	Mara River Basin

MWI	Ministry of Water and Irrigation
NDVI	Normalized Difference Vegetation Index
NDWI	Normalised Difference Water Index
NIR	Near Infra-Red
RGS	River Gauging Stations
SOE	State of Environment
SSA	Sub Saharan Africa
TAR	Third Assessment Report
TM	Thematic Mapper
UNEP	United Nations Environmental Program
UNEP	United Nations Environmental Programme
USGS	United States Geological Survey
WRMA	Water Resources Management Authority
WFP	World Food Programme
WWF	World Wide Fund

ABSTRACT

Africa's water resources are at risk due to climate variability further aggravating the water scarcity and also ability to cope with other external pressures and calamities. Climate variability on intra-seasonal and decadal time scales has had significant impact on water resources. The main objective of the study is to assess the vulnerability of water resources to climate variability in Mara River Basin. To achieve this, study analysed rainfall, river flow and satellite imagery data. The rainfall data spanned from1980 to 2011 and satellite imagery from the years 1985-2010. The study relied on secondary data (rainfall, temperature, river gauges measurements and satellite imagery) various empirical tools such as key informant interviews and field observation guides. Numerical tools for data analysis comprised descriptive statistics and non-parametric test. Satellite imagery were analysed by use ILWIS and Arc GIS software's and climatic data analysed through Microsoft excel. The study results showed great inter annual variability of rainfall and corresponding river flow. Temperature data trend line analysis showed an annual increase of 0.2^0C. Rainfall showed an increase of 0.02mm/yr at Narok station while Ilkerin weather station showed a decreasing trend of 0.002mm/yr. The rainfall showed uneven distribution both in spatial and temporal scales with cyclic nature of high intensity followed by drought periods. The inter-annual variability in rainfall is more sporadic and unpredictable, and this affects water supply both to the ecosystem, domestic and agricultural use. The study predicts that this will have detrimental effect on the basin water resources at a local level and regional. Vegetation cover type and trend over time was utilised as an indicator of water resources vulnerability. The analysis of NDVI, NDWI and LULC thematic maps from 1985-2010 provided compelling analysis of vegetation density and distribution in the basin. Forest/shrubland reduced by 38% while cropland/shrubland increased by 28% and surface water aerial coverage reduced by 10.7% within the same period. There is direct relationship between vegetation cover change and reduction of aerial coverage of surface water. Majority of the respondents interviewed were farmers (24.4%) planting mainly maize and pastoralists (45.5%). Drought and crop failure were the many effects of climate variability. The respondents (45.2%) experienced more than 5months of food deficiency. Majority associated the insufficiency to climate variability. Distance travelled to access water averaged 2-5km,while most of the water resources were seasonal (56.7%), apart from distance other challenges affecting water accessibility include dirty water and conflicts with neighbours. To overcome these challenges there is need to develop basin management strategies geared towards increased forest conservation. The need for education and awareness creation on crop diversification and investment in both household and community water harvesting strategies. There is need for integrated waters resources management especially on education on efficient water use mechanisms both for domestic and agriculture.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Different African regions have been recognized to have climates that are among the most variable in the world on intra-seasonal to decadal timescales. The continent is characterized by a highly variable climate (Hulme *et al.,* 2001) climate change models suggest that, in general terms, the climate of Africa will become more variable. Although the exact nature of the changes is not known and remains debatable, there is general consensus that extreme events will more frequent and may get worse (Elasha, 2006). The (IPCC, 2001) report cites changes in some extreme climate phenomena indicating that extreme events, including floods and droughts, are becoming increasingly frequent and severe. According to (IPCC, 2001), impacts of climate change in Africa are likely to be more severe on the continent's water resources and food security, precipitation and insulation, length of growing seasons, water availability, carbon uptake, incidences of extreme weather events, changes in flood risks, drought, distribution and prevalence of human diseases and plant pests. It is probable that these increased frequency of disasters results from a combination of climatic variability, socio-economic and demographic changes.

The variability in climate particularly the changes in temperature, precipitation and sea levels are expected to impact on availability of freshwater. This is of particular concern to Africa, where around 300 million people have no access to potable water (UNEP, 1999). Also, much of the population relies on surface water for supplies (De

Wit & Jacek, 2006). Due to the inter-annual variability of rainfall, people are becoming reliant on other sources like groundwater and water harvesting as their source of freshwater. Studies by (Stutcliffe & Knott, 1987: Groove, 1996; Conway, 2002) demonstrate high levels of inter-annual variability in many river basins of Africa. This variability is experienced mostly in dry areas (less than 800mm of rainfall per annum).

Global warming is rendering the climates of some regions dryer and all more variable and unpredictable (Parry, 1992). For example, the arid and semi-arid of sub-Saharan Africa (SSA) are characterized by limited water supply, low and highly variable rainfall, and recurrent droughts. High temperatures and intense precipitation, associated with a changing climate, causes increased water loss through evaporation and run off, respectively (IRR, 2002). The rainfall is bimodal and characterised by spatial-temporal uncertainty. Rainfall seasonality affects forage availability, livestock production and ultimately the livelihoods of pastoralists. The 1998 El Niño phenomenon produced an estimated five-fold increase in rainfall (Glalvin *et al.*, 2001) the phenomenon fell between some of the worst drought years in 1997 and 1999 according to (WFP, 2000). Such extremes of climate variability make fundamental changes to ecosystem structure and function. These in turn affect human land-use, wildlife and livelihoods and have the potential to make these populations more vulnerable. The Mara River, rises on the Mau escarpment in Kenya an important water tower, is one of the most ecologically important trans-boundary river basins in Sub-Saharan Africa. Climate variability has serious impact on the future sustainability of the river basin, with potentially detrimental impacts on the ecosystem as a whole. This study therefore attempts to assess the vulnerability of the water resources within the basin caused by climate variability.

1.2 Statement of the problem

Climate adaptation research, while it has provided vital information in understanding climate change and variability, it has had its focus on climate change scenarios emphasizing more on technical and infrastructural adaptive strategies to climate variability. This approach limitedly accounts for varying climates in terms of rainfall amounts, duration and temperatures especially at local levels, where adaptive and coping strategies are needed most. The Mara river basin is undergoing ecological changes that are associated with deforestation on the Mau catchment, and land tenure changes due to expansion of cash crops and settlements, among other factors. The above factors coupled with potential climatic variability, already witnessed in the East African region, have negatively impacted on water resources within the Mara river basin. This study therefore seeks to add information and knowledge on the status of the water resources and the impact of climate variability to ensure timely detection and predication of any impacts.

1.3 Justification of the study

Water resources and livelihoods particularly in Sub-Saharan Africa are highly vulnerable to year-year climate variability. To resource-limited households who depend on rain-fed agriculture and surface water, overcoming food insecurity and water scarcity remains a challenge. It is anticipated that assessment of vulnerability to climate variability would go a long way to capture the multiple factors that impact on people's livelihoods especially to water sources. This study identified the Mara river basin in Kenya, a semi arid area susceptible to rainfall variability, the main social economic activity being pastoralism, tourism and both small and large-scale mechanized farming. The area depends on Mara River, swamps and seasonal rivers namely Talek, Engare Ngobit and Sand River. Given the effect of climate variability on water resource. This assessment offers a wider scope in developing strategies for efficient water resource management in the basin, as there is need to adapt to changes in the volume, timing and quality of water (Wigley, 2005)

1.4 Research questions

i. How are the hydro-climatic trends in the Mara river basin?

ii. How does the trends interact with land use/land use change to influence vulnerability of water resources

iii. How do the trends influence vulnerability of socio-economic livelihoods?

1.5 Objectives of the study

1.5.1 Main objective

The main objective of the study is the assessment of vulnerability of water resources to climate variability in Mara river basin.

1.5.2 Specific objectives

i) To examine the hydro-climatic trends in the Mara river basin

ii) To examine the hydro-climatic trends interactions with land use/land use change that influence water resources vulnerability.

iii) To assess the influence of climate variability on the socio-economic livelihoods in the Mara river basin.

1.6 Significance of the study

Climate variability and water resources management are significant global issues with regional, national and local impacts. This is evident in Kenya where an increasingly variable climate has resulted to prolonged drought and widespread flooding. This study assesses the risks to water resources due to climate variability and change. This is significant in policymaking and implementation especially in water resources management, planning and design of infrastructure. It is widely recognized that improved incorporation of current trend of climate variability would make future adaptation easier. Water resources management is clearly linked to other policies; hence the study aligns adaption measures across multiple water dependant sectors.

1.7 Scope and limitations of the study

The study is based in the Mara river basin in Kenya, the middle catchment of the basin on the Amala, Nyangores other tributaries and focuses on assessing the vulnerability of water resources to climate variability within the sub-catchment. It utilises datasets such as river flow data, temperature, and rainfall and satellite images. The study utilizes river flow gauging stations namely Nyangores and Amala, two weather stations namely Narok (1980-2010), and Ilkerin Integral Development (1980-1999). Assessment of vulnerability relies heavily on data and this was the biggest limitation scanty data on rainfall, temperature and river flow data, due to lack of temperature data the study utilised data of adjacent weather stations with similar altitude. Other limitations encountered in the field were language barrier and false responses from respondents. However, efforts were put in place to minimise their impact on the outcome of the study.

1.8 Operational definition of terms

Adaptation: adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Climate change: Changes in the mean climate on a global scale

Climate variability: Is defined as inter-seasonal and/or inter-annual variation of the climate within a specified geographic location.

Livelihood: The capabilities, assets and activities required for means of living.

Mitigation: Actions that limit the level and rate of climate change.

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate–related stimuli.

Vulnerability: The degree to which water resources in the basin are susceptible to, or unable to cope with, adverse effects of climate variability (rainfall and temperature as the indicators of study due to their spatial and temporal variability)

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews empirical works done by other scholars in the field of climate variability and its effect on water resources and management. The chapter deals with role of climate variability and the link to water resources, and inherently the assessment of the future vulnerability and conceptual framework. It reviews studies done specific to the basin and identifies gaps that this study attempts to fill.

2.2 Overview of climate change vulnerability

A decade of research on climate change vulnerability shows that inevitably it is the poor and the most vulnerable who suffer the impacts of changing environmental conditions (Adger, 2000; Downing, 2003), Vulnerability is both spatial and temporal variable; manifested in local economic, social and cultural characteristics, as well as the local physical conditions. The World Bank (2002) states that the linkages of climate variability impacts to water resources are dynamic, often inter-connected, and context-specific reflecting geographic location; economic, social, and cultural characteristics; prioritization and concerns of individuals, households, and social groups; as well as institutional and political constraints. This means that the assessment of vulnerability must be made at the appropriate spatial scale for example at sub-basin in order for it to be useful for defining the appropriate adaptation responses (Stern, 2006)

2.3 Impact of climate change and variability on water resources

Rainfall and water resources in Africa display high levels of variability across a range of spatial and temporal scales with important consequences for the management of variability and risk in water resource systems. Studies by (Stutcliffe & Knott, 1987; Groove, 1996; Conway, 2002) demonstrate high levels of inter-annual variability in many river basins of Africa. Detailed studies of smaller size river basins in East Africa highlight changes in daily flow characteristics; for example, in Tanzania, (Valimba *et al.*, 2008) identified the effects of human activities on the land surface and their influence on flow regimes in the Mara River Basin. He found out that the main driver of variability in river flows was of course rainfall, particularly at the scale of large river basins. Nevertheless, in spite of the large influence of rainfall fluctuations on river flow variability the response may be influenced by other factors such as changes in land cover or land use, abstraction, hydrological characteristics (Ribot *et al.*, 1996) argues. The actual hydrological conditions will also mediate the effects of rainfall variability; for example, lake and wetland systems may smooth and delay runoff responses according to (Adger, 2000) and semi-arid river basins with low runoff coefficients often exhibit high sensitivity to rainfall fluctuations (Nemec & Schaake, 1982).

2.4 Linking climate change and water resources

The vast majority of the Earth's water resources are saline with only 2.5% being fresh water. Approximately 70% of the fresh water available on the planet is frozen in the icecaps of Antarctica and Greenland leaving the remaining 30% (equal to only 0.7% of total water resources worldwide) available for consumption. From this remaining 0.7%, roughly 87% is allocated to agricultural purposes (IPCC, 2007). Since the Third Assessment Report (TAR) by the IPCC, there have been many studies on trends in river flows during the 20th century at scales ranging from catchment to global. Some of these studies have detected significant trends in some indicators of river flow, and some have demonstrated statistically significant links with trends in temperature or precipitation. Groundwater flow in shallow aquifers is affected by climate variability and change through recharge processes as studied by (Chen *et al.*, 2002) as well as by human interventions in many locations (Petheram *et al.*, 2001). A variety of climatic and non-climatic processes influence flood characteristics, resulting in river floods. Floods depend on precipitation intensity, volume, timing, antecedent conditions of rivers and their drainage basins amongst others. Kron & Berz (2007) however observed that the increase in precipitation intensity and other observed climate changes often trigger floods, and that climate change might already have had an impact on the intensity and frequency of floods.

2.5 Assessment of vulnerability and climate variability

The literature on vulnerability and variability assessment is very large and increasing rapidly. Brooks (2004) point out that even in the (IPCC, 2001) there is inconsistent use of the term vulnerability assessment. According to (O'Brien *et al.*, 2002) multiple processes govern climate variability and stressors which if addressed enhance adaptive capacity of a system. Therefore we look vulnerability as two types:

biophysical vulnerability, or the sensitivity of the natural environment to an exposure to a hazard; and social vulnerability, or the sensitivity of the human environment to the exposure.

Mutal *et al.* (2002) identified vulnerability indicators of the water resources to climate variability; they found out both natural (temperature, rainfall, evapo-transpiration) and artificial factors associated with human activities like settlements, land use/ cover change, and population increase. For the purpose of this study, the research focused on rainfall and temperature as the indicators of study due to their spatial and temporal variability. Artificial factors were used in mapping as they enhance or exacerbate the vulnerability. Kundzewicz *et al.* (2007) looked at impact of climate change on freshwater resources and how it has influenced water management and achievement of Millennium Development Goals (MDGs). They found out that Arid and Semi Arid Lands (ASALs) areas already experiencing water scarcity would be the most vulnerable due to decreasing water resources resulting from the decline on surface and subsurface flows. They recommend shift in water management to go beyond infrastructure development to address the problem and include forecasts, models and climate variability science in developing the water management policies.

Sullivan & Huntingford (2009) in their study on water resources, climate change and human vulnerability, found out that millions of people are relatively at high risk of climate change, though their studies were on Asia they acknowledges that Africa needs more focus due to its inherent low adaptive capacity. They acknowledge that national representation does not provide any indication of how risks are distributed across a country or region and they recommend assessment of vulnerability be considered beyond the national scale. They point out that the assessment be done at appropriate spatial scale in order to be useful for defining adaptation and mitigation measures. It is against this recommendation that this study seeks to assess the vulnerability at a local scale.

A hydro-meteorological data analysis by (Melesse *et al.,* 2008) for the Mara river basin showed an annual decline of 14% of rainfall in the Kaptunga forest, the river flows of Amala and Nyangores had different hydrologic responses with Amala having a low dry flow and a high wet flow unlike that of the Nyangores. He concludes that high wet season and low dry season flows can be attributed to less vegetation cover leading to low recharge in the headwaters and also flashy runoff due to less infiltration associated with less vegetation cover but recommends further studies on the actual cause of the flow reduction in the basin. Further research by (Melesse *et al.,* 2008) to model the impact of Land-cover and rainfall regime scenarios on the flow of Mara River; used the Soil and Water Assessment Tool (SWAT) Model to consider different input scenarios of land-cover and precipitation pattern to estimate the changes in the hydrologic flow of the basin, The analysis showed that a 20% reduction in rainfall translates to a 46% flow reduction annually, the model predicts a rainfall decline by 20% for the period of 2010-2030. But according to (Ringus *et al.,* 1996) there is contradiction with this study. His simulations of climate change in Africa indicated that Kenya would be about 1.4^{0}C warmer by the year 2050; annual rainfall will increase by 20% within the same period especially in the highlands while potential evapotranspiration (PET) is expected to increase in Africa region.

2.6 Climate Variability analysis by NDVI

Maps and time series of Normalized Difference Vegetation Index (NDVI) help to get insight in the changes that occur in the fractional vegetation cover pattern at a global scale. The degradation and intensification is not solely dependent on climate change. Many factors play an important role in the variation of vegetation cover; like deforestation for wood production and agricultural cropping cycles and due to forest fires and disasters. Besides this, there is a natural variation of rainfall, solar radiation and temperature depending on the seasons. Other variations occur in shorter and longer cycles, which can have decadal and multi-decadal periods. Labat (2008) analysed the long-term annual fluctuations of large river discharges by means of wavelet transforms. He concluded that the investigated rivers show interannual, 15–20-year and 28–30-year variability. Since river flow reflects rainfall and rainfall induces green vegetation, these time scales should be found in the variations of the vegetation cover as well. This can be studied by means of a NDVI time series to quantify the actual fractional vegetation cover changes caused by climate change and human activities

Time series of NDVI to map the spatial-temporal behaviour of vegetation cover. To use NDVI as a correct representation of spatial temporal vegetation cover behaviour, relations between NDVI and measured vegetation need to be established. NDVI is used to study changes in the fractional ground cover. Changes in the vegetation cover are often related to variations in seasonal weather conditions and the moisture availability in the subsoil. Therefore relation between phonological behaviour, climate and land use exists (Labat, 2008)

The phenology of vegetation is influenced by temperature, moisture and soil conditions (Andreas *et al.,* 1984). Vegetation varies within biannual, annual and inter-annual periods. Variations in the vegetation cover are strongly related to the amount and distribution of rainfall (Anyamba & Eastman, 1996). The correlation between precipitation and NDVI was demonstrated by (Gray & Tapley, 1985; Greegor & Norwine, 1986; Justice *et al.,* 1986; Nicholoson *et al.,* 1990; Tucker & Nicholson, 1999; Eklundh & Olsson, 2003 and Martiny *et al.,* 2006). A near linear relation between the NDVI growing season and the rainfall was found for East Africa and the Sahara by (Justice *et al.,* 1986) and (Tucker & Nicholson, 1999). A strong correlation has been found between rainfall anomalies and the onset variability of the vegetation species in Northern Europe. Hermann *et al.* (2005) also found a correlation between precipitation and vegetation cover behaviour.

Vegetation variability is strongly related to variations in surface temperature. Buermann *et al.* (2003) examined the NDVI time series to relate inter-annual variations in vegetation greenness to climate variability. They concluded that during springtime spatial-temporal vegetation variation was strongly correlated to the surface temperature. The El Niño Southern Oscillation (ENSO) causes the surface temperature variability. This variability is the main driver for the inter-annual greenness variation in the Northern Hemisphere. According to (Zhou, 2003) there is a significant relation between changes in NDVI and land surface temperature. This relation corresponds with ground-based measurements of temperature. These researches show that vegetation cover and NDVI variability are strongly related to climatic variability.

The registration of vegetation cover behaviour by satellites presents a global database for the analysis of phenology responses to climate variability. Besides regular variations, changes occur that are more permanent. According to several researches trends in vegetation cover behaviour occur. Trends were found by among others (Verhoef *et al.,* 1996; Anyamba & Eastmen, 1996; Archer, 2004; Herman *et al.,* 2005). Myeni *et al.* (1997) found a global increase in photosynthetic activity, between 1981 and 1991, due to an increase in temperature. Eklundh & Olsson (2003); (Olsson *et al.,* 2005) studied vegetation greenness (1982-1999) for the African Sahel and found a strong positive trend. They fitted linear functions through the data using least-squares regression. Also (Herman *et al.,* 2005) found increased greenness (1982-1999) for the African Sahel. They concluded however that the increase was to a larger extent related to an increase in soil moisture than to instantaneous precipitation. Observed trends in the vegetation cover could give an indication of changes in the hydrological system. However the causes of these changes have to be determined first.

Vegetation cover changes can also be directly due to anthropogenic effects. Therefore a distinction has to be made on which anomalies occur due to climatic changes and which occur due to anthropogenic influences. According to (Olsson *et al.*, 2005) a positive trend in vegetation greenness can to a large extent be explained by an increase in rainfall. They stated that climatic influences could not explain differences entirely, which means other factors play a part in vegetation cover changes. Herman *et al.* (2005) made a distinction between climate driven and anthropogenic vegetation variability. They determined spatial vegetation dynamics and trends in NDVI and rainfall by means of fitting simple linear functions through the time series. Evans & Geerken (2004) did research in Syria comparing change in greenness to ground data. They found that large-scale anthropogenic increase in livestock caused changes in vegetation cover, which were observed in satellite data. Other causes for anthropogenic vegetation cover change are for instance cutting down forest, change of land-use and diversion of water for irrigation.

2.7 Conceptual framework

The risks associated with anthropogenic climate change call for a broad spectrum of policy responses to reduce the vulnerability of climate sensitive systems (F"ussel & Minnen, 2002). The conceptual framework figure starts with the emission of greenhouses gases to the atmosphere that causes the atmospheric concentrations of these gases especially CO_2 to increase. The increased concentrations alter the climate system over time a scenario commonly referred to climate change. Climate is a multi–dimensional phenomenon that exhibits variations on different time scales.

Burton (1997) suggests a hierarchy of weather and climate phenomena to distinguish single climate variables, specific weather events, and long–term processes (such as anthropogenic climate change). Climate impacts are a function of (the change in) the exposure of a system to climatic stimuli and of its sensitivity to these stimuli. Climate variability and change, will affect regional climate variability in various ways such as the frequency, intensity, and location of extreme events. Non–climatic factors denote a wide range of properties that affect the vulnerability of a system or society to climate change. They include ecological, economic, social, demographic, technological, and political factors. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

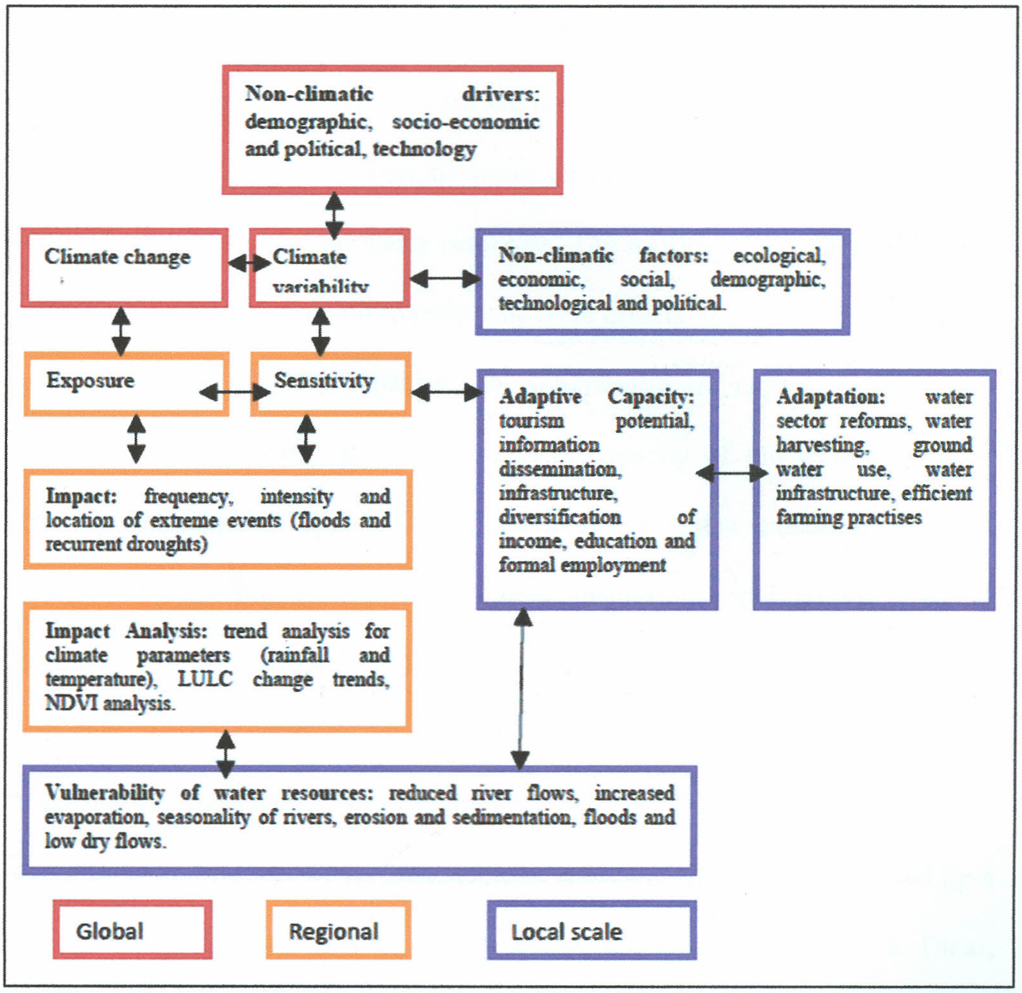

Figure: 2-1 Conceptual framework for assessing climate vulnerability. Adopted and modified from (F"ussel & Minnen, 2002)

In this conceptualization, the vulnerability of a system to climate change includes both an external dimension, which is represented by its exposure to climate variations, and an internal dimension, which comprises its sensitivity to them and its adaptive capacity (Bohle *et al.,* 1994). Mitigation and adaptation adjustments can either be anticipatory, reactive, private or public, autonomous and planned adaptation. In this conceptual framework we combine adaptation measures that are targeted directly at the vulnerability of water resources and those that affect non-climatic factors influencing the water resources. The adaptive capacity of the water resources determines its potential to reduce adverse effects of climate variability and change. As a result, adaptive capacity and vulnerability are negatively correlated. Non–climatic factors clearly affect the adaptive capacity of the water resources. Determinants of adaptive capacity in social systems comprise economic resources, technology, information, skills, infrastructure, institutions, and equity (Smit & Pilifosova, 2001; Yohe & Tol, 2002). Non-climatic driving forces often influence the adaptive capacity of a system or social set up such as demographic, economic, socio–political, and technological. Thus, vulnerability is understood as a function of three components: exposure, sensitivity and adaptive capacity, which are influenced by a range of biophysical and socio-economic factors according to (Tiwari & Dinar, 2003). It is generally assumed to be more efficient to develop response strategies that reduce the vulnerability of water resources in the Mara river basin to multiple stressors simultaneously than to formulate independent adaptation strategies for each of them.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction.

This chapter introduces the area of study, climatic and socioeconomic activities of the area. It further presents the sampling procedure, data sets and type, data collection and data analysis methods. This is represented through maps, satellite images, thessian polygons and equations.

3.2 The study area

This study was carried out in the Mara River basin, between $0^{0}45'0''$S and $34^{0}45'0''$E in and between $2^{0}0'0''$S and $35^{0}45'0''$E. The figure 3:1 below represents the area of the study. The entire Mara River Basin covers an area 13,325 km^2 around Mara River, while the area of study covers 6,336km^2. The basin highlands are at 2,915m above sea level and the low lands are at 1,140m above sea level at Lake Victoria. The basin covers Nakuru, Bomet and Narok counties in Kenya. There are numerous streams in the basin that drain into the Mara River. The main tributaries are Amala, Nyangores, Engare Ngobit, Talek and Sand Rivers. The Amala and Nyangores tributaries from the Mau forests are the only permanent tributaries to Mara River.

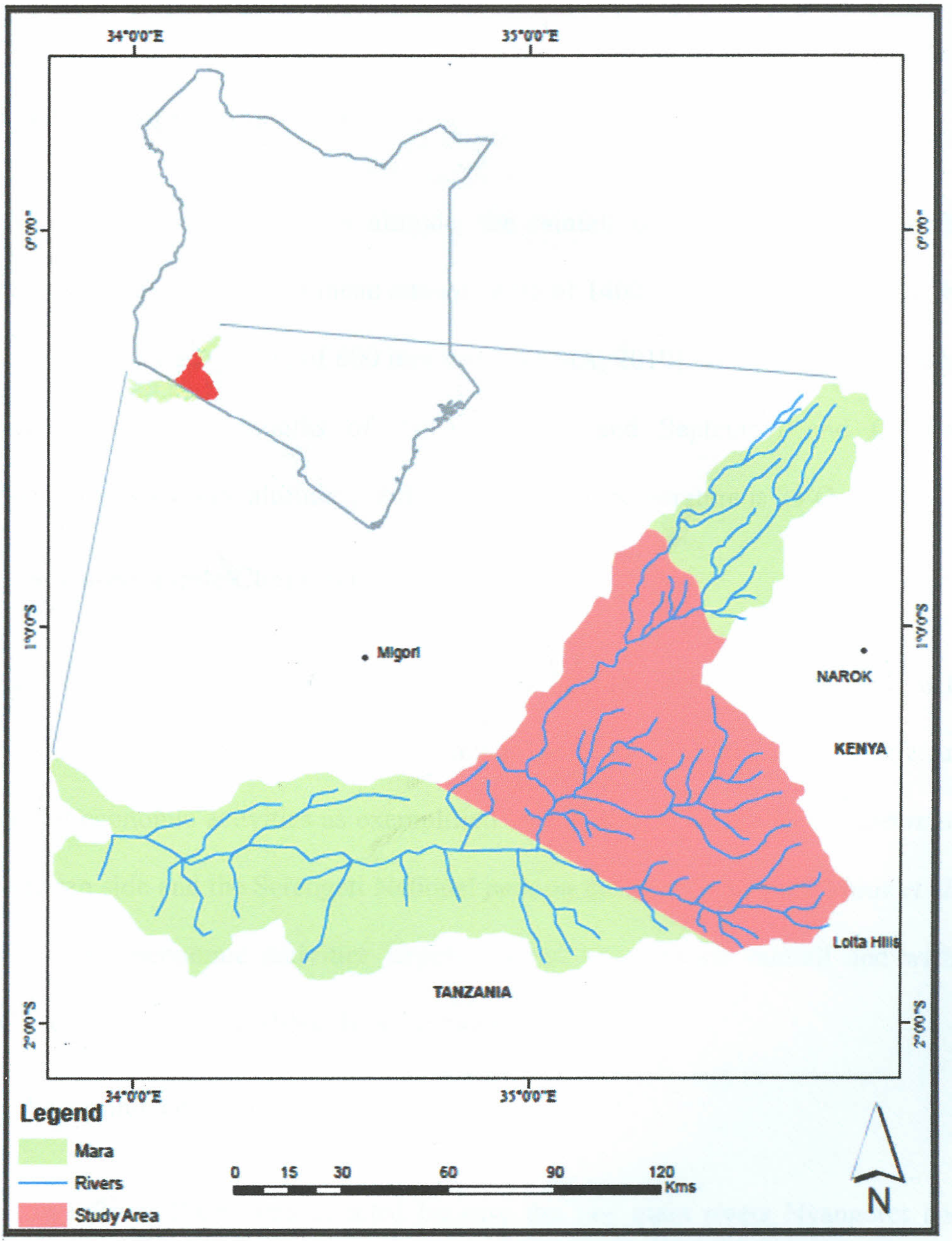

Figure 3-1 Area of study Source: Author, (2012)

3.3 Climate of the study area

The climate varies greatly with altitude; the rainfall is generally greatest on the highlands of the basin with a mean annual value of 1400 mm year and lowest in the lowlands with a mean value of 600 mm year (NEMA, 2010). The rainfall is bimodal expected during the months of April to May and September and October. Temperatures vary with altitude, but the mean annual temperature is 25^{o}C.

3.4 Socio-economic Characteristics

About 62% of the households are smallholder farmers (Aboud *et al.,* 2002) with livestock rearing being the second dominant activity. Tourism and wildlife are important economic activities as exemplified by the Maasai Mara Game Reserve on the Kenyan side and the Serengeti National park on the Tanzanian side (Mutie *et al.,* 2006). These economic activities largely depend on adequate rainfall and water supply to maintain the livelihoods and ecosystem integrity.

3.5 Sampling Techniques

The Mara River Basin was selected because the two main rivers Nyangores and Amala merge to Mara River, a key river in the Maasai Mara National Reserve an ecosystem of world importance. These two rivers from previous studies have shown inter annual variability to climatic conditions, hence the need for assessing the vulnerability of water resources within this basin to climate variability.

The study applied mixture of sampling techniques guided by the objectives. Objective one and two applied purposive sampling while, objective on household survey applied random sampling with a total number of households being 9,500 (KNBS, 2009). The sample size of the study was based on the total number of households in the sub-catchment, and was calculated using the following formula (Equation 1) that was adopted from (Yamane, 1967) cited in (Glenn, 1992). This formula is best placed for qualitative studies like for the case of this study.

$$n = \frac{N}{1+N(\alpha)^{2}}$$ --Equation: 3-1

Where:

n= is the sample size

N= is the total number of households in the catchment

α =is the level of precision and/or margin of error set at 10%

The sample size computed by the formula is 98.6 (approximately 99). An additional 5% was added to cover for the anticipated non-response and fouled questionnaires and to increase the power of the study. Thus the total sample size was 104. With this sample size for the study area, a proportionate random sampling was developed and distributed accordingly to represent the population characteristic of the households in the basin (Mugenda & Mugenda, 1999). This technique ensures that sub-groups that constitute the majority in the population are also presented proportionately (Mugenda, 2008)

3.6 Data collection and quality control

During the research there were challenges of data collection, such limitations in availability of good field data sets. Though it was impractical to collect comprehensive data on all hydrological variables at time-scales appropriate to catchment-scale processes, efforts were made to make use of available for the purposes of this study. Yet even with these difficulties, such data was vital in order to understand catchment behaviour and response to climate variability and change. Data used in this research was collected from various institutions and agencies while some were downloaded various research institutions. These included hydro-meteorological data, land cover, digital elevation model (DEM), and satellite imagery. Quality control was done by use of graphical, statistical and ground-truthing methods.

3.7 Data type and sets

3.7.1 Objective One: Hydro-meteorological data

Climatic data (temperature and rainfall) data sets were obtained from Kenya Meteorological Department (KMD). River flows data sets were obtained from Water Resources Management Authority (WRMA). The data span varied as follows, Narok (1980-2011) and Ilkerian (1980-1999) stations with long-term time series data were used for the identification of temperature and rainfall variation. Figure 3:3 Despite Narok station being outside the area of study, the data was used as it had both temperature and rainfall unlike other stations, which had only rainfall. The temperature data from Narok Station was presumed to represent the average basin temperature for the purposes of this study. The river flow data was acquired for Nyangores (1LA03) (1980-2008) and Amala (1LB02) (1980-2007). The stream flow data utilized the velocity area method to determine the volumetric stream conveyance averages. The projection was determined based on the trends to adequately cover the study duration.

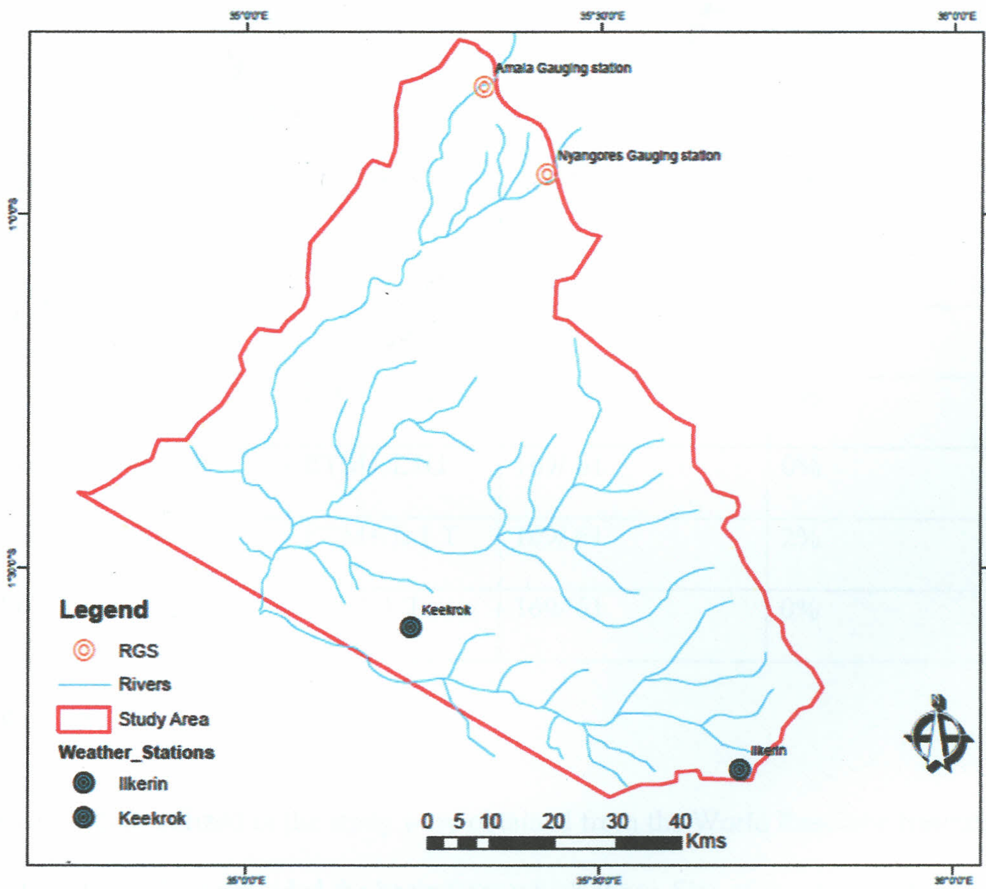

Figure 3-2 River gauges and weather stations in the area of study. Source: Author, (2013)

3.7.2 Objective Two: Satellite images and Remote Sensing Data

Varied categories of data were collected. Secondary data included LANDSAT satellite images which were obtained mainly from Global Visualization website of the United States Geological Survey (USGS). The satellite images were used to generate false image, NDVI and NDWI images of the study area for the years 1985, 1989, 2000, 2002 and 2010. The images utilized in the study are summarized in the table below.

Table 3-1: Satellite images used in the study

Scene Capture Date	LANDSAT	SCENE PATH/ ROW	CLOUD COVER
9TH January, 1985	TM L 1 T	169/ 61	0%
1ST March, 1989	L 4 – 5 TM	169/ 61	0%
27TH January, 2000	ETM+ L1G	169/ 61	0%
1ST January, 2002	ETM+ L 1 T	169/ 61	2%
18TH December, 2010	TM L 1 T	169/ 61	0%

Source: (GloVis, 2012)

Other GIS data utilized in the study were obtained from the World Resource Institute (WRI) website. This provided the basis from which shape files of the Area of Interest (AOI) were generated. The Landsat satellite images for the study duration were sampled based on their clarity, quality and equally important their availability. This formed the criteria for the choice of image years. To ensure consistency and reliability of NDVI and NDWI analysis, the image dates were concentrated almost at the same time of the year for the sampled years. Image processing and classification utilized field knowledge, observation, ground truthing and use of GPS control points to ensure high thematic output maps' accuracy.

3.7.3 **Objective Three: Socio-economic data**

The study further reviewed the understanding on vulnerability of water resources to climate variability on shocks or risks to which households are exposed. To determine this vulnerability, risk factors, the data was obtained using variables such

i) Socio-economic and demographic characteristics (Age, Gender, level of education, main occupation, length of stay at study area, type of housing)

ii) Resource ownership and utilization (size, utilization, type of food crops)

iii) Water resource (access and availability)

iv) Climatic changes (noticeable seasonal changes, early warning systems and effects)

Primary data was collected using a structured questionnaire and key informant interviews. A structured questionnaire was used to gather data from the 104 sampled households. Key informant interviews with 13 relevant key persons in the area (including water department and environment office at the district and water resource users at the local levels, opinion leaders and community groups) were used to collect data and at the same time to complement and/or give more detailed information gathered using questionnaires.

3.8 Data analysis methods

The study applied various analysis methods to achieve the objectives of the study as elaborated below.

3.8.1 Objective One: Hydro-meteorological

Hydro-meteorological time series almost always exhibit seasonality due to the periodicity of the weather. This seasonality arises from seasonal variations of precipitation volume and evapo-transpiration. Such kind of data requires require trend analysis that incorporates the seasonal component hence the use of trend analysis methods in this study. Simple linear regression (Y) is one of the most useful parametric models to detect trends was used in this study.

The model for Y can be described by the equation below:

$Y = aX + b$ --Equation: 3-2

Where,

X=time (year),

a=slope coefficients;

b=least-square estimates of the intercept.

The slope coefficient indicates the annual average rate of change in the hydrologic characteristic. If the slope is statistically significantly different from zero, the interpretation is that it is entirely reasonable to interpret there is a change occurring over time. The sign of the slope defines the direction of the trend of the variable: increasing if the sign is positive, and decreasing if the sign is negative.

3.8.1.1 Determining river flow rates

River flows are dependent on factors such as temperatures, precipitation, soil properties and catchment vegetation cover amongst other factors. Therefore, the capacity to measure accurately river flow is vital to effectively plan for and manage water resources. This includes improved ability to accurately predict floods and estimate the water and sediment regimes over time. The stream flow trend analysis over years has provided an insight in determining the change in water deficit, essentially sustained decline in stream flows can be used to confirm that an area is becoming water deficit. The data is recorded river heights, recorded daily at equal times in the morning and evening. Utilizing the RGS records the stream flow is determined based on the continuity equation. This equation optimizes the velocity-area stream flow method. This method depends on measuring the average velocity of flow and the cross-sectional area of the channel and calculating the stream flow based on stream velocity (Hudson, 1993).

The formula is as follows

$Q = A * V$ --Equation: 3-3

Where: Q = Total recharge (m^3/s)

V = Stream velocity (m/s)

A = Cross sectional area of the stream profile defined by the river transect (m^2)

3.8.1.2 Determining the climatic trends

Precipitation is the primary source of ground and surface water resource recharge, in assessing water resource vulnerability in the basin, rainfall trend therefore provides a vital inception into the water balance. The historical data that was utilized in generating rainfall distribution, pattern and trends in the basin. The data acquired had various gaps of missing years and inaccurate data, there was therefore need for data reconstruction to fill in the missing gaps, rainfall time series were filled with seasonal mean values for the specific missing dates. The data ranged from as early as 1980-2008. Five stations whose details are summarized below were utilized to generate trend curves and maps. The table 3:2 below represents the station location and coordinates.

Table 3-2 Weather stations utilized in the study

Station ID	Station Name	Location/ Coordinate	
		Latitude	Longitude
1.	Ilkerian	S 01.7833	E 035.7000
2.	Narok	S 01.0901	E 035.8773

(Source: Author, 2013)

3.9.3 Objective Two: Digital image processing and analysis

The study mainly utilized ILWIS and ArcGIS 10 for digital image processing. In ArcGIS there are two ways for classifying multiband raster images, which is supervised and unsupervised classification. This study employed supervised classification, which relies on the researcher's knowledge of the study area to achieve good results. This involved three major processes; image restoration, image enhancement and image classification. Image classification procedure in ArcGIS logically follows the steps illustrated in the Image classification workflow figure below.

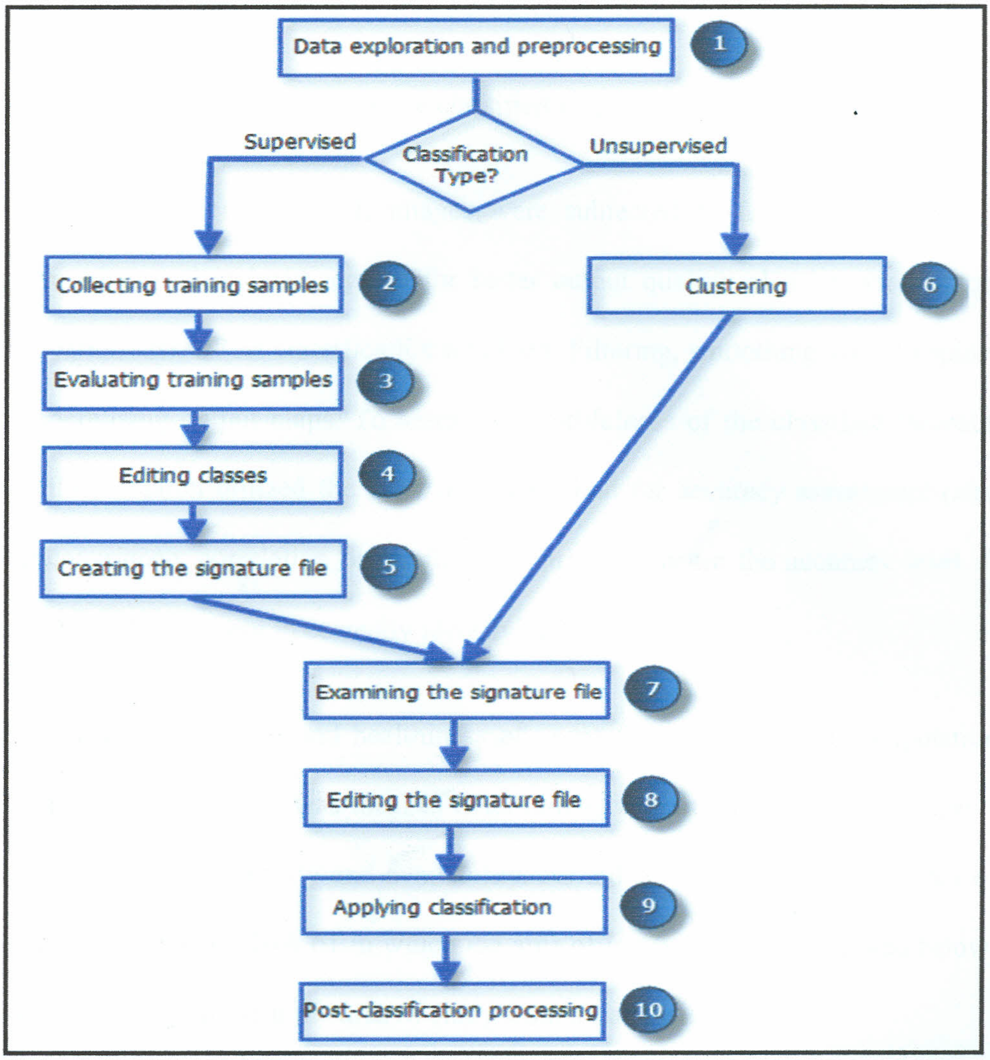

Figure 3-3 Image classification workflow (Source: ESRI, 2010)

The steps can be summarized as:

i. Display three band composite image

ii. Choose representative training samples for the desired classes

iii. Generate, manage and evaluate signature file

iv. Execute the Maximum Likelihood Classification tool

v. Colour code and show the classified image

To ensure high accuracy level, images were subjected to further processing to remove noises and isolated regions for better output quality; also known as post-classification tasks. Post classification involved: Filtering, smoothing and clumping, and generalizing output maps. To assess the truthfulness of the classified thematic maps; this research utilized the error matrix method for accuracy assessment (also called covariance, correlation or confusion matrix) to ensure the accuracy level of image processing system in correctly identifying selected classes.

To assess the distribution and healthiness of vegetation cover, NDVI computation was used. NDVI function was ideal in determining vegetation change, an indicator water resources vulnerability and availability. As indicated above, the path/ ram of the images utilized are 169/ 61 in which the area of interest lies as illustrated below. Figure 3:4 below represent the area of study from a Landsat image.

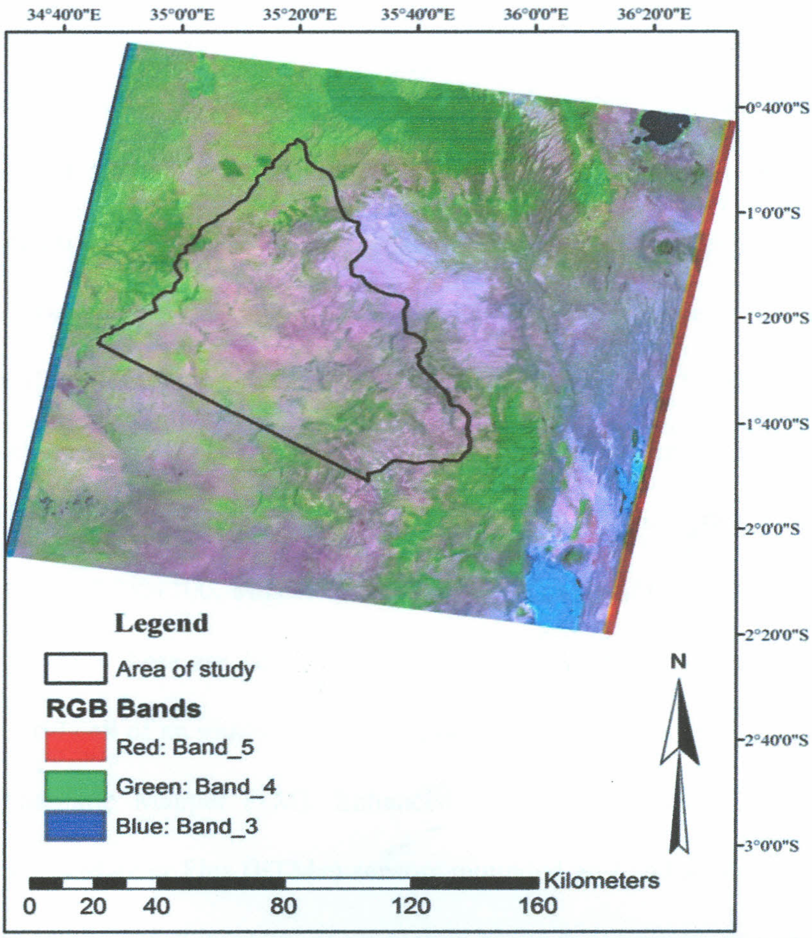

Figure 3-4 Area of study in the context of the Landsat scenes used (Source: Glovis, 2012; WRI, 2008)

NDVI uses the intensity discrepancy of bands 3 and 4, to compute the bustle of vegetation symbolized as:

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)};$$ --Equation: 3-4

Where RED and NIR represent the spectral reflectance value recorded in the red and near-infrared (NIR) ranges in the electromagnetic spectrum respectively. NDVI values range between -1 to +1, but vegetation has NDVI values of between 0.1 and 0.7 (Roettger, 2007). The higher the NDVI the higher the fraction of live green vegetation present in the area. Landsat band 4 (0.77 – 0.90 μm) measures the reflectance in NIR region and Band 3 (0.63 – 0.69 μm) measures the reflectance in Red region. ArcGIS generates the output using the following formula: NDVI = ((IR-R)/(IR+R))*100+100. This results in a value in range of 0 - 200 and fit within an 8 – bit structure, these are the zeros and ones that computer space uses to write value to each grid cell of an image. The bulk of the LANDSAT images utilized were captured by Thematic Mapper (TM), Enhanced Thematic Mapper (ETM) and Enhanced Thematic Mapper Plus (ETM+) sensors mounded on Landsat 4–7. From the images, the healthiness and intensity of vegetation cover is computed, this capacity provided for in the calculate geometry command. The 1st order classes based on physical characteristics of the land cover were used. The classes are forest land, barren land, water, tundra, agricultural land, built-up land, range land and wetland (Anderson, *et al.*, 1976) as applicable. Trend analysis was especially conducted based on the variation in vegetation cover change and surface water coverage trends in relation to the area's water balance.

NDVI utilizes the chlorophyll present in plants leaves. Chlorophyll absorbs more energy at ~0.45 μ (micron) (blue) and also marginally light at ~0.65 μ (red), while it moderately reflects ~0.55 μ (green) and strongly reflects ~0.86 μ (NIR). This accounts for the green colour of most plants. NDVI utilizes this distinctive spectral behaviour of chlorophyll for visualization, depicted by the difference between calculated solar reflection from a satellite band very sensitive to chlorophyll (~0.65 μ) and a band in the red part of the visible spectrum (~0.65 μ). Values below 0.15 are not shown in NDVI but instead are replaced by natural colour imagery that represents barren land (Wu, Niu, Tang, & Huang, 2008).

3.8.2 **Objective Three: Socio-economic data analysis**

The data analysis compromised both qualitative and quantitative techniques. Data screens were prepared using SPSS version 19, then the corded data was keyed on the software for descriptive analysis. The descriptive analysis gives frequencies and proportions. This study used bivariate analysis techniques to assess to the relationships between independent and dependant variables: cross tabulations were used to generate the rows and column percentages for the interactions between the various categories the variables.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and discusses the findings of the study. The results are divided into two climatic data and land cover data analysis. The findings are presented in form of graphs, tables and satellite images. Photographs taken in the field also formed part of data presentation. Interpretation was done in reference to the stated study objectives and hypothesis.

4.2 Objective One: Hydro-climatic trends results

To understand the study objective, this study sought to analyse the nature and trends of temperature and rainfall and river flow in the middle catchment of the Mara River Basin. Rainfall and temperature were presented in graphs and weather maps. River flow was analysed and presented in graphs monthly and yearly totals.

4.2.1 Climatic trend analysis

The figures below provide a synthesized aggregate summary of the Mara Basin monthly and annual rainfall from Ilkerian and Narok station. The data span varied as follows Narok (1980-2011) and Ilkerian (1980-1999)

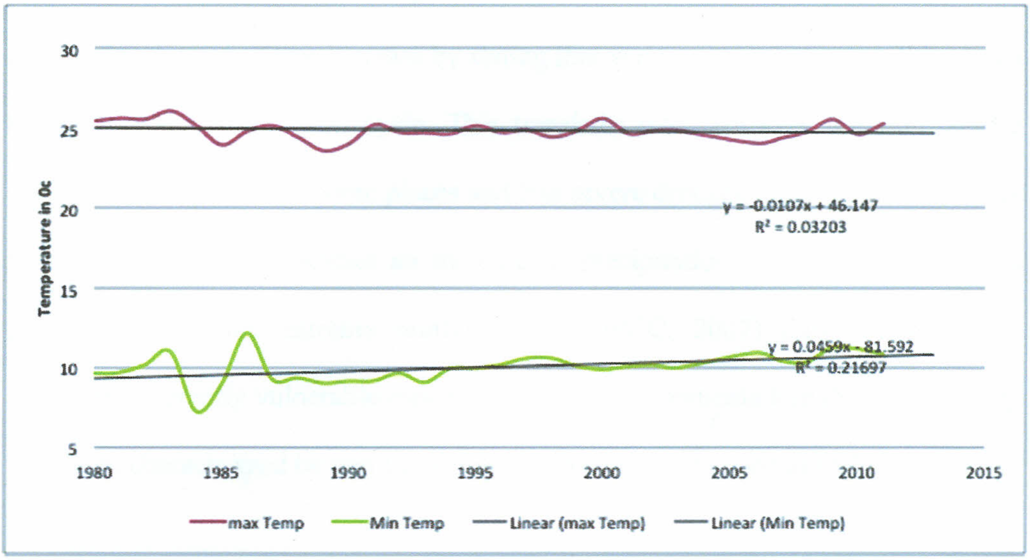

Figure 4-1: Maximum and Minimum temperature at Narok Station. Source: (Field Data, 2013)

Figure 4:1 shows a slight increase in minimum temperature at the Narok Station. The R^2 is given as 0.21697 indicating that the temperature has increased with an average of 0.2^0C every year and therefore projected to increase with the same margin. Where Y equation shows a negative, the R^2 denotes a decreasing trend and vice versa when the equation shows positive. Thus the maximum temperature has an R^2 of -0.033 this shows a decreasing trend. These results represent close findings by (Odada & Olago, 2002; IPCC, 2007) which indicated that the air temperature in East Africa would increase by 5^0C by 2050, while us rainfall will increase by 20%. The increase in temperature has a significant effect on water resources due to evaporation increase, open surface water, wetlands and water pans will experience increased evaporation.

Increased temperature will lead to loss soil moisture a significant in agriculture and determining the NDVI of the vegetation. The IPCC (2007) report summarizes the effect of such temperature increase by stating that warmer temperatures will lead to a more vigorous hydrological cycle. This translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. IPCC models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events (IPCC, 2007) thus making water resources inherently vulnerable especially in arid environments like the area of study which are characterized by non linear relationships between rainfall and run off.

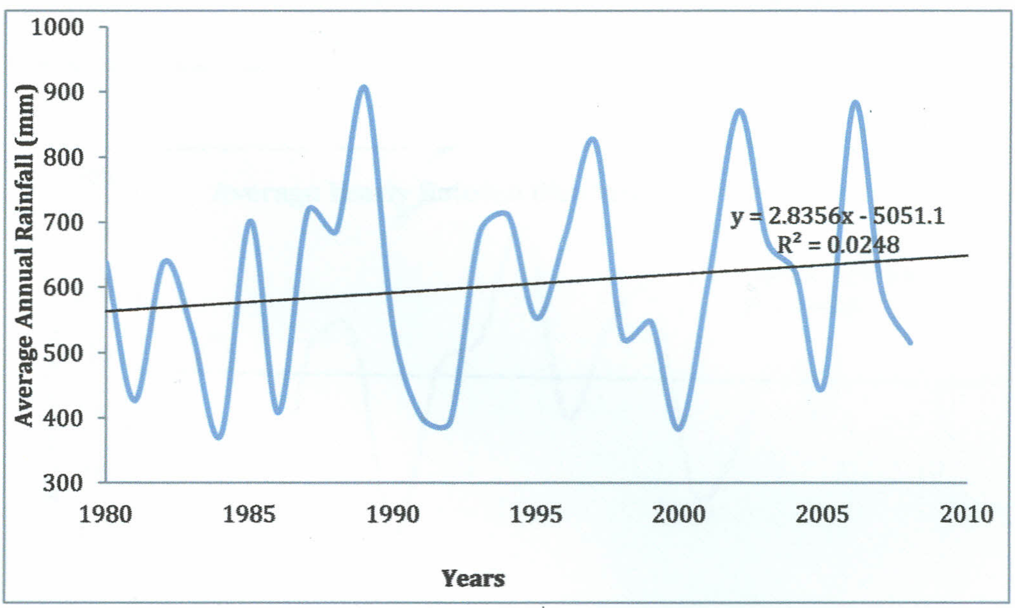

Figure 4-2 Average annual rainfall at Narok station. Source: (Field data, 2012)

Figure 4:2 representing Narok weather station shows an increasing rainfall trend. The trend analysis is from 1980 to 2011. The slope coefficient indicates the annual average rate of change in the hydrologic characteristic. If the slope is statistically significantly different from zero, the interpretation is that it is entirely reasonable to interpret there is a change occurring over time. The sign of the slope defines the direction of the trend of the variable: increasing if the sign is positive, and decreasing if the sign is negative. Thus the R^2 is given as 0.02 indicating a linear increase of rainfall annually by about 0.02mm of rainfall. The graph shows peak years of 1989, 1997, 2002 and 2006. The results show a cyclic trend at first then the period of the cyclic reduces to about 5years. The years 1984, 1986, 1991, 1992, 2000 and 2005 shows low rainfall amounts. This low rainfall below 400mm annually could be attributed to the drought. These results shows much inter annual variability as compared to other stations

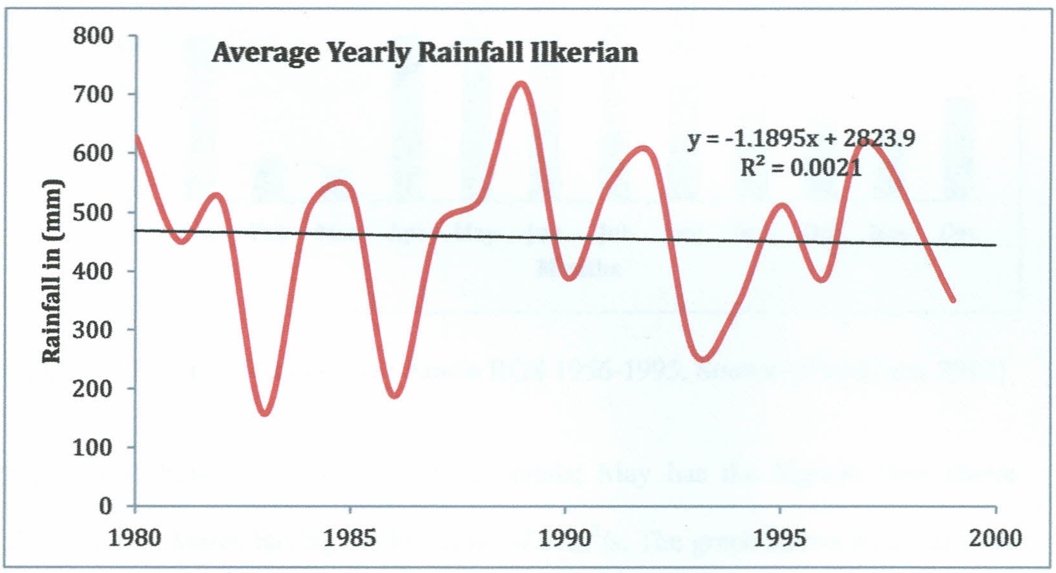

Figure 4-3 Average yearly rainfall at Ilkerin station. Source: (Field data, 2012)

Figure 4:3 represents Ilkerin weather station data, the data shows inter annual variability, the rainfall between consecutive rainfall vary greately. The Y equation is negative indicating a decreasing a gradient of 0.002 as shown by the R^2. R^2 shows a negative linear equation indicating that there 0.002 mm annual decrease of rainfall. The station is located on the lower edge of the basin thats exhibits higher aridity characteristics as compared to other stations.

4.2.2 **River flow trend analysis results**

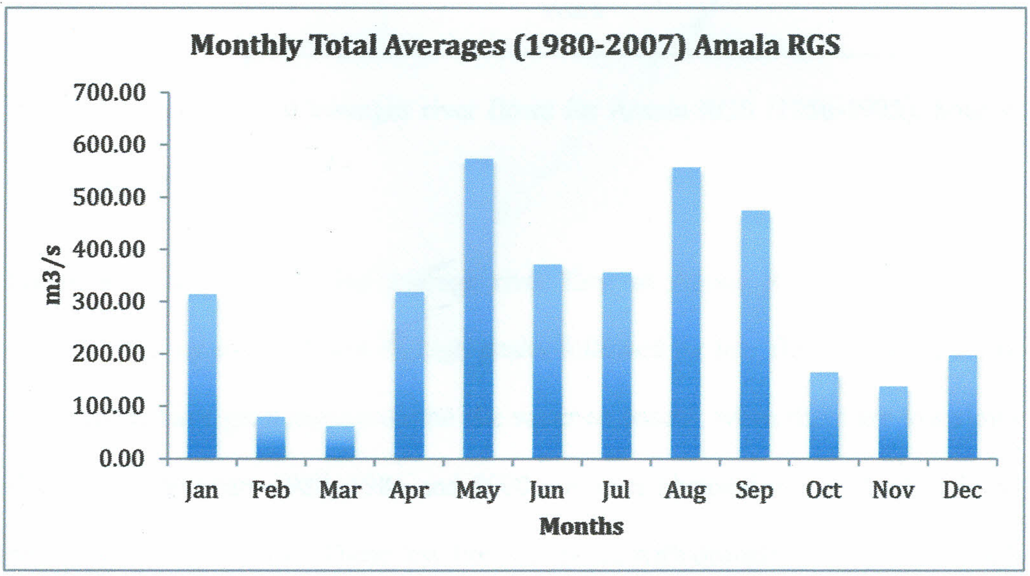

Figure 4-4 Monthly total average Amala RGS 1956-1995. Source: (Field data, 2012)

Figure 4:4 shows the monthly average totals; May has the highest flow above $572m^3/s$ with March having the low flow of $61m^3/s$. The graph shows seasonal river flow with high flows experienced during the months of April to September and relative flows during October, November, February and March. The river flow can be said to be bi-modal replicating the rainfall patterns of the study area.

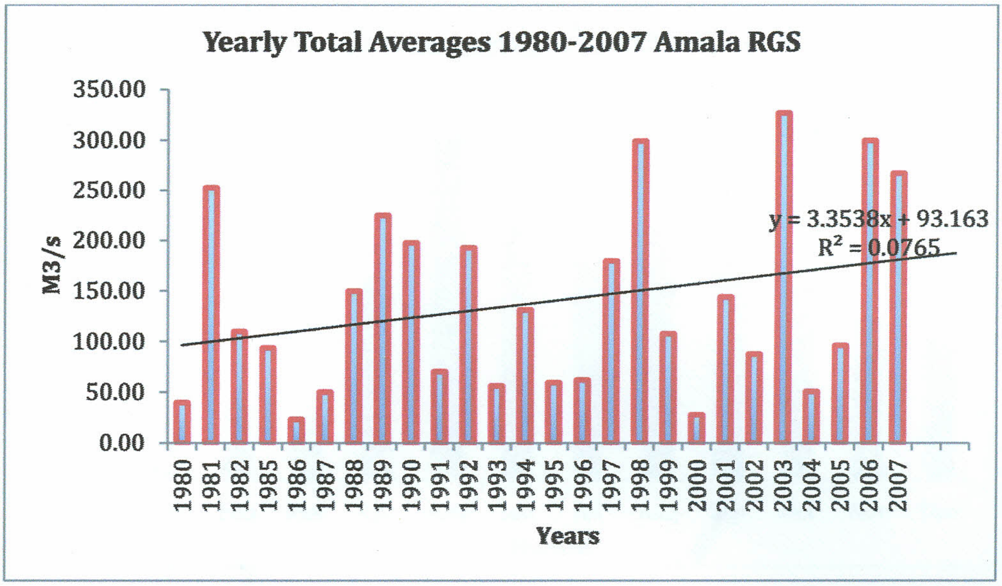

Figure 4-5 Total annual averages river flows for Amala RGS (1956-1995). Source: (Field data, 2012)

Figure 4:5 shows the annual average river flow at Amala RGS. The flows are characterized by cyclic trends of high peaks followed by low flows. The nature of these trends have great impact on the use water resources, when there are low flows like during the years 1980, 1986 and 2000 any over abstraction may lead to flows beyond the reserve flows. These low flows coincide with droughts and famine. High flows are associated with favourable rainfall seasons, the area experiences flash floods mostly by the seasonal rivers as opposed to permanent rivers such as Nyangores and Amala.

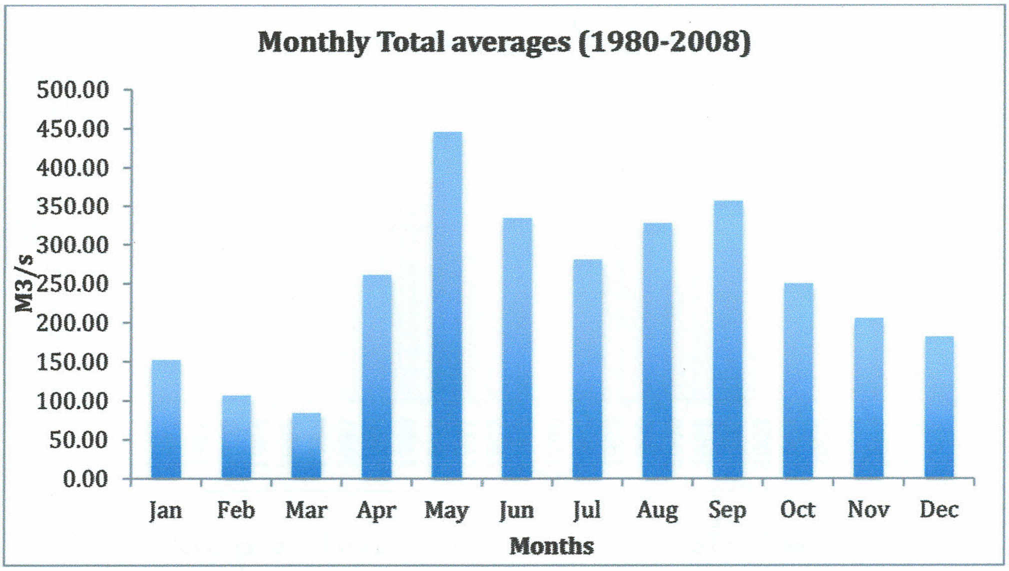

Figure 4-6 Monthly average totals Nyangores RGS (1964-1999). Source: (Field data, 2012)

Figure 4:6 shows the monthly averages at Nyangores river, the results indicate different river flows as compared to Figure 4:4 the monthly averages of Amala RGS. The river shows higher river flows with the month of May having the highest flow of above 450m^3/s, the flows remain above 300m^3/s and rise again to above 400m^3/s in September and drop gradually to March and then start to rise again in April. These flows have implications in water resources in that Nyangores shows higher river flows supplying much of the water to Mara River.

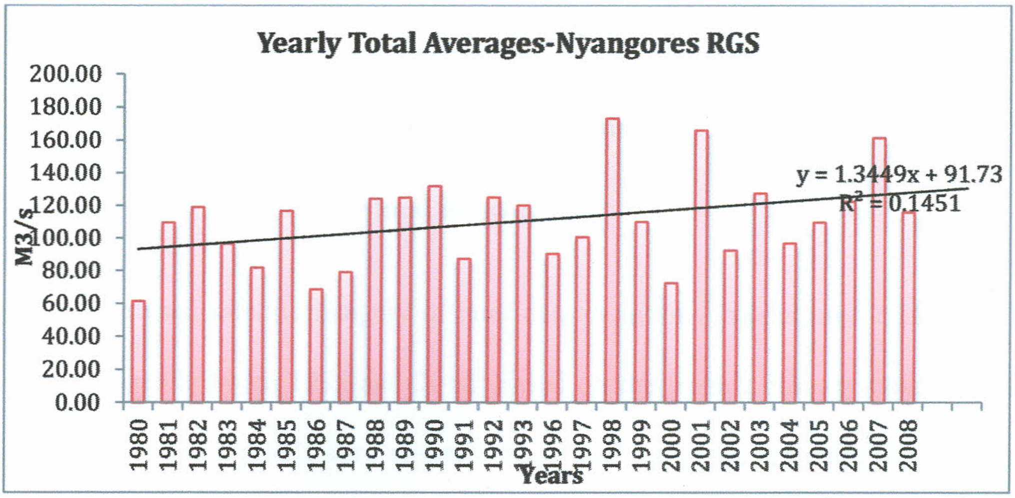

Figure 4-7 Total averegae flows Nyangores RGS. (Source: Field data, 2012)

Figure 4:7 shows the annual average river flows. The trend line shows cyclic nature with high peaks and low flows. The high peaks fall between years 1970, 1978 followed by a relative flow above 120m3/s for years 1982, 1988, 1989, and 1992. Low flows of below $60m^3/s$ are also recorded in the years 1972, 1973, 1984, 1994 and 2000. The high flows concide with with high rainfall recorded as shown in figure 4-5. There is attenuation of the river flow with the time between the onset of the rains and the peak flow getting smaller over the years. Since rainfall and land surface conditions are the factors that affect river flow, and since the rainfall pattern has not changed much, the basin surface conditions are left to be the major factor affecting stream flow.

4.3 Objective Two: Satelite imagery analysis results

4.3.1 Assessment of Land use/ land use change

The study analysed satellite imagery of inter-data variations in land-use/ land-cover (LULC) changes between 1985 and 2010. Based on the basin's climatic conditions which influence the region's agro-climatic zone, anthropogenic activities, flora and fauna, and water distribution the Landsat images were classified into four land-use classes namely: forest/ shrub land, crop land/ range lands, water and bare land. As indicated below, the basin's LULC phenomena have substantially varied between 1985 and 2010.

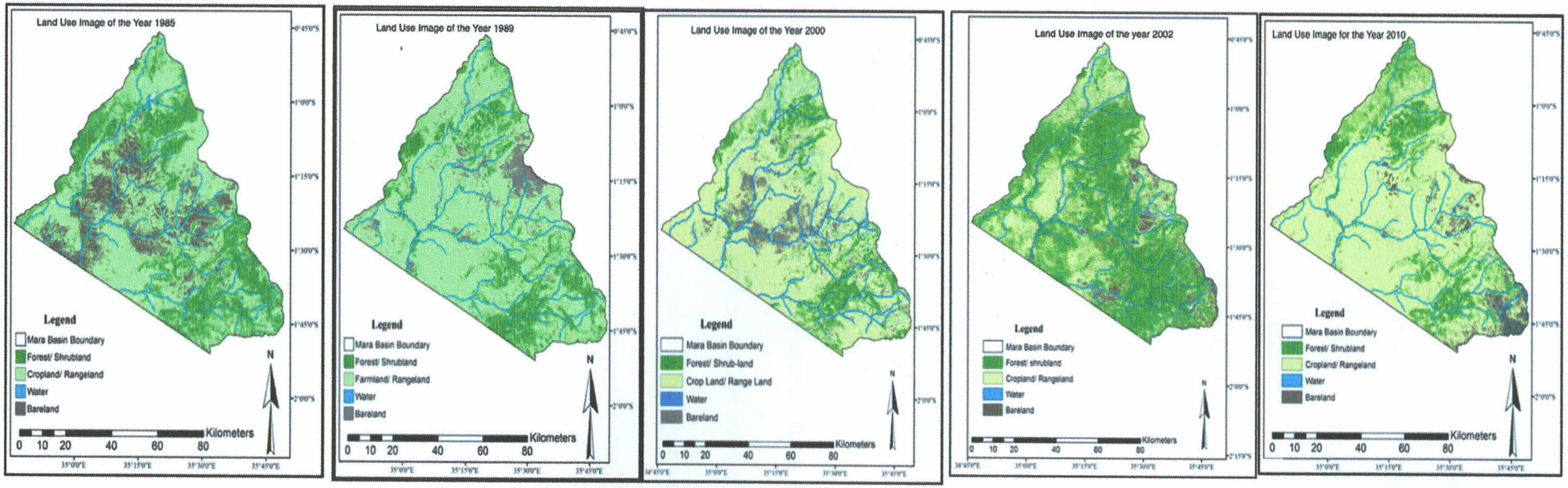

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Figure 4-8: Land use thematic maps from 1985-2010. (Source, Author 2013)

Figures 4:8 above shows the land use thematic map indicating areas of forest/ shrub land, river streams indicated as blue and bare lands indicated in shades of grey. The dense green colour indicates forests and shrub lands, the light green indicating farmlands/rangelands, blue colour indicating water bodies and grey shades indicating bare land. Figure 4:8a indicates the land use thematic map of 1985 showing patches of dense forests and quite significant percentage of bare land. Figure 4:8b indicates the land use of 1989 an improvement with reduced bare land increased rangelands and less dense forests. Figure 4:8c a rather decreased shade of green, indicating stressed vegetation starved off water with central region showing patches of bare land. Figure 4:8d indicates the dense green shades, this was after the rains where the ecological phenology characteristic of grass allows it to sprout within a short time after the rains. However the areas bordering Loita Hills and Nguruman Escarpments continues to indicate dense forests on the southeast edge of the map. Figure 4:8e showed increased aridity as indicated by an increased in bare land especially in new locations earlier not noted in the previous analysis. There is quite a significant percentage in grassland and farmlands.

Table 4-1: Summary of Land use thematic map

Land-use class	Area in square kilometres (km²)					Change	%
	1985	1989	2000	2002	2010		
Forest/ Shrub-land	1,378.4	986	879.5	2587.6	849.3	-529.10	-38.39
Crop-land/ Range-land	4,122.6	5,126.7	5,134.7	3510.8	5,314.5	1.191.90	28.91
Water	17.7	14.4	12.8	11.9	15.8	-1.90	-10.73
Bare-land	1114.4	505.9	606.1	522.8	453.5	-660.90	-59.31

(Source: Field data, 2013)

The table 4:1 above summarizes the inter-data variations in land-use/ land-cover (LULC) changes between 1985 and 2010. Based on the basin's climatic conditions which influence the region's agro-climatic zone, anthropogenic activities, flora and fauna, and water distribution the Landsat images were classified into four land-use classes namely: forest/ shrub land, crop land/ range lands, water and bare land. The basin's LULC phenomena have substantially varied between 1985 and 2010. Water resource availability as depicted through the aerial extent of water distribution indicates that water vulnerability is on the increase in the duration of 25 years (1985 – 2010).

Forest/ shrubland decreased from 1378.4km² to 986 km² due to decreased rainfall in 1989 and 2000. The image was taken on January 9th and the river flow recorded a monthly low flow of 5.3m^3/s during the same month the rainfall stations did not record rainfall while Narok station recorded 15.3mm. In 2002 the surface coverage increased tremendously to 2587.5km^2 the same month and year recorded river flows of 1.96m^3/s and 1.32m^3/s in Nyangores and Amala respectively. This difference can be explained due to the phenology of the vegetation which turn lavish green with little rainfall

4.3.2 Assessment of Normalized Difference Vegetation Index (NDVI)

NDVI represents the greenness of vegetation with deep green indicating dense forest with healthy vegetation and red colour indicating no vegetation. Maps and time series of NDVI help to get insight in the changes that occur in the fractional vegetation cover pattern. Since rainfall induces green vegetation, time series analysis should indicate the variations of the vegetation cover as well. To get a correct variations of the vegetation behaviour NDVI must be established. Changes in the vegetation cover are often related to variations in seasonal weather conditions and the moisture availability in the subsoil. This is the relation between phonological behaviour, climate and land use which the study sought to assess. Temperature, moisture and soil conditions influence the phenology, thus vegetation varies biannual, annual and inter-annual periods. Variations in the vegetation cover are strongly related to the amount and distribution of rainfall.

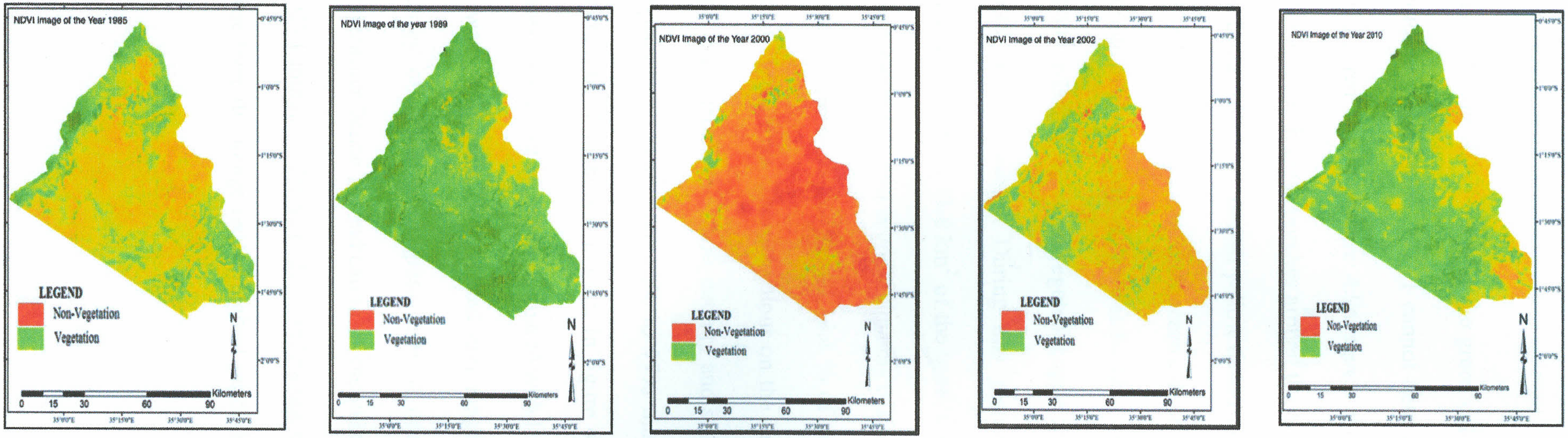

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Figure 4-9: Normalised Difference Vegetation Index (NDVI) Images (1985-2010). (Source: Field data, 2013)

Generally during NDVI analysis the green colour denotes healthy vegetation while red colour no vegetation, NDVI cannot detect any chlorophyll on the vegetation, hence the red colour. Figure 4:9a shows the NDVI for year 1985 with mixed indications of dark green parches around the Lolgorian forest reserve and the eastern part in Loita Hills. The reddish yellow denotes no vegetation. When compared to the year 1989 in figure 4:9b the dark green colour intensifies indicating that by the time of satellite image the vegetation was healthy. Figure 4:9c shows NDVI image of the year 2000 indicates the worst vegetation quality and distribution this is echoed by the land-use thematic values. During this year the basins surface water resources constituted only about 12.8 km^2 of the basin's aerial coverage of about 6633 km^2 as shown in Table 4:1. This is approximately 0.2% of the basins land mass. This a huge decrease compared to 17.7% and 14.4 % of the previous image analysis of figure 4:8a and Figure 4:8b. The red colour on the image could be attributed to the 2002 drought that affected the whole country and study area as well. There is an increase in cropland/range land from 62% to 77% this is probably attributed to cropland devastation by drought and famine. In figure 4:9d shows pale red and yellow, this indicates no vegetation. When compared with land use thematic image in figure 4:8d there was an increase in cropland and rangeland, due to the characteristics of phenology of grass, when grass dries it denotes vegetation devoid of enough moisture/water hence the indication of the pale red and yellow. Figure 4:9e shows the NDVI image of the year 2010 indicating improved conditions, this same year land use thematic image record highest percentage of crop land and reduced forest cover with water bodies surface area increasing by $4km^2$ as compared from the previous figure 4:8d.

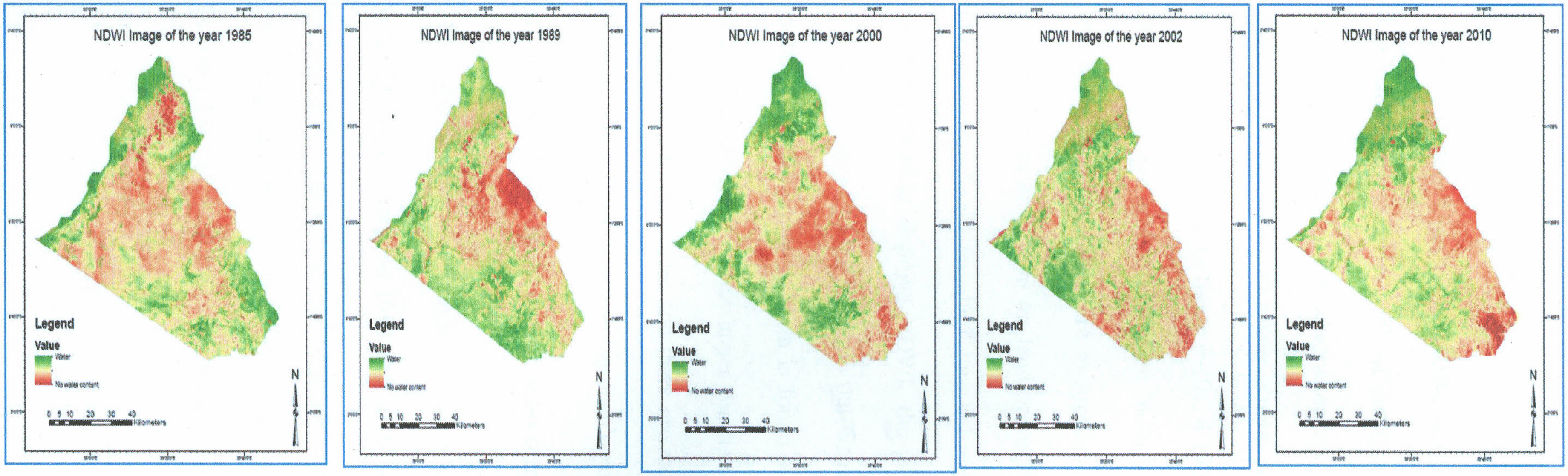

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Figure 4-10: Normalized Difference Water Index (NDWI) images (1985-2010). Source (Field data, 2013)

Figure 4-10 above shows the NDWI images for varying years from 1985 to 2010. The red colour indicates lack of water content or water deficient environments meaning that the NDWI is negative or less than zero. The green colour indicates the presence of water. The red colour is more pronounced at some sections of the image indicted as bare land. In figure 4-10c, 4-10d and 4-10e shows consitency in redness indicating severe arid regions in the basin. The bare land, non-vegetation amounts to less water in the soil moisture to support vegetation. The green color denotes the presence of water content on land especially wet soils and rush green vegetation indicating moist soils thus high forested regions have green colour density. The red patches indicating negative NDWI, the patches have been consistent in location within the study area as it singles out water deficient parts of the basin, while the green colour in the lower basin is found within the protected areas of the Maasai Mara Naitonal Reserve and upper reaches where mixed farming if practised and farmers have planted trees and there are natural forest. These regions fall with the ecotone, zone of transition from agroecological zone three and four.

4.3.3 Mara River Basin water bodies trend from 1985 to 2010

The figure below summarizes the inter-data variations in land-use/ land-cover (LULC) changes between 1985 and 2010. Based on the basin's climatic conditions influences the region's agro-climatic zone, anthropogenic activities, flora and fauna, and water distribution. The analysis of water bodies showed a gradual decline between 1985 and 2010. Water resource availability as depicted through the aerial extent of water distribution indicates that water vulnerability is on the increase in the duration of 25 years (1985 – 2010).

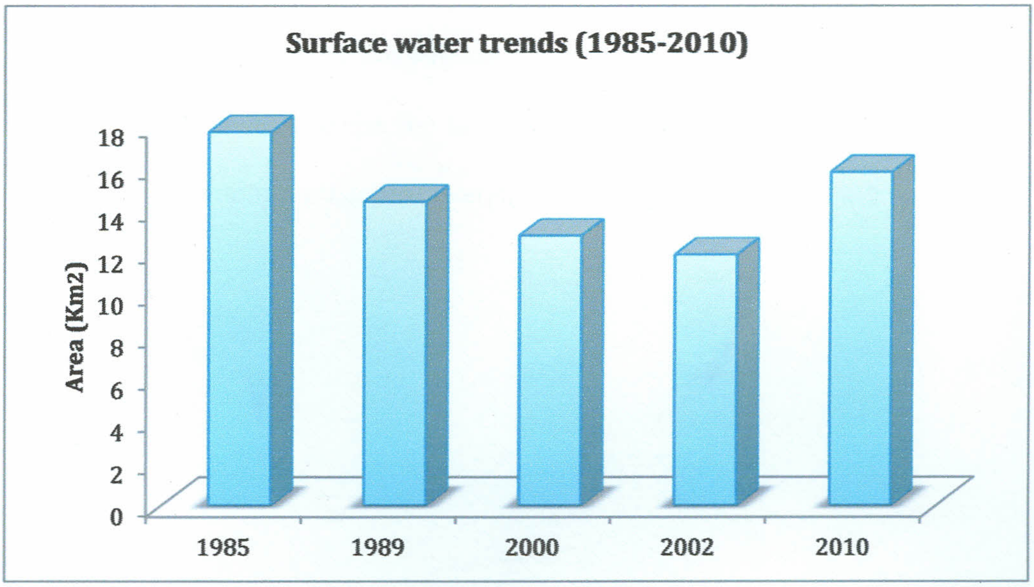

Figure 4-11: Summarised surface water trends from 1985-2010. Source (Field data, 2013)

4.4 Objective Three: Socio-economic and livelihood vulnerability

The households within the Mara River Basin were examined both qualitatively and quantitatively for their vulnerability to climate change indicators (weather parameters, flood, drought and changing water resources). The specific aspects of vulnerability considered were socio-economic and livelihood indicators, resource ownership and utilization, water resources and climate change. This section presents findings of analysis of the data from the sub-catchment.

4.4.1 **Influence of climate variability on the socio-economic livelihoods**

The basin consists of different households with diverse occupation and livelihoods. This study sought to characterize the households in terms of sex, age, occupation, level of education amongst other characteristics shown below in Table: 4-2

Table 4-2: Summarised household characterization

Sex of the Respondents										
Female	40%									
Male	60%									
Time of Residence in the Basin (yrs)										
15-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66>
4.2%	18.6%	26.0%	14.2%	14.3%	6.8%	5.8%	5.0%	3.3%	1.6%	0.0%
Level of Education										
None	Pri Std 1-4	Pri Std 5-8	Sec	Higher education						
17.10%	13.10%	24.40%	30.80%	14.50%						
Marital Status										

Single	Married	Widow/er	Separated/Divorced		
24%	64.8%	8.8%	2.4%		
Head of Household					
Male Headed	Female Headed	Youth Headed			
76.8	17.6	5.6			
Occupation					
Farming	Livestock Keeping	Salaried	Self Business	Unemployed	Others
24.4%	45.5%	13.0%	13.0%	3.3%	0.8%
Type of Housing					
Grass thatched	Semi permanent	Stoned walled (permanent)	Manyatta		
31.1%	34.4%	9.0%	25.4%		

Source: (Field survey, 2013)

4.4.1.1 Age, marital status and sex of the respondents

Majority of respondents interviewed were male at 60%, most of them aged 26-30years and those who have been residents for more than 50years were 9.9%. Majority of the respondents were married (64.8%) and majority of the households we headed by a male at 76.8%.

4.4.1.2 Level of education

The study sought to establish the level of education of the respondents, the level of education influences vulnerability to climate variability since education offers better understanding to adaptive and coping strategies, moreover offering alternative source of income due to opportunities of skilled employment. The majority of the respondents 30.8% had attained secondary school, 14.5% had higher education while a significant percentage of 24.8% had schooled up to class 8. This indicates that almost half of the population have attained basic education.

4.4.1.3 Socio-economic occupation

The Mara river basin exhibited diverse and mixed occupations with farming and pastoralism being the most practiced. The type of occupation influences the house holds impact and adaptation to climate variability. Livestock keeping accounted for 45.5% of the respondents while farming 24.4%. Climate or weather related occupations are solely dependent on the prevailing weather conditions thus prone to vulnerability. The type of occupation the study area is determined by both climatic and geographical location. Given that most of the households depends on farming and livestock keeping, increased incidences of drought would thus affect more than 70% of the livelihood occupation, leaving them susceptible and vulnerable.

4.4.1.4 Type of housing

The type of housing varied, majority of the respondents had semi permanent houses, followed by grass thatched at 31.1% and Manyatta at 25.4%. Type of housing especially roofing can either mitigate or exacerbate vulnerability to climate change, houses with iron sheets offer the household to harvest rainwater for use during the dry season as opposed to thatched and Manyatta houses.

4.4.2 Resource ownership

The study sought to establish the different uses, ownership and utilization of land resources in the Mara river basin as well as the management practices.

4.4.2.1 Size of land

Size of land as an indicator of livelihood can predict the potential of a household to sustain large crop farming. The majority of respondents (57%) had more than 5acres, while 21% had between 2-5acres. Given that the size of land can determine the possible yield thorough a direct proportionality, it can be assumed that those who owned smaller sizes of land in the study area would have lesser production than those who owned larger sizes. Based on the results shown below in Figure 4-12 below, it can be probable that smaller land sizes are vulnerable to drought than large sizes of land.

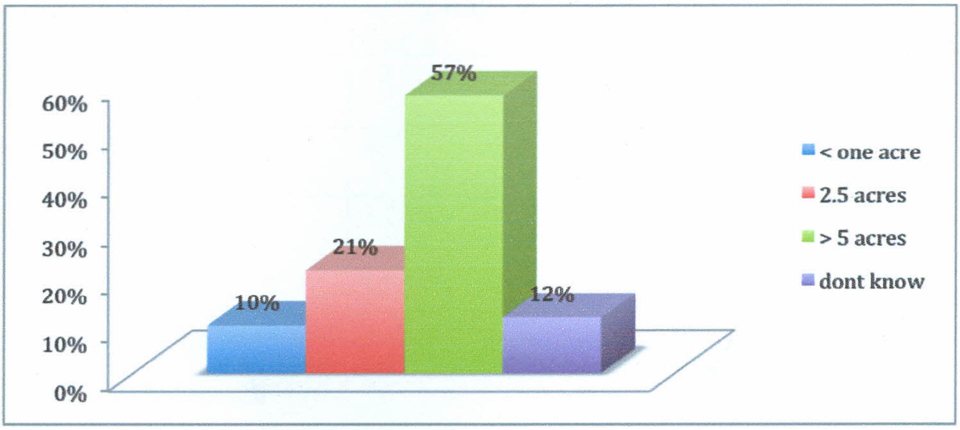

Figure 4-12: Size of land of the respondents. Source: (Field survey, 2013)

4.4.2.2 Utilization of land

In the Mara river basin land utilization depend mostly on the climate and size of the land. Majority of the respondents (46%) practiced livestock keeping, 30.6% mixed farming and 20.2% were farmers mostly located along the rivers and areas where climate was favourable.

Table 4-3: Land utilization

Activity	Percentage practised
Farming	20.20%
Livestock keeping	46%
Commercial farming	3.20%
Mixed farming	30.60%

Source: (Field survey, 2013)

IPCC, (2007) points out that nomadic pastoralism or lifestyle is an effective way of adapting and mitigating against climate change. However with increasing sedentary lives of the pastoralists abandoning nomadic lifestyle exposes the livelihoods to climate vulnerability.

4.4.2.3 Type of crops grown

The type of food crop grown in the area of study is determined by climate conditions, geology and altitude. Majority of the respondents 55.6% and 40.3% planted maize and beans. Drought resistant crops that adapt to climate change like cassava and millet accounted for 3.2%. Short durations food crops like beans are important to curb vulnerability. The dependant on rain fed agriculture which is vulnerable to climatic conditions makes the livelihoods susceptible to any negative climatic change especially drought. Majority of the respondents also reported that their harvests are never enough at 70% and thus have to supplement with buying from market.

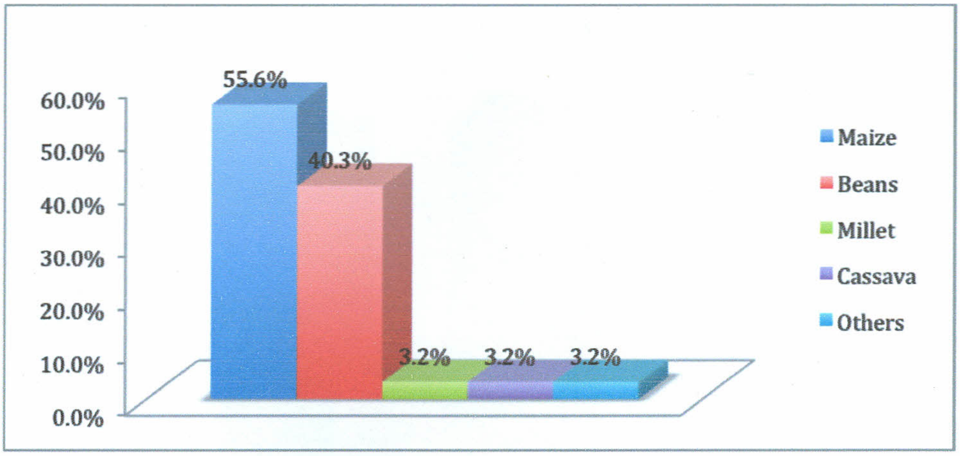

Figure 4-13: Type of crops grown (Source: Field survey, 2013)

4.4.2.4 Food deficient months

Food sufficiency is generally considered as a livelihood factor among households, the assessment of the ability of the households to sustain their food supply was considered thorough a measure of how many months the households was food deficient in a year. Deficient is the near inability to provide at least one meal a day for the household member. Generally there is food deficiency in the catchment, with 42.9% of the respondents experiencing less than 4months and 45.2% experiencing more than 5months. This indicates that during these months if the respondents solely depend on farming, they are susceptible to period without food. Since most of the livelihoods in the study area depend on farming and livestock their food sufficiency would depend on their success in farming, thus any factor affecting farming like drought would ultimately affect household food sufficiency.

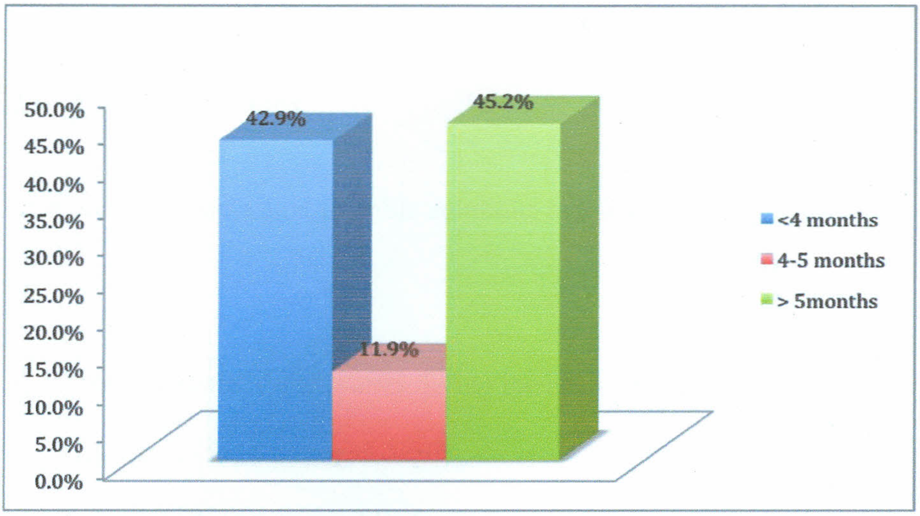

Figure 4-14: Food deficiency months. (Source: Field survey, 2013)

4.4.2.5 Reasons for food deficiency

Majority of the respondents associate food deficiency to drought at 57%. Other factors like floods (13.7%), lack of farm inputs (29.8%) and land degradation were also stated as reasons for food deficiency.

Table 4-4: Reasons for food deficiency

Reason	
Drought reasons for low production	57%
Floods reasons for low production	13.7%
Lack of farm inputs reasons for low production	29.8%
Lack of enough land reasons for low production	22.6%
Other reasons for low production	2.4%

Source: (Field survey, 2013)

4.4.2.6 Possible solutions

The respondents were asked possible solutions to vulnerability of farming to climate change.

a) Conservation of flood waters during the rainy season
b) Irrigation of land during drought
c) Provision of farm inputs like fertilizer and drought resistant crops
d) Growing drought resistant crops like cassava, sorghum and yams
e) Growing short duration maturing crops, three to four months that can grow during the wet season.

4.4.3 Livestock farming

The study sought to know the type of livestock the respondents keep. Different types of livestock adapt to climate change differently due to their mode of feeding whether browsers and grazers, size and adaptability to the prevailing conditions.

4.4.3.1 Type of livestock

Majority of the respondents kept mixed type of livestock, most of the respondents over 70% of the respondent's cows and goats. Mixed livestock increases adaptability and resilience to drought and famine as opposed to keeping one type of livestock.

Table 4-5: Type of livestock

Type of Livestock	
Cattle	97.60%
Goats	86.30%
Donkeys	30.10%
Sheep	67.50%
Other livestock	2.40%

Source: (Field survey, 2013)

4.4.3.2 Challenges of livestock keeping

Majority of the respondents rated lack of pasture as the biggest challenge to livestock keeping at 92.7%. Lack of water and enough grazing lands were rated 71.8% and 55.6% respectively.

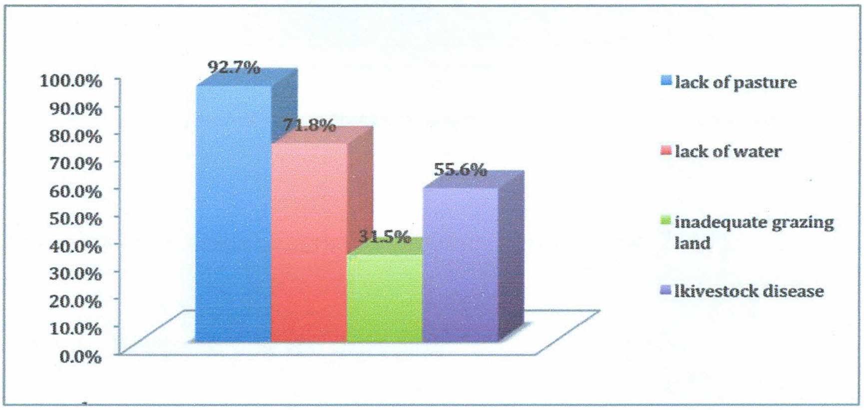

Figure 4-15 Challenges of livestock keeping. (Source: Field survey, 2013)

4.4.3.3 Causes of drought

Majority of the respondents 94.3% have in their lifetime experienced unusually prolonged droughts and famine. Prolonged drought and famine extend beyond the dry season and have great effect on wildlife and livestock causing death, migration and human wildlife conflict. The respondents blamed climate change, deforestation and drying water resources at 76.4%, 66.7% and 34.4% respectively as shown in figure 4:16 below.

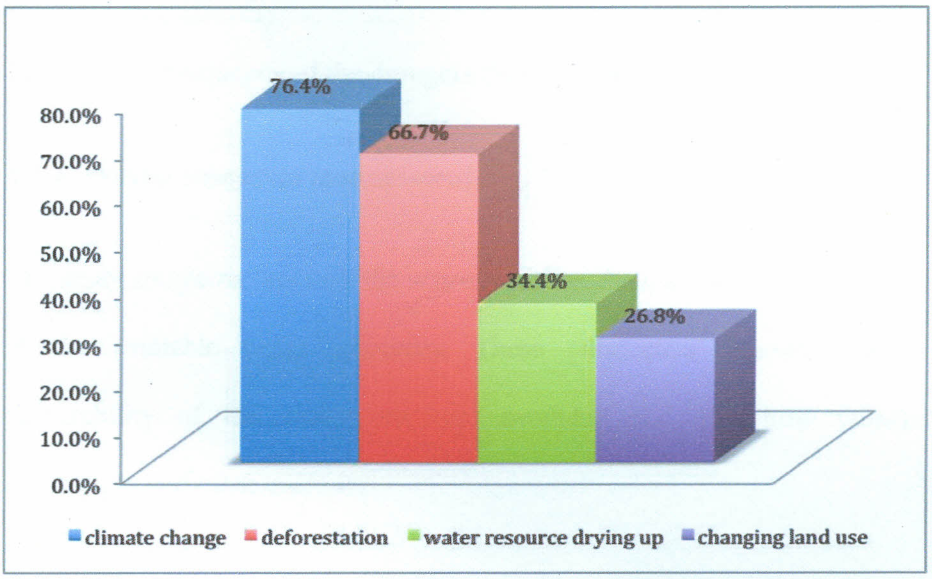

Figure 4-16: Causes of drought (Source: Field survey, 2013)

4.4.3.4 Frequency of the droughts

Majority of the respondents rated the droughts and famine as common at 62.8% while 4.1% said they were not significant.

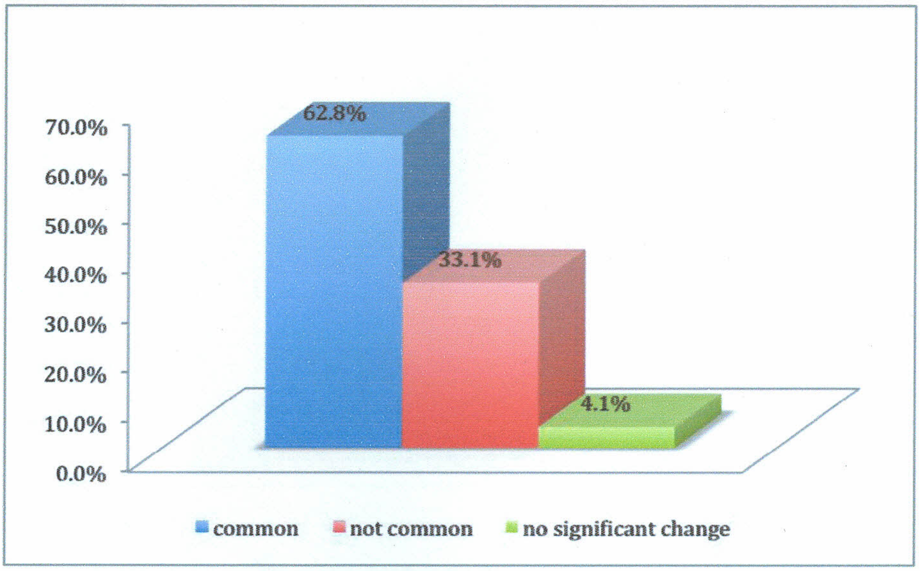

Figure 4-17: Frequency of the droughts (Source: Field survey, 2013)

4.4.4 Water resources management

The study sought to establish the source, quality, distance and management practices of the available water resources. These parameters expound more on the vulnerability of the water resources available and also how vulnerable the community and other users are.

4.4.4.1 Water access and availability

The accessibility and availability of water has been largely affected by prolonged droughts and unpredictable rains.

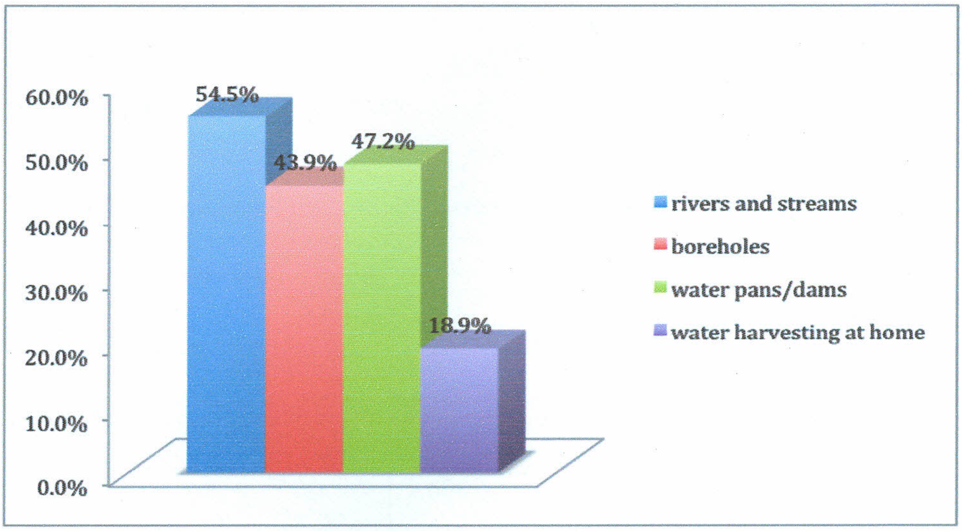

Figure 4-18: Sources of water in the study area. (Source: Field survey, 2013)

The main sources of water were rivers and streams, bore holes, water pan/dams and water harvesting at 54.5%, 43.9% and 47.2% respectively. The water from rivers and pans is shared with livestock and wildlife and in most cases dirty and polluted. Water uses include domestic uses at 95.9% and Livestock at 74.8% with little use in farming activities.

Table 4-6: Types of water uses

Types of water uses	Percentage
Farm uses	12.2%
Domestic uses	95.9%
Livestock uses	74.8%
Other uses	1.6%

Source: (Field survey, 2013)

4.4.4.2 Distance to water sources

Majority of the respondents (48.4%) travel between 1-2km, while 36.3% travel 36.3% to the nearest water source.

Table 4-7: Distance travelled

Distance to water source	**Percentage**
<1km	1.6%
1.2km	48.4%
3.5km	36.3%
>5km	13.7%

Source: (Field survey, 2013)

4.4.4.3 Availability of water sources

Of the available water sources 56.7% of the respondents said the water sources were seasonal while 43.3% permanent sources.

Table 4-8: Types of sources of water

Type of water source	**Percentage**
Permanent	43.30%
Seasonal	56.70%

Source: (Field survey, 2013)

4.4.4.4 Challenges of water accessibility

The majority of respondents endure dirty water and long distances of walking to access water at 70.2% and 64.2% respectively. Water scarcity was rated at 31.5% and quite a significant response on conflicts with neighbours at 22.6%.

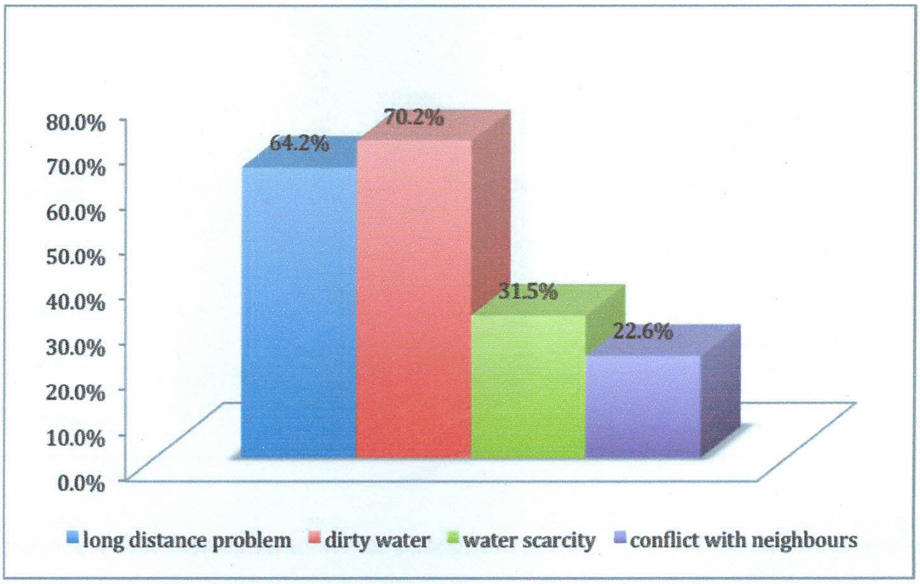

Figure 4-19: Challenges in water accessibility. (Source: Field survey, 2013)

The respondents attributed these challenges to

- Change in rainfall patterns and unpredictable patterns
- Prolonged drought and dry periods
- Failure to protect rivers sources and buffer zones
- Destruction of catchment areas especially the Mau forest complex

4.4.4.5 Suggested solutions to water accessibility and availability

Protection of water sources was rated at 65.3% while water harvesting and protecting wells rated 50%.

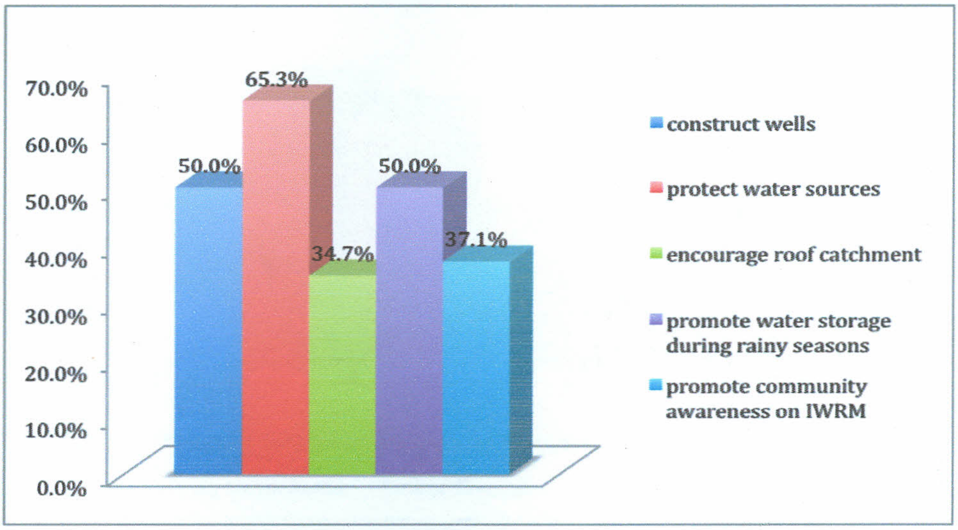

Figure 4-20: Solutions to water accessibility and availability. (Source: Field survey, 2013)

4.4.5 **Climatic changes**

The study sought to establish the respondent's knowledge and awareness of the climatic changes that have taken place in the area of study. The households and the community were examined for their observations of climate change markers in their community. The markers examined were drought, floods and changing water sources. The markers were based on adverse weather effects (drought and floods), the respondents rated unpredictable rainfall patterns 76.6% and 69.4% prolonged droughts followed by very hot seasons at 38.7% as shown in figure 4:21 below. This shows that climate change manifests itself to the respondents mostly as unpredictable rainfall, prolonged droughts and very hot seasons and not floods

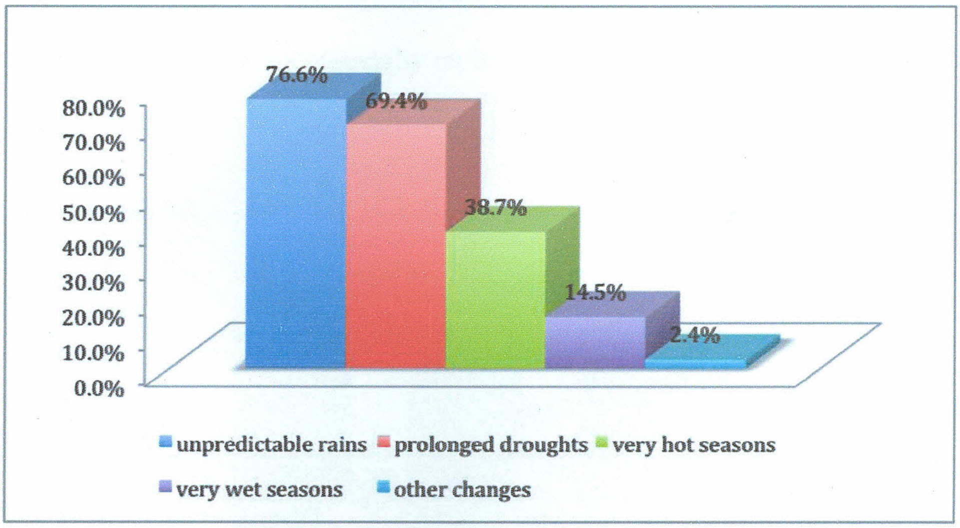

Figure 4-21: Observed climate changes. (Source: Field survey, 2013)

According to the respondent's and KII, the major changes in the past years they have observed

a) Reduced amount of rainfall

b) Increased rainfall intensity

c) Very hot seasons during the day and very cold at night

d) Erratic rainfalls (unpredictable and unreliable)

e) Prolonged droughts and dry seasons

f) Shifting seasons

g) Reduced length of wet season especially in the upper catchment.

4.4.5.1 Major climate change effects on the households

The effects of the climate change differed with regard to occupation of the respondents. crop failure and famine were rated 52% and 51.6% respectively. Disruption of settlement especially on the pastoralists in search of pasture and water rated 37.9%.

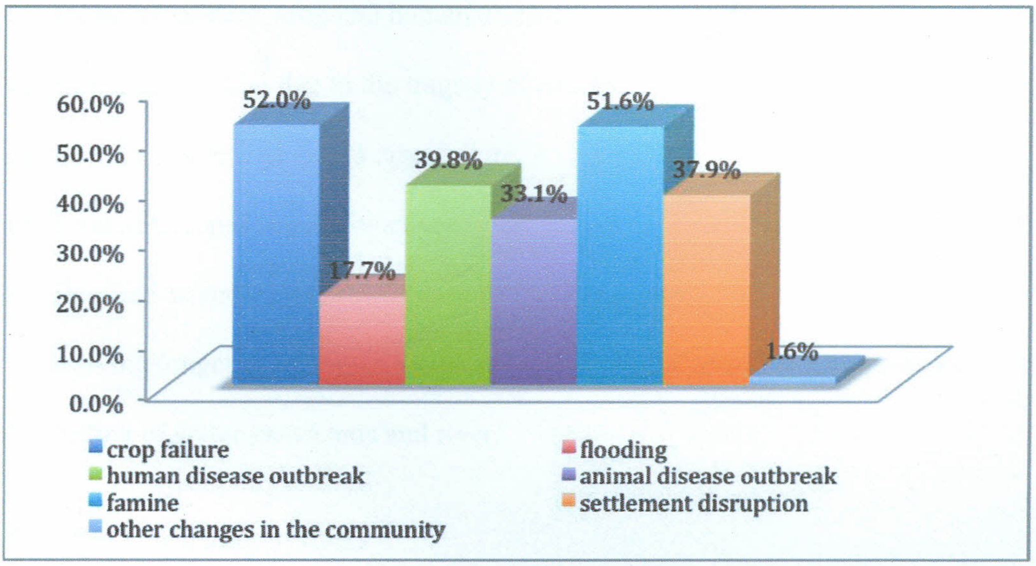

Figure 4-22: Major effects of climate change on the households. (Source: (Field survey, 2013)

Implementation of adaptation and mitigation measures should focus on the major household effects of the respondents such as food security that solves the major effects like crop failure and famine. Food security measures should extends benefits livestock health and thus control disease outbreaks.

Interviews with KII and further focused group discussion stated the following as other effects on the households

a) Reduced crop yields leading to food insecurity
b) Increased animal, crop and human diseases
c) Increased conflict due to the tragedy of commons
d) Repeated plantings due to crop failure
e) Loss of tree and vegetation cover
f) Reduced water levels in streams and river drying up
g) Moving longer distances in search of water both for domestic and livestock
h) Silting of water pans/dams and river.

4.4.5.2 Early warning Systems

The study sought to know whether the household have access or aware of early warning systems and their applicability in adapting and mitigating against climate change. Majority of the respondents responded in the affirmative at 89.6% this shows that the respondents are aware of the early warning systems. The presence of early warning systems and information greatly enhances household and community adaptation, resilience and mitigates against adverse effects of droughts and famine.

4.4.5.3 Source of EWS information

The majority of the residents received EWS information from the mass communication Radio and TV 62.5%. This could be attributed to establishment of local vernacular radio stations that is widely listened and understood. Government agencies play a major role as 23.2% of the respondents source of information.

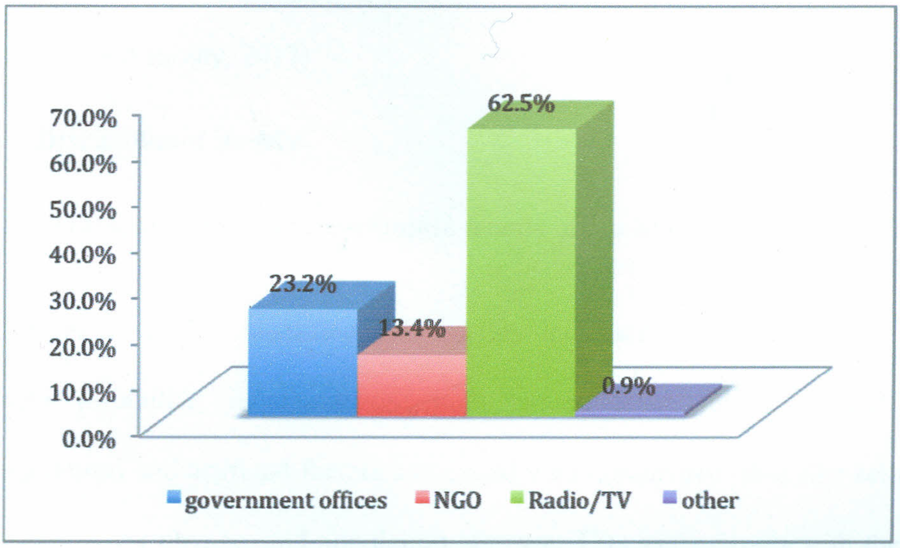

Figure 4-23: Source of Early warning systems. (Source: Field survey, 2013)

When the respondents were asked whether they follow the information, majority of the respondents 95.5% follow the information. With regard to effectiveness 90.2% said the information was effective. Generally majority of the respondents adhered and said the information was effective. The focus on education and awareness on EWS and any other information regarding climate change effects mitigation can best reach the intended recipient though mass media.

Table 4-9: Adherence and effectiveness of EWS information

Adherence to EWS	
Yes	95.5%
Effectiveness	
yes	90.2%

Source: (Field survey, 2013)

4.5 Discussion of Results

4.5.1 Objective One: Hydro-climatic trends in the Mara river basin.

Mutua *et al.* (2002) identified vulnerability indicators of the water resources to climate variability; he found out both natural (temperature, rainfall, evapo-transpiration) and artificial factors associated with human activities like settlements, land use/ cover change, and population increase. This study agrees with them since temperature and rainfall showed an increasing trend, rainfall patterns showed decadal and inter-annual variability, the inter-annual variability showed great variations with subsequent years having very peak rainfall followed by low rainfall years. Melesse *et al.* (2008) did study the hydro-meteorological trends of the basin and showed an annual decline of 14% of rainfall in the Kaptunga forest, further research using SWAT model that incorporated land cover the analysis showed 20% reduction for the period 2010-2030. This study however comes up with different results showing both an increasing rainfall pattern 0.024 mm/year at Narok station and a decreasing trend of 0.002mm/yearr at Ilkerian station, The results of this study agrees with studies done by (Ringus *et al.,* 1996) whose simulations indicated that Africa and Kenya will experience increased temperatures and rainfall by the year 2050. This study shows river flows of both Nyangores and Amala having different characteristics. Nyangores has higher discharge, both in the wet season and dry season, unlike the Amala river. These results reports the same scenario observed by (Melesse *et al.,* 2008) where the hydrologic response of Amala had a low dry flow and a high wet flow unlike that of the Nyangores. This difference in river flows can be attributed to upper catchment degradation especially in the Mau forest which causes low recharge. Vegetation cover increases runoff because of less infiltration as the rainfall has less time to percolate in the ground. These human activities have significant impact on land surface and subsequent influence on flow regimes in the basin as (Valimba *et al.,* 2008) also found out. Studies by (Stutcliffe & Knott, 1987: Groove, 1996; Conway, 2002) demonstrated high levels of inter-annual variability in many river basins of Africa and they concluded that rainfall and water resources in Africa display high levels of variability across a range of spatial and temporal scales with important consequences for the management of variability and risk in water resource systems.

4.5.1.1 Influence climate variability on water resources vulnerability

The results of the study indicate that rainfall variability in the Mara River Basin will result in uneven distribution of water resources over space and time. These trends in river flow detected have significantly demonstrated links with trends in temperature and precipitation. This is further compounded by (IPCC, 2007) and the Third

Assessment Report, which found statistical, links with trends and temperature in both catchment and global rivers. A variety of climatic and non-climatic processes influence water resources vulnerability resulting to climate extremes such us floods and droughts. Floods depends on climatic processes such us precipitation intensity, volume, timing, antecedent conditions of rivers and their drainage basins amongst others according to (Kron & Berz, 2007) while droughts depends on amount and rainfall distribution over space and time. These characteristics do influence water resource vulnerability especially when they recur unexpectedly. Floods in the basin are inform of flash floods especially along seasonal rivers and streams, the study agrees with (Kron & Berz, 2007) over the climatic processes preceding floods. There have been seasonal droughts known to occur every 5-7 years in the Mara river basin, but in the recent past droughts have recurred within 2 years and prolong unexpectedly. The extremes can be attributed to the inter-annual variability in rainfall, which has become more sporadic and unpredictable, and this affects water supply both to the ecosystem, domestic and agricultural use. The Mara basin is characterised by arid and semi-arid regions, such regions are characterised by limited water supply, low and highly variable rainfall and recurrent droughts (Parry, 1992; IRR, 2002) further indicates that high temperatures and intense precipitation experienced in such regions are associated with changing climate, causing increased water loss through evaporation and run off.

Climate variability has resulted in seasonality of surface water sources such river and streams, this seasonality have great impact on surface water resources in spatial and temporal scales. (SEA, 2012) Supports this by noting that if the variability the Mara river may actually dry up during the dry period and have great impact on the ecosystem. Though it cannot be conclusively concluded that the increase in ground water extraction

The recipient water resource vulnerability is inherently the users, domestic, agricultural and the ecosystem. The linkages of climate variability impacts to water resources are dynamic, often inter-connected, and context-specific reflecting geographic location; economic, social, and cultural characteristics; prioritization and concerns of individuals, households, and social groups (World Bank, 2002) discusses. Often there are factors that further exacerbate the vulnerability to the society such as poverty, low incomes, and geographical location with respect to accessibility to available water sources, education and socioeconomic activities. Agriculture and livestock are two main economies practiced in the basin and are highly dependent on rainfall; any climate shock over a prolonged time is bound to have great impact on the economies. Coupled with increasing population, permanent settlement land division's traditional coping and farming mechanisms are no longer feasible. Subsequent years of unusual long droughts and failure of communities to accept beneficial trade offs further alienates the communities and also low level of trust in climate prediction products.

According to (O'Brien *et al.,* 2002) multiple processes govern climate variability and stressors which if addressed enhance adaptive capacity of a system. But the focus when it comes to water resources adaptation is focussing on water infrastructure such as multipurpose dam, water harvesting structures and water piping though efficient there is need to diverse further to include forecasts, models climate science in developing water management policies (Kundzewicz *et al,* 2007) affirms.

The IPCC (2007) reports that annual precipitation is likely to decrease in most of Africa, however in east Africa and Kenya an increase in mean annual rainfall is projected in the next decades. This study found an increasing trend in the annual catchment mean in rainfall though with great margins between year to year comparison. These marginal increases explains the inter year variablity. The impact of climate variability on the water resources of the Mara River Basin has been decadal but in the recent years changing to inter annual, inter annual variability has detrimental effect on the basin water resources at both local level and regional level. The inter-annual variability in rainfall is more sporadic and unpredictable, and this affects water supply both to the ecosystem, domestic and agricultural use.

There is an increasing trend in rainfall, this increase as the study shows a variability tendency, the rainfall is expected to be of high intensity and within a short period this creates a scenario whereby there will be little percolation and infiltration for ground water recharge. This high intensity and short period shows increased river flow but this cannot be used to conclude that the basin has increased water resources. This is because there is no sustainability for continued use and storage of the excess water flowing. The change in the monthly runoff values is therefore more important than the overall annual change and is significant in the sub-basin water resources and use. This high intensity and short period rainfall also affects soil moisture and subsequent vegetation reflected in satellite images. The water resources in the basin are therefore vulnerable to climate variability, especially in the distribution of runoff throughout the year. With climate change, the runoff has become much more seasonal and as a result small streams remain completely dry up for part of the year. This has severe effect on the socio-economy of the sub-basin, as the pastoralism agriculture and wildlife management here are totally dependent on rainfall and the rural water supply sources are mostly small streams and springs. The low flows during the dry season fall below the environmental reserve flows, the limit beyond which key aquatic ecosystem are severely affected.

Table 4-10: Temperature and rainfall scenarios and potential effects on water resources

	Rainfall		
Temperature	No change (0)	Decrease (-)	Increase (+)
No Change (0)	Category A (0) Category B (+)	Category A (-) Category B (+)	Category A (+) Category B (+)
Increase (+)	Category A (-) Category B (+)	Category A (-) Category B (+)	Category A (+) Category B (+)
Category A: are water resources attributes, which are affected directly by climate change Quantity, levels. Etc. Category B: are water resources attributes which are affected indirectly by Climate Change such as water-use, quality, drought and flood frequencies, etc.			

Source: (NEMA, 2010)

The table 4:10 above summarizes possible scenarios the study found out would occur both at normal, decrease and increase in temperature and rainfall. If temperature and rainfall remains normal the water resources attributes directly affected by climate change such as discharge would remain normal, category of attributes indirectly affected by climate change would increase because on non-climatic factors such increasing demand of water from increasing population. This scenario changes when there is decrease in rainfall, category A decreases while category B increases this is repeated in case of an increase in temperature. When rainfall and temperature increases the situation worsens with an increase in both category A, increase in water quantity, aridity, water use, quality, drought and flood frequencies.

Such scenarios will significantly affect key sectors of the livelihoods including water for domestic use, crop and livestock production. The communities have been forced to travel long distances to water their livestock. Table 4-10 indicates that majority of the respondents (46.6%) in the upper catchment travel between 1-2km and it's common to sight women carrying water with 20 litre jerry cans (ALRMP, 2011). In response there is increasingly installation of water harvesting and storage structures. The spatial reduction in water resources as indicated in Figure 4-11 have compelled the community to encroach on marginal lands such as riparian lands, wetlands and swamps for cultivation and grazing of livestock. This encroachment exacerbates human wildlife conflicts as the pastoralists illegally enter the game reserve to graze and water their livestock, leading to attacks by wild animals. When water becomes scarce, competition in accessing it intensifies, leading to conflicts, degradation and over use especially by complementary users as shown figure 4-19 and 4-22.

4.5.1.2 Effects of the climate variability on surface waters

4.5.1.2.1 Surface waters

Climate variability has directly affected the surface water resources both in quantity and quality of water resources as shown from the river flow analysis in figures 4-5 to 4-7, and challenges that face water accessibility as shown in figure 4-19. Though not solely to blame for low dry flows, climate variability has resulted in seasonality of river flows, this seasonality has great impact on surface water resources in spatial and temporal scales. This study found that threatened surface water like Mara river, that during the drought years there are several months that the river flows below the reccommeded reserve flows (SEA, 2012). The reserve refers to both the quantity and quality of river flows, thus in the Mara River Basin allocations of water for agriculture, industry, and municipal supplies exceeding 25 litres per day per person should be made only from the portion of flow in excess of the reserve (SEA, 2012). During a dry year peak flows at times reach only $8m^3/s$, while during a wet year peak flows may extend over 150 m^3/s. Along the entire length of the river, low flows can approach $1m^3/s$ during dry years, although the river has never dried up completely. Many other tributaries, however, such as the Sand and Talek Rivers, do stop flowing during the dry season. This decreasing trend is heading towards an unacceptable alterations of the flow regime of the Mara river.

This is confirmed by (Valimba *et al.,* 2008) who found out that the main driver of variability in river flows was of course rainfall, particularly at the scale of large river basins but other factors such as changes in land cover or land use, abstraction, hydrological characteristics cannot be ruled out (Ribot *et al.,* 1996) argues. Many streams and river flowing to the Mara River are seasonal such as sand, Talek, Engare Ngobit rivers and streams along Narok Ololaimutia road (Plates 4-1 and 4-2) below shows seasonal river beds common in the basins. During the rainy season the seasonal rivers turn destructive, flash floods loaded with debris and trees, which damages bridges and roads especially during the months of July and September when the monthly average discharge reaches a maximum of over $500m^3/s$ in Amala river and $450m^3/s$ as shown in figures 4-4 and 4-6. The effect on water resources is sedimentation and the silt reduces the ability of these surface water bodies to hold water for long periods. The government through the Ministry of Northern Kenya and other arid lands have invested of water infrastructure to help adapt and mitigate the effects of drought. Water pans and rock water harvesting have been constructed in the basin. The water pans are silted due to high erosion.

Plate 4-1: Seasonal dry riverbeds along Narok-Sekenani road. Source: (Author, 30/8/2012)

4.5.1.2.2 Ground water resources

The Mara river basin has groundwater potential and its variable, both spatially and temporally, in quality and quantity and in terms of the level of the water table and depth. There are 26 boreholes in the Mara River basin (Khroda, 1996). During the field survey, the Narok north district water officer confirmed increased number of boreholes to about 50 licensed and many others that are not licensed and therefore not accounted for. The boreholes in areas of volcanic rocks are deep averaging about 80-125m. Most of the town centres and hotels solely rely on boreholes for water supply. While there are no comprehensive studies on ground water potential in the

Mara river basin, the basin being in a semi-arid area and the nationally ground water recharge has been estimated to be 5% of the annual rainfall in the semi-arid lands especially where evapo-transpiration losses are high (NEMA, 2010). Ground water recharge is replenished by rainfall and by infiltration through the ground. Thus it is dependent on climatic factors such rainfall, temperature and evaporation. Ground cover and topography do play significant roles in enhancing infiltration and percolation. A change in the amount of effective rainfall will alter recharge, but so too will change in the duration of the recharge season (NEMA, 2010). This reaffirms the effects of climate variability effects on the groundwater resources. IPCC (2007) GCM models and groundwater models shows that small negative changes in rainfall could lead to large negative changes in recharge and hence impact negatively. Thus changes in recharge therefore show a direct correlation with rainfall patterns. Due to lack of data on ground water this study relied on interviews from the users found using the boreholes during the survey. The study found an increase in boreholes overtime to about 50, this could be attributed to the search for alternatives water sources. Interview with the district water officer Narok South acknowledges that most of the boreholes dug were part of the drought management program during the 2009/2010 droughts when the government sought to increase water supply. The study cannot however conclusively conclude that climate variability is the only cause that has led to an increase; non-climatic factors do play a major role such as increasing demand for water both for irrigation and domestic use. Most of the boreholes are concentrated along the town centres, hotels and camps mainly for water supply, due to lack of piped water service. Plate: 4-2 below shows borehole at

Aitong relying on wind energy to pump water. Such boreholes are common with many located at the MMNR to supply water to the lodges and park entrance gates and other established facilities.

Plate 4-2: Borehole using wind energy at Aitong town centre. (Source: Author, 30/8/2012)

4.5.1.3 Climate extremes in the basin

The temperature and rainfall trend line shows an increasing scenario in figure 4-1, 4-2,while 4-3 shows a decreasing trend. This shows climate variability trends, which only exacerbates the risk of both floods and drought. There exist climatic and non-climatic factors already that influence floods and drought in the study area. Floods include river and flash floods were found to be the most common in the area, the cause was attributed to precipitation intensity, volume, timing, antecedent conditions of rivers and surrounding environments (e.g., type and vegetation cover). Flow data have been used to estimate intervals of specific low flows and floods reports (SEA, 2012). The report found that Mara river generally experiences very low flows on annual basis, though unlikely the river will go completely dry, this study reaffirmed these findings as shown in figure 4-4 and 4-6 of flows below $100m^3/s$. Human encroachment into flood plains and lack of flood response plans increase the vulnerability to floods disasters. Drought was reported to be recurring more often than it used to be, Majority of the respondents rated the droughts and famine as common (62.8%) as shown in table 4-17. Droughts were especially reported in 2000 and 2005 when the annual rainfall was less than 400mm as shown in figure 4-2 and 4-3, where the communities lost livestock and there was increased human to human and human to wildlife conflicts as the scarce water resources were exploited. Droughts were characterised by long dry spells and the permanent water sources remain the single sources supplemented by the boreholes.

4.5.1.4 Water resource vulnerability and its effect on demand and supply in the basin

To understand the effect of water vulnerability to water demand and supply the study looked the competing uses of water resources in the basin. The competing uses in the Mara basin include domestic use versus agriculture and minimum flows versus ecological flows. There are multiple stakeholders and the most notable were agriculture, domestic, municipal users, commercial, recreational and riparian landowners. Changes in water access and availability were dependent on volume, variability and seasonality and the efficient of existing water infrastructure. Thus the respective institutions that govern water allocation will play a large role in determining the overall social impacts of a change in water availability, as well as the distribution of gains and losses across different sectors of society. The quantity of water is not the only important variable but also increased precipitation intensity periodically results to in increased turbidity on the surface water sources.

Water demand has two fronts, competing and complementing uses (Kundzewicz *et al.,* 2007). These competing uses undermine the use of water by other sectors e.g. irrigation and domestic uses. Due to these uses of the river system, choices made in one portion implictly affect those living downstream. Complementing users are mostly the environmental and ecological uses which make the resource be used for other benefits. The water use for environmental and ecological uses will be threatened with continued variability due to low flows. This is very critical especially within protected ecosystems that are fragile and of global importance like the Maasai Mara National Reserve. The low flows and future uncertainty of the effects of climate variability will have great impact on the ecosystem.

With increasing water demands there is inherent sectoral change in response to climate variability (Kundzewicz *et al.,* 2007). This change will result in localized growth in water demand undermining the resource to provide safe, affordable water supply. Climate variability will actually alter the desired and actual uses of water demands. Water vulnerability will result in even supply of water leading to water scarcity, which will in turn increase demand. This ripple effect is expected to result in ways in which provision of water is done in the basin. To address such challenges the Bomet water supply under Tililbei water and sewerage company has installed piped water and installed water meters to improve water efficiency, this is especially so in Bomet town.

On the competing uses for water resources, climate variability alters river discharge resulting in in either unsustainable high flow or low flow to support socioeconomic activities like livestock, and domestic uses. Since water supply is a function of river flow, aquifer conditions and supply infrastructure (Tiwari & Dinar, 2003) climate variability will lead to increased irrigation water demands especially because the study area practises dry land agriculture, the surface water will most likely not satisfy all such demands. The study therefore concluded that water vulnerability should not only be assessed as a function of climate variability, but also of changing water use and the importance of non-climatic drivers (income, water-use efficiency, water productivity) increases as affirmed by (Faruqui *et al.*, 2001).

4.5.2 Objective Two: Assessment of land use/ land use changes in the Mara river basin

Among the various hydrologic processes that take place in a catchment, surface runoff and river flow indicates the water resources response to changing land cover. The images used for the study were taken during the months of January 1985, March

1989, January 2000, January 2002 and December 2010. During these months the results of Amala and Nyangores RGSs indicates that have low flows as depicted in figure 4-5 and 4-7 at 116m^3/s, 124m^3/s, 72.61m^3/s and 92.55m^3/s for Nyangores and Amala had 93.74m^3/s, 224m^3/s, 27.77m^3/s and 87.7m^3/s. The results obtained for land cover changes in the figure 4-8 have an impact on streamflow due to land cover change. Decreased vegetative cover generally increases the average surface runoff due to lack of landcover. Cropland/range land demands less soil moisture than forest thus rainfall satisfies the soil moirture deficit in croplands more quickly than forests thereby more runoff. Forests have the effect of reducing runoff, thus the smaller the area the more the runoff. This shows a correlation effect that LULC change and especially between forest/shrub land and cropland/range land has had on the hydrological regime of the Mara river basin. The changes in LULC over the period 1985-2010 have been significant and have contributed to a considerable increase in runoff. Table 4:1 shows that cropland/range land area has increased by 28% margin from 1985 to 2010, while forest/shrubland has decreased by 38% margin. At the same time period the river flow showed an increasing trend of 0.0073m^3/s for Amala River and 0.115m^3/s for Nyangores river as shown in figure 4-5 and 4-7. Increased river flow is detrimental to soil moisture, the discussion above could presumably indcate that the ground water resources are not well replenished as all the surface waters drain in the rivers. This further aggrevates the role of ground water in suplementing surface water resources in provision of both ecological and human needs. This analysis has provided a broad-scale framework for assessing the response and vulnerability of Mara river basin to altered streamflow regimes attributable to changes in land cover and cimate variablity that have occurred over for long time-frames.

The table 4-1 and Figure 4:8 above shows that range lands constitute the most predominant LULC proportion in the basin. Range lands generally are areas that on average receive below average rainfall of less than 750 mm per annum, the results show an increase of about 28%, being classified under rangeland and crop land this show increase in farming lands as land is cleared to pave way for agriculture. The water resources include swamps; wetlands, rivers and artificial water pans have reduced by 10%. Surface water resources aerial coverage's trend-line equation between 1985 and 2010; $y=-0.63x+16.41$ confirms that annual surface water resources are depreciating at an annual rate of about 0.63 Km^2 as presented by the slope coefficient which indicates the annual average rate of change. The slope coefficient indicates the annual average rate of change in the characteristic. If the slope is statistically significantly different from zero, the interpretation is that it is entirely reasonable to interpret there is a change occurring over time. The sign of the slope defines the direction of the trend of the variable: increasing if the sign is positive, and decreasing if the sign is negative.

Vegetation cover type and trend over time is an acceptable indicator towards an area's water vulnerability. From 1985, both the NDVI images and the land-use thematic maps provide vital insight into vegetation density and distribution in the basin. The Basins forest cover/ shrub-land has drastically varied during the study period (1985 – 2010) by up to an index of about 1,738.3 Km^2. Forests and shrub-lands depend mainly on the soil moisture for growth and regeneration, soil moisture is primarily recharged by the rain water in most parts. Deficiency of soil moisture as depicted by poor vegetation cover and increased shades of yellow red in the NDWI image indicate water and soil moisture deficiency. The surface water resources, mainly rivers are the only open water sources to wildlife and pastoralists who depend on these sources for their animals and domestic uses. But as the water resources in the area become more vulnerable to climatic change and destruction of vegetation cover as shown by decreasing forest/shrub land as indicated in Table 4:1 by the steadily increasing conversion of land to farm land and expanding rangeland areas are vital indicators towards the increasing susceptibility of the basin's water resources. Using this basis, the basin's water resources vulnerability is therefore arguably on the increase. Mara river basin greatly relies on Mau forest catchment, which has been subjected to degradation threatening the area's future water resource availability and Mara river base flow especially during the dry seasons.

Fluctuating water resource stability indicators as depicted above makes it difficult to predict and devolve the basin's water balance because of the external influence of the global climatic trends and activities in the upper Mara catchment, which directly affects the water resources availability and distribution over time. Decreased basin's vegetation cover reduces the time lag between peak of precipitation and peak run-off as the buffering capability of the watershed. Because vegetation retains water increasing percolation rate, this increases time taken for runoff to accumulate and reach the river channels. Reduced vegetation cover on the other hand has a threefold effect: first, flash floods increasingly become a common phenomena as infiltration ability of the catchment declines; second, the runoff and rivers become loaded with contaminants including the sediments which settle in dams affecting the dam's lifespan and efficacy of performing its functions; and lastly, the basins recharge capacity during dry seasons is greatly hampered. This wholly put adversely hastens the basin's water vulnerability as the net loss of received recharge is increased leaving very little water available for use especially during the dry spells.

The reduction of surface water coverage in 25 years by 10.7% from 1985-2010 as shown in Table 4-1 depicts a volatile situation. This can be attributed to evaporation by high temperatures and the land under vegetation cover as compared to the proportion of the basin exposed to direct sun (bare land). Bare land increases loss of water through evapo-transpiration while also reducing the amount of water percolating into the sub-surface and duration required in generating run-off during the rainy season. These aspects point towards water resource vulnerability. Hydrologic response is factor of land cover change. Basin vegetation cover change in the long-run affects the areas evapo-transpiration, total annual water yield, quick flow and base flow rates. Vegetation cover change impacts on water resources are complex depending on the affected aerial extent. Catchment vegetation cover change affects water cycle processes like water interception, evapo-transpiration and soil moisture levels. Decline in vegetation cover extent against declining surface water resource directly yields water vulnerability quotient. As the basin's vegetation cover extent drastically declined as shown in Table 4-1 by 38% from 1985-2010 and surface water resources declined by 10.7% during the same time, the area's water balance equation is put at stake thus threatening especially the pastoral and agricultural dependent livelihoods and wildlife resources. The Basin's water sources vulnerability maybe heightened by water use patterns and climatic variability. Since man is a central driver in the change in water resource utilization and a subject of water vulnerability.

4.5.2.1 NDVI, NDWI analysis and climate variability

River flow reflects rainfall and rainfall induces green vegetation, thus the study of NDVI time scales is imperative to show the variations of the vegetation cover as well. Thus NDVI time series analysis can be used to quantify the actual fractional vegetation cover changes caused by climate variability and human activities (Labat, 2008). The changes witnessed in the study can therefore be related to seasonal weather conditions and the moisture availability in the sub soil, thus there exists a vivid relation between phonological behavior, climate and land use. Rainfall distribution in Mara river basin is greatly influenced by land use and land cover. The vegetation varies within biannual, annual and inter-annual periods. The reduction witnessed in forest/ shrub cover by 38% from 1985-2010 as shown in Table 4-1 contributes to climate variability and further exacerbates the forest ability to sequestrate CO_2 in the atmosphere. The 10.7% decline in surface water resources between the years 1985-2010 corresponds at the same time when rainfall shows great inter annual variability with frequent peak and low points. This decrease in surface water resources is mainly associated with LULC and the climate variability; rainfall shows an increasing trend but a big disparity between peak and low rainfall. These findings are further ascertained by (Mute *et al.*, 206) who indicate that variability in Mara River is exacerbated by land use and land cover and subsequently by erratic rainfall patterns. Jacob (2008) reports that the decrease of Mara River flows is a result of changes in the most tributaries becoming seasonal. This variability has resulted to reduced stream flow, seasonal rivers and drying up of wetlands and swamps. The analysis indicates decreased forest/shrub land, which increases surface runoff and reduces infiltration capacity of the water. Though there exists a linear relationship between climate variability and NDVI time scale analysis. It cannot be conclusive that all the changes in NDVI are due to climate, human activities have great role in either enhancing the greenness through irrigation and prudent environmental conservation measures. Olsson *et al.*, (2005) expounds further that climatic influences cannot alone explain differences entirely. This means other factors definitely do play part in vegetation cover changes. Such factors in the Mara river basin include large herds of livestock, farming, deforestation and mechanized irrigation.

4.5.3 Objective Three: Assessment of the influence of climate variability on the socio-economic livelihoods in the Mara river basin.

Impacts of climate variability in the Mara River Basin are predominantly harmful where a significant population of the communities occupy. This vulnerability will vary not only in nature, rate and severity of the changes in climate but also on the risk factors that will further entrench these effects. These include social and economic status of the community and governance issues. Vulnerability will be entrenched by the ability of the particular households and communities in responding to/or coping with such effects.

4.5.3.1 Drought and floods

69.4% of the respondents interviewed said that climate variability in the Mara River Basin is manifested through prolonged drought as shown in Figure 4-21. This prolonged drought has resulted in community and household vulnerabilities due to crop failure, reduced food production increase in crop and livestock diseases and water scarcity as indicated on Figure 4-22. The Mara River basin is already experiencing changes in onset of rainfall seasons. The households practising farming have reported decreased crop yields and diminishing food security. This is evidenced in the Figure 4-14 by the number of food deficiency months, where majority of the respondents 45.2% have more than 5 months of food deficiency. Subsequently livestock production has greatly been affected mainly due to scarcity of pasture (97.2%) and lack of 71.8% of the respondents as indicated in figure 4-15.

Households that have not diversified their crops and rely mainly on maize as opposed to more adaptive crops like cassava and millet and short durations crops like beans. Figure 4-13 shows 55.6% of respondent's plant maize and 3.2% planting drought resistant crops such as millet and sorghum. Reliance on maize farming and lack of diversification further exacerbates the household vulnerability. Traditional cultures do not favour women, while men go out in search of alternative source of income to supplement the earnings from crop and livestock women are left caring for children and livestock. This puts women at great risk, as they cannot make decisions on their own as regards on type of crops and livestock in their farms. Lack of extension services further aggravates the situation as they lack information that could help them adapt and mitigate against droughts. At community level, potential conflicts in resource use and scarce resources results in high vulnerability. Figure 4-19 cited 22.6% of the respondents said conflicts are among the challenges in accessing water resources. Households with large herd of livestock are at risk in spite of the wealth tag on such number of livestock.

Floods have serious effects on food production, especially households in lowlands areas. In Mara River Basin the risks of flooding are not significant with respect to affecting food production. Figure 4-22 shows 17.7% of respondents said flood affects households as compared to crop failure and famine that were rated at more than 50%. Flash floods are more common in the basin, they sweep out bridges and create gulley's blocking roads and access routes in the basin. This hurts crop harvest production when roads become impassable, coupled with poor post harvest storage facilities harvested food crops are destroyed in the granaries.

Drought and flood effects have also been felt through impact on resources, which deplete incomes and reduce food security. Collectively increases in droughts, flooding added stress on water resources, human health and animal health and infrastructure leading to decrease in the well being and livelihood of communities.

Households suffering from diseases are more vulnerable to other external shocks and this has great effect on their productivity.

Table 4-10 shows 48.4% and 36.3% of the respondents travel between 1-2km and 3-5km respectively to access water. Table 4-11 further shows that of all the water resources 56.7% are seasonal. Reduced availability and access to water resources has brought risks both at the household and community levels. Figure 4-19 shows that amongst the challenges cited by the respondents in accessing water they were long distance (64.2%) and dirty water (70.2%). Lack of access to clean and safe water affects human health. Majority of the households travels between 1-5km to access water, which is mostly not clean, there is generally lack of piped water through out the basin except in major towns.

Changing water levels in rivers and streams pose another risk as rivers have less water thus increasing competition. Mara River during prolonged droughts has low flows affect the great wildebeest migration. Women are forced to daily fetch water over long distances, thus the aged and sick have become more vulnerable. Figure 4-20 shows respondents solutions to these challenges solutions include protecting water (65.3%), promoting water storage (50%) and roof catchment (34.7%). Storage facilities in households will determine how much water can be used at a particular time. This further shifts focus on the ability of the household to buy the storage facilities. The changing water resources have serious implications in government planning and expenditure due to infrastructure development as the sources keep on shifting. The water intake levels during dry season are below the water levels thus cuts supply when water is needed most. This at times calls for greater investments thus households with low capacity to share costs involved in the provision of water services are at higher risk of not receiving clean and safe water.

4.5.3.2 Non-climatic indicators

Non-climatic factors compromise adaptive capacity of the households against climate variability. Such factors reduce their resilience such as lack capacity to replenish their stocks to previous numbers after drought. If this climate related effects become recurrent their adaptive capacity can be eroded completely. Table 4-2 shows that 30.8% and 14.5% of the respondents have gone through secondary and higher education respectively. Education offers better understanding to climate variability and easy to absorb or implement adaptive and coping strategies. The table further shows that 13% of the respondents are either salaried or self employed while 3% are unemployed. Salaries and wages offer alternative sources of income apart from traditionally sources like farming and livestock. Communities with low individual and social capital such as membership to groups are greater risk of climate effects. Where social capital is high, community members support each other in terms of food, money and labour. Household with diversified incomes sources are less vulnerable than households that solely depend on farming and livestock.

4.5.3.3 Adaptation and coping strategies

Mitigation and adaptation are the most feasible options to deal with negative effects of climate variability, however any effective adaptation is constrained by the household adaptive capacity. A number of factors can explain low adaptive capacity such include financial constraints, low education and few institutions with capability to deal with adaptation as well as abject poverty in an area where a large population are poor Table 4-2 shows that only 30.8% and 14.5% of the respondents have gone through secondary and higher education respectively and further 13% of the respondents are either salaried or self employed while 3% are unemployed. However the communities have evolved and developed ingenious strategies to enhance resilience such formation of savings groups and access to microfinance, exchange of livestock with relatives from different locations in case of death one has reserve. Equally important we have organizations like WWF, the county government and the Maasai Mara National Reserve management that have put up aid systems and community response systems such as livestock uptake programmes when drought is fore warned. Figure 4-23 indicates that 62.5%, 23.3% and 13.4% get information on EWS from mass communication, governments and NGOs. Farmers have also started timing of planting season to coincide with onset and cessation of rainfall. This has resulted in changing land preparation, planting and harvesting dates, though the change from traditional cash crops is yet to be fully adopted.

CHAPTER FIVE: SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter deals with summary of main findings, conclusion, the recommendations of this study and areas for further research. The main objective of the study was to assess the vulnerability of water resources to climate variability in middle catchment of the Mara river basin. To this end, it set the objectives of coming out with the nature and trends of climate and water resources, the link and how the two influence each other, the study also maps the vulnerability trend in terms NDVI and NDWI indicating the variability effect on soil moisture, the drivers of vulnerability and adaptation and mitigation measures. Empirical tools used in conducting the field survey were, key informant interview guide, field observation guide and photography. Analytical tools were mainly quantitative and qualitative analysis, descriptive statistics (frequencies and percentages) and geographical information systems.

5.2 Summary of findings

5.2.1 Objective One: To examine the hydro-climatic trends in the Mara River basin

There is increasing trend in minimum temperature has an R^2 of 0.2064 indicating that the temperature has increased with an average of 0.2^0C every year. The slope coefficient indicates the annual average rate of change in the temperature characteristic. If the slope is statistically significantly different from zero, the interpretation is that it is entirely reasonable to interpret there is a change occurring over time. The sign of the slope equation defines the direction of the trend of the variable: increasing if the sign is positive, and decreasing if the sign is negative. The maximum temperature has an R^2 of -0.033 this shows a decreasing trend. This could be attributed to both changes in local and global climates overtime. Such warming temperatures will lead to more vigorous extremes of hydrological cycle such droughts and floods. Rainfall increased in Narok showed an increasing trend of 0.025mm/yr. while in Ilkerin it decreased by 0.002mm/yr. In these stations the trend showed and inter-annual variability with peak years followed low flows within very short period 2-3years, signifying the recurrent trend of high intensity rainfall not necessarily leading to floods and dry long spells of droughts.

Analysis of river flows for the two river gauging station showed that Amala in May and August has the highest flow above 527m^3/s while February and March 78.5m^3/s and 60.95m^3/s respectively. The graph showed seasonal river flow with high flows experienced during the months of August to October and relative low flows during the April to July. The river flow is bi-modal replicating the rainfall patterns of the study area. Inter annually the flows were characterized by cyclic trends of very high flows followed by low flows.

Rainfall largely determines the extent of water availability in space and time. Rainfall variability will result in uneven distribution of water resources over space and time; this variability will have significant negative impact on access and utilisation of water resources. The variability is more pronounced inter-annually than seasonally, this variability has detrimental effect on the basin water resources at both local level and regional level. The increasing rainfall trend coupled with increasing inter-annual variability creates a scenario whereby there will be little percolation and infiltration for ground water recharge. Such intensity compromises storage capacity of the water infrastructure for use during dry periods.

Climate variability has directly affected the surface water resources both in quantity and quality of water resources. Though not solely to blame for low dry flows, climate variability has resulted in seasonality of river flows. Many streams and river flowing to the Mara river are seasonal, community members interviewed shared the same experiences, and the seasonality has been worsening with time. Rivers stated to have such great effect are Sand, Talek, Engare Ngobit rivers and streams along Narok Ololaimutia road. There has been an increasing trend in investment in ground water abstraction with the number of boreholes increasing. Almost all town centres in the study area are supplied with water from boreholes, all the hotels and camp lodges depend entirely on ground water.

Climate extremes in the basin include floods and drought, though the study cannot conclusively conclude that the causes of the climate extremes are primarily on climatic factors. Mara river basin generally experiences very low flows on annual basis, though unlikely the river will go completely dry. Flood frequency analysis indicates that annual flood events occur with larger, channel shaping characteristic every 2years. Floods occur mostly as increased river discharge above normal rather than literally flooding the flood plains. Drought is usually inform of prolonged dry spells with little or rainfall at all.

Competing and complementing uses affect demand of water in the study area. The change in water availability was dependant of volume, variability and seasonality and the efficient of existing water infrastructure and any investment in new infrastructure. Climate variability will actually alter the desired and actual uses of water demands. Water vulnerability will result in even supply of water leading to water scarcity, which will in turn increase demand. This ripple effect is expected to result in ways in which provision of water is done in the basin. To improve water use efficiency there has been introduction of water use meters.

5.2.2 Objective Two: To examine the hydro-climatic trends interactions with land use/land use change that influence water resources vulnerability.

Land use/land cover analysis summarizes the finding as Forest/ Shrub-land decreased by 38.38% Crop-land/ Rangeland increased at 28.91% and Water resources declined by 10.73% and bareland reduced by 59%, based on the 1985 satelite image as our base year and 2010 satelite imager analysis. The images used for the study were taken during the months of January 1985, March 1989, January 2000, January 2002 and December 2010. During which these months the results of Amala and Nyangores RGSs indicates that have low flows as depicted in figure 4:8 at $100m^3/s$. Decreased vegetative cover generally increases the average surface runoff. Thus high stream flow can be concluded to be as a result of increased cropland/range land and decreased forest as observed. The water resources include swamps, wetlands, rivers and artificial water pans have reduced by 10%. Fluctuating water resource stability indicators as depicted above makes it difficult to predict and devolve the basin's water balance equation because of the external influence of the global climatic trends and activities in the upper Mara catchment that directly affects the water resources availability and distribution over time.

5.2.3 Objective Three: To assess the influence of climate variability on the socio-economic livelihoods in the Mara river basin

Majority of the respondents interviewed were farmers (24.4%) and pastoralists (45.5%) and majority had lived in the basin for more than 30 years thus could give detailed account of climatic changes in the area. Grass thatched (31.1%), semi-permanent (34.4%) and Manyatta (25.4%) dominated the type of housing. Type of housing influnces vulnerability as it promotes household to harvest rainwater for use during the dry season as opposed to thatched and manyatta houses. Given that most of the households depends on farming and livestock keeping increased incidences of drought would thus affect this segment of the population.

The majority of the residents owned land above 5acres and the main utilization was farming 20.2% and pastrolism (46%). The type of food crop grown in the area of study was determined by climate conditions, geology and altitude mostly dormainated by maize (55.6%). Majority of the respondents (45.2%) experienced food inadequacy for more than 5months and drought accounted for 57% as the reason for the insufficiency. Majority 76.4% belived that drought was as a result of climate variability.

Majority of the respondents 48.4% and 36.3% traveled between 1-2 Km and 3-5 Km to access water. Of the available water resources 56.7% were seasonal. Challenges facing water accessibility and avalabilty were long distances of walking to access water, dirty water and conflicts with neighbors over water access. Climate variability manifested it'self to the respondents as unpredictable rainfall (76.6%) and prolonged droughts (69.4%). Crop failure (52%) and famine (57.6%) were major effects according to the respondents. Majority of the respondents were aware of the EWS and adhered to the comunications, most of such information came from Radio and TV. This was attributed to establishment of local vernacular radio stations that is widely listened and understood.

5.3 Conclusion

5.3.1 Objective One: To examine the hydro-climatic trends in the Mara River basin

This study has presented analyses of rainfall river flow and satellite imagery with the objective of assessing the vulnerability of water resources to climate variability. Future water resources will be highly dependent upon whether and how variability is affected by climate change. While there is uncertainty in estimating potential climate variability impacts, according to the study results, climate variability is likely to pose an additional water resource stress to the Mara River Basin. Although water is a renewable resource through the hydrological cycle, the resource will be significantly affected by climate change and variability primarily because the main source of water is rainfall, a component of climate. The variability will have ripple effect in the uneven distribution of water resources over time and space, and this will have a significant negative impact on access to and utilisation of water resources. Water availability varies geographically, and stream flows fluctuate on daily, seasonal, annual, and decadal time scales. River flow depends on climatic processes that, to some extent, follow regular seasonal patterns that are predictable. However, within those seasonal patterns, there is a great deal of intra-seasonal and inter-annual variability. The variability is, to some extent, the random outcome of nonlinear interactions among independently varying components of the climate system. The close link between climatic variations and water availability suggests that water resources in the basin will be sensitive to the regional effects of global climate change. Prospective climate change complicates long-term water resources planning because it will alter stream flow probability distributions. The marginal annual increase in temperature locally, nationally and globally will have substantial changes in mean annual stream flows, the seasonal distribution of flows, and the probabilities of extreme high or low flow conditions. Such warming will be accompanied by changes in precipitation; evaporation, and runoff, runoff characteristics may change considerably over the next several decades. Rapid population growth, increasing environmental concerns, and resulting changes in the character of water demands have led to increased competition for water even under normal flow conditions. These same changes contribute to increased vulnerability to water resources. Under low flow conditions, the risk of shortages now falls on a growing set of competing uses and values. Thus, the significance of water resource variability is growing at a time when anticipated global and regional climate variability has increased our level of uncertainty regarding the future of water resources characteristics of the Mara River Basin. Effective design of long-term policy will require an understanding of the existing relationship of climate to water resources in the basin, the nature of potential climate changes, the sources of uncertainty, and the prospects for resolving the uncertainties.

5.3.2 Objective Two: To examine the hydro-climatic trends interactions with land use/land use change that influence water resources vulnerability.

Surface runoff and river flow indicate water response to changing land cover. The decreasing trend in forest/shrub-land by 38% from 1985-2010 and increase in crop pland by 28% ove the same period indicate the changing land cover and this has resulted in a decrease of 10.7%. Decreased vegetative cover generally increases the average surface runoff due to lack of landcover. Forests have the effect of reducing runoff, thus the smaller the area the more the runoff. During the same periods the river flow increased. Increased river flow is detrimental to soil moisture needed to support plant growth and contribute to ground water recharge. Thus increased surface run off have an effect in ground water replenishment. The increasing crop land/range land shows the conversion of rangelands to farm lands for agriculture.

Vegetation cover type and trend over time helps us understand water vulnerability, analysis of NDWI depicts deficiency in soil moisture. Soil moisture is important for growth and regeneration and is recharged mainly by rainfall. Thus NDWI images show increasing shades of yellow indicates that water and soil moisture deficiency. The surface water resources, mainly rivers are the only open water sources to wildlife and pastoralists who depend on these sources for their animals and domestic uses. But as the water resources in the area become more vulnerable to climatic change and destruction of vegetation cover as shown by decreasing forest/shrub land there will be increasing susceptibility of the basin's water resources.

Decreased basin's vegetation cover reduces the time lag between peak of precipitation and peak run-off as the buffering capability of the watershed. Because vegetation retains water increasing percolation rate, this increases time taken for runoff to accumulate and reach the river channels. Lack of vegetation cover presents three pronged challenge flash floods, run off and rivers become loaded with sediments and the basin recharge capacity is compromised. This puts into perspective the growing vulnerabilities of the basin water resources. This exacerbated by reduced surface water coverage in 25 years by 10.7% from 1985-2010 depicts a volatile situation. Bare land increases loss of water through evapo-transpiration and reduce percolation rate. These factors point towards water resource vulnerability. The increasing demand for already varying water resources further compounds the increasing vulnerability.

5.3.3 Objective Three: To assess the influence of climate variability on the socio-economic livelihoods in the Mara river basin

Impacts of climate variability on the basin residents vary in nature, rate and severity. Droughts and crop failure were listed as the major effects, they have led to reduced food production and increased water scarcity. With basin residents experiencing food insufficiency for more than 5 months every year this is significantly affect their food security and resilience capabilities. Crop diversification remains a dream, with over reliance on maize despite continued year-to-year failures. The farmers need to diversify and introduce short duration crops and drought resistant varieties. There is also bound to have resource use conflicts centred on water resources.

Drought and crop failure deplete incomes couples with poor post harvest storage facilities aggravate household vulnerabilities. Lack of access to clean and safe water affects human health. Lack of proper sanitary facilities especially downstream brings out the possibility of water borne diseases. This affects animal and human health, diseases expose susceptibility to other external shocks and reduces the households productivity. The households travel between 2-5 Km to access water which is not safe and clean for human consumption. Challenges of access cascades especially to women who has to make daily trips to fetch water. This disadvantages the women productivity and shifts focus on the ability of the household to buy and install water storage facilities.

The basin residents have developed ingenious adaptive and coping strategies to cope with prolonged droughts and increasing water scarcity. However the recurrent nature of the droughts especially erodes their resilience. Lack of social and subsequently individual capital puts the residents at a greater risk. Where mitigation and adaptation strategies are in place they constrained by the household adoption capabilities. Education plays a significant role in mitigation and adaptation to climate variability effects. However when the households compels the girl child to early marriages and the boy child is left to herd the livestock their adaptability is compromised as the only means of source of income is threatened by climate variability. A number of factors constrains adoption such as financial, low education, as well as poverty in the basin. However all is not lost in the basin, the households have developed certain coping mechanism such as group savings, microfinance and exchange of livestock between friends and relatives from different locations in case of drought in one part, there is a reserved stock to replenish the stocks.

5.4 Recommendations

5.4.1 Objective one: To examine the hydro-climatic trends in the Mara River basin

i) Develop basin conservation management strategies aimed at increasing river flows such as rehabilitation of degraded Mau forest.

ii) Installation of hydro-climatic monitoring instruments for forecasting and early warning.

5.4.2 Objective two: To examine the hydro-climatic trends interactions with land use/land use change that influence water resources vulnerability.

i) Develop a GIS database and LULC monitoring program for the basin to assist in better management and understanding of basin land cover changes.

ii) Develop strategies water conservation and management strategies aimed at increasing the surface water aerial coverage.

5.4.3 Objective three: To assess the influence of climate variability on the socio-economic livelihoods in the Mara river basin

i) Educate the basin residents on the importance of education in responding to challenges of climate variability, since majority of them have attained form four education and below.

ii) There is need to diversify sources of income and crops from traditional the traditional maize farming and livestock keeping.

iii) Adoption of efficient agricultural practises propels increased quality food production that fetch higher prices and offer alternative livelihoods

iv) There is need for increased investment in household and community water harvesting infrastructure to cater for competing and complementing users.

v) There is need for continued and sustained awareness on mitigation and adaptation measures that enhances resilience of the households.

vi). Promote adherence and application of modern technologies on EWS to complement traditional warning systems.

REFERENCES

Aboud, A. A., Obweyere, G. O., Mutinda, M. M., & Raini, J. A. (2002). *A Rapid Participatory Socioeconomic Assessment of the Mara River Basin. Mara River Catchment Basin Intiative.* WWF Nairobi, WWF-Eastern Africa Regional Office. Nairobi: WWF.

Adger, W. N. (2000). Social and ecological resilience: are they related? *Progress in Human Geography*, *24* (3), 347-364.

ALRMP. (2011). *ALRMP Bulletin.* Nairobi: National Drought Management Authority.

Andreas, E. L., Tucker, W. B., & Ackley, S. F. (1984). Atmospheric Boundary - Layer Modification, Drag Coefficient, and Surface Heat Flux in the Antatctic Marginal Ice Zone. *Journal of Geophysics Resolution*, *89* (6), 649-661.

Anyamba, A., & Eastman, J. R. (1996). Interannual variability of NDVI over Africa and it's relation to El Nimo/Southern Oscilation. *International Journal of Remote Sensing*, *17* (13), 2533-2548.

Archer, E. R. (2004). Beyond the "climate versus grazing" impasse: Using remote sensing to investigate the effects of grazing system choice on vegetation cover in the Eastern Karoo. *Journal of Arid Environments*, *57*, 381-408.

Bohle, H. G., Downing, T., & Watts, J. (1994). Climate chnage and social vulnerability. *Global Environmental Change* , *4*, 37-48.

Brooks, N. (2004). Drought in the Africa Sahel; Longterm perspective and future prospects. *Tyndall Centre for Climate Change Research* , *61*, 31-37.

Buermann, W., Anderson, B., Tucker, C. J., Dickinson, R. E., Lucht, W., Potter, C. S., et al. (2003). Interannual covariability in Northern Hemisphere air temperatures and greenness associated with El Nino_Southern Scillation and the Arctic Oscillation. *Journal of Geophysical Resolition* , *108*, 1029-2002.

Burton, I. (1997). Vulnerability and adaptive responses in the context of climate and climate change. *Climate Change* , *36*, 185-196.

Chen, M., Xie, P., & Janowiak, J. E. (2002). Global land precipitation: a 50-yr monthly analysis based on gauge observations. *Journal of Hydrometeorology* , *3*, 249-266.

Conway, D. (2002). Extreme Rainfall events and Lake level changes in East Africa: Recent Events and Historical Precedents. (E. O. Odada, & D. O. Olago, Eds.) *The East Africa Great Lakes: Limnology, Palaeolimnology and Biodiversity* , *12*, 63-92.

De Wit, M., & Jacek, S. (2006). *Changes in Surface Water supply across Africa with predicted Climate Change.* University of Cape Town. Cape TOwn: Africa Earth Observatory Network.

Downing, T. (2003). *Toward a vulnerability/adaptation ScienceL Lessons from famine early warning and food security.* (J. Smith, & S. Huq, Eds.)

Eklundh, L., & Olsson, L. (2003). Vegetation index trends for the African Sahel 1982-1999. *Journal of Geophysical Resolution , 19*, 563-568.

Elasha, T. (2006). Background paper on Impacts,vulnerability and adaptation to climate change in Africa. *Africa Workshop on Adaptation Implementation of Decision 1/CP.10 of the UNFCCC.* Accra Ghana: UNFCCC.

Evans, J. P., & Geerken, R. (2004). Discrimination between climate and human induced dryland degradation. *Journal of Arid Environments , 57*, 535-554.

F"ussel, H. M., & Minnen, J. G. (2002). Climate impacts response functions for terrestial ecosystems. *Integrated Assessment , 2*, 183-197.

Galvin , K. A., Bone, R. B., Smith, N. M., & Lynn, S. J. (2001). Impacts of climate variability on East African pastralists: Linking social science and remote sensing. *Climate Research , 19*, 161-172.

Gray, T. I., & Tapley, J. B. (1985). Vegetation health; Nature's climate monitor. *Vegetation Health: Advanced Space Resolution , 5* (6), 371-377.

Greegor, D. H., & Norwine, J. (1986). Global habitability and remote sensing: The role of meteorological satelite data. *The Science of the Total Environment , 55*, 187-196.

Groove, A. T. (1996). African river discharges and lake levels in the twentieth century. (T. C. Johnson, & E. O. Odada, Eds.) *The limnology, climatology and paleo-climatology of the East Africa Lakes* , 95-100.

Hermann, S. M., Anyamba, A., & Tucker, C. J. (2005). Recent trends in vegetation dynamics in the African Sahel and their relationship to climate change. *Global Environmental Change , 15* , 394-404.

Hulme, M., Doherty, R., Ngara, T., New, M., & Lister, D. (2001). African Climate Change. *Climate Research , 17*, 145-168.

IPCC. (2001). *Climate Change 2001: The Scientific Bias.* Cambridge: Cambridge University Press.

IPCC. (2007). *Climate Change 2007: Impacts of Adaptation and Vulnerability.* Intergovernmental Panel on Climate Change . New York: UNFCCC.

IPCC. (2001). *Imapcts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Third Assessment Report.* New York: Cambridge University Press.

IRR. (2002). *Managing Dryland Resources - An extension manual for Eastern and Southern Africa.* Nairobi, Kenya: International Institute for Rural Reconstruction .

Justice, C. O., Holben, B. N., & Gwynne, M. D. (1986). Monitoring East African vegetation using AVHRR data. *International Journal of Remote Sensing* , *7* (11), 1453-1474.

Khroda, G. (1996). Strain and Environment consequences and water management in the most stressed water systems in Africa. In E. Rached , E. Rathgeber, & D. Brooks, *Water Management in Africa and the Middle East: Challenges and Opportunties* (pp. 112-117). Nairobi: WMI.

KNBS. (2009). *Kenya Population and Housing Census.* Nairobi: KNBS.

Kron, W., & Berz, G. (2007). Flood disasters and climate change: trends and options a (re)insurer's view. In J. L. Lozan, H. Grabl, P. Hupfer, L. Menzel, & D. C. Schowiese, *Global Change: Enough water for all?* (pp. 268-273). Hamburg: Oxford.

Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Doll, P., Kabat, P., Jimenez, B., et al. (2007). Freshwater resources and their management. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. Van der Linden, & C. E. Hanson, *Climate Change 2007: Impacts, Adaptation and Vulnerability.* (pp. 173-210). Cambridge: Cambridge University Press.

Labat, D. (2008). Wavelet analysis of the annual discharge records of the worlds largest rivers. *Advances in Water Resources* , *31* (1), 109-117.

Martiny, N., Camberlin, P., Richard, Y., & Philippon, N. (2006). Comapred regimes of NDVI and rainfall in semi-arid regions on Africa. *International Journal of Remote Sensing* , *27* (33), 5201-5223.

Melesse, A. M., McClain, M., Abira, M., & Mutayoba, W. (2008). Hydrolometeorological Analaysis of the Mara River Basin, Kenya/Tanzania. *World Environmental & Water Resources Congress*. Honolulu, Hawai.

Mugenda, A. G. (2008). *Social Science Research. Theory and Principles: Applied Research.* Nairobi: ACTS Press.

Mugenda, O. M., & Mugenda, A. G. (1999). *Reasearch methods: Quantitative and Qualitative Approaches* . Nairobi, Kenya: ACTS Press.

Mutie, S., Mati, B., Home, P., Gadain, H., & Gathenya, J. (2006). Evaluating land use effects on river flow using USGS Geospatial stream flow model in Mara River Basin, Kenya. *Proceedings of 2nd Workshop of the EARSel* (pp. 45-51). Bonn: EARSel.

Mutua, M., Oyieke, H., Gatheru, S., Githeka, J. U., & Mwango, F. (2002). *The Water Resources Sector. Factoring of weather and climate information and products into disaster management policy: A contribution to strategies for disaster management.* Nairobi, Kenya: IGAD and DMCN.

Myeni, R. B., Nemani, R., & Running, S. (1997). Estimation of global leaf area index and absorbed PAR using radiative tranfer models. *Transactions on Geoscience and Remote Sensing*, *35*, 1380-1393.

NEMA. (2010). *State of Environment.* National Environment Management Authority. Nairobi: NEMA.

Nemec, J., & Schaake, J. (1982). Sensitivity of water resource systems to climate variation. *Hydrological Sciences Journal*, *27*, 327-343.

Nicholson, S. E., Davenport, M. L., & Malo, A. R. (1990). A Comparison of the vegetation response to rainfall in the Sahel and East Africa using NDVI from NOAA AVHRR. *Climate Change*, *17*, 207-241.

O'Brien, K., Eriksen, S., Schjoden, A., & Nygaard, L. (2002). *What's in a word? Conflicting interpretations of vulnerability in climate change research.* Berlin: CICERO.

Odada, E. O., & Olago, D. O. (2002). *The East African Great Lakes: Limnology, Paleolimnology and Biodiversity.* Netherlands: Kluwer Academic Publishers.

Olsson, L., Eklundh, L., & Ardo, J. (2005). A recent greening of the Sahel - trends, patterns and potential causes. *Journal of Arid Environments*, *63*, 556-566.

Parry, M. (1992). *Climate change and world agriculture.* London: Earthscan.

Petheram , C., Walker, G., Grayson, R., Thierfelder, T., & Zhang, L. (2001). Towards a framework for predicting impacts of land use recharge. *Australia Journal of Soil Research* , *40*, 397-417.

Ribot , J. C., Magalhaes, A. R., & Panagides, S. S. (1996). *Climate Variability, CLimate Change and Social Vulnerability in the Semi-arid Tropics.* Cambridge: Cambridge University Press.

Ringus , L., Downing , T. E., Hulme, M., Waughray, D., & Seldrod, R. (1996). *Climate Chnage in Africa-Issues and Challenges in Agriculture and Water for Sustainable Development.* Oslo: Center for International Climate and Environmental Research.

SEA, M. (2012). *The Transboundary Mara River Basin Strategic Environmental Assessment (MRB SEA).* LVBC, WWF, USAID, GoK, STK. Kisumu: LVBC.

Smit, B., & Pilifosova, O. (2001). Adaptation to climate change in the context of sustainable development and equity. In *IPCC Climate Change 2001: Impacts, adaptation and Vulnerability* (pp. 879-906). Cambridge: Cambridge University Press.

Stern, N. (2006). *The Stern Review: The Economics of Climate Change.* London: HM Treasury.

Sullivan , C. A., & Huntingford, C. (2009). Water Resources, Climate Change and Human Vulnerability. *International Congress on Modelling and Simulation.* (pp. 2377-2383). Wellington: Int Association of Mathematic and Computer in Simulation.

Sutcliffe, J. V., & Knott, D. G. (1987). The influence of climate change and climatic variability on the hydrologic regime and water resources. In *Historical variations in African water resources* (pp. 463-476). Oxfordshire: IAHS Publication.

Tiwari, D., & Dinar, A. (2003). Balancing future food demand and water supply: the role of economic incentives in irrigated agriculture. *Journal of International Agriculture* , *41*, 77-91.

Tucker, C. J., & Nicholson, S. E. (1999). Variations in the size of the Sahara Desert from 1980 to 1997. *Ambio* , *28* (7), 587-591.

UNEP. (1999). Water availability in Africa. In UNEP, *Global ENvironmental Outlook 2000* (p. 398). London: Earth Scan.

Valimba, P., Mtalo, F. W., & Servat, E. (2008). Evidence of changing flow regime in the Mara River Basin in Kenya/Tanzania. *Hydrological Sciences* , *45*, 56-61.

Verhoef, W., Menenti, M., & Azzali, S. (1996). Covers a colour composite of NOAA_AVHHR-NDVI based on time series analysis (1981-1992). *International Journal of Remote Sensing* , *17*, 231-235.

WFP. (2000). *Kenya's drought: No sign of any let up.* World Food programme. Rome, Italy: WFP.

Wigley, T. M. (2005). The Climate Change Commitment. *Hydrological Sciences Journal , 307*, 1766-1769.

World Bank . (2002). *Poverty and climate change: Reducing the vulnerabilities of the poor.* Washington DC: World Bank.

WRI. (2008). *World Resources Institute.* Washington DC: WRI.

Wu, C., Niu, Z., Tang, Q., & Huang, W. (2008). Estimating content from hyperspectral vegetation indices: Modeling and validation. *Journal of Agricultural and Forest Meteorology , 148*, 1230-1241.

Yamane, T. (1967). *Statistics: An Introductory Analysis.* (Harper, & Row, Eds.) New York.

Yohe, G., & Tol, R. (2002). Indicators for social and economic coping ca[acity moving toward a working defination of adaptive capacity. *Global Environmental Change , 12*, 25-40.

Zhou, X. Y. (2003). Monitoring Vegetation Phenology using MODIS. *Remote Sensing of Environment , 84*, 471-485.

APPENDIX I: INTERVIEW GUIDE

PREAMBLE

Good morning/afternoon: My name is Waithaka R Kamau. I am a student at Kenyatta University studying M.sc. in Integrated Watershed Management. Currently I'm conducting a study on *Assessment of Vulnerability of Water Resources to Climate Variability in Mara River Basin, Kenya* I would like to ask you a few questions in relation to the study. The information you provide will be kept strictly anonymous and confidential and will be used solely for research on finding solutions to common problems.

Name	
Institution	
Position/Profession	
Area	

1. What forms of climate variability do you experience in your area?
2. Would you explain the extent of climate variability effects on water resources in the Mara basin?
3. What is the effect on river regimes?
4. How about other water resources like swamps, boreholes, wetlands etc?
5. How consistent are the rainfall patterns?

6. What do you think is the future predictions or expected effects of climate variability?
7. What is the impact of climate variability on the livelihood of the people?
8. What is the impact variability on rain fed livelihoods?
9. Who is more vulnerable to the impacts of climate variability? Why?
10. What are the mitigation and adaptations on the effect of climate variability on water resources?
11. What challenges do you experience in implementing the Mitigation and adaptations?
12. How do you think they can be improved?

APPENDIX II: HOUSEHOLD QUESTIONNAIRE

Good morning/afternoon: My name is Waithaka R Kamau. I am a student at Kenyatta University studying M.sc. in Integrated Watershed Management. Currently I'm conducting a study on *Assessment of Vulnerability of Water Resources to Climate Variability in Mara River Basin, Kenya* I would like to ask you a few questions in relation to the study. The information you provide will be kept strictly anonymous and confidential and will be used solely for research on finding solutions to common problems.

SECTION 1: SOCIO-ECONOMIC ANDDEMOGRAPHIC CHARACTERISTICS			
Q. NO	**QUESTION**	**RSPONSES**	**RESPONSE**
	Name (OPTIONAL)	....	
1.1.	Location	....	
1.2.	What is your age? (Years completed)	....	
1.3.	Gender of respondent	1=Female	
		2=Male	
1.4.	Highest level of education attained by respondent?	1= None	
		2= Primary (std 1-4)	
		3= Primary (std 5-8)	
		4= Secondary	

		5= Higher Education	
		6= Don't know	
1.5.	What is your marital/relationship status? *(If response is* ***1,3,and*** *4,skip to 1.7)*	1= Single	
		2=Married	
		3= Widow/er	
		4= Separated/Divorced	
1.6.	If married what is the highest level of education attained by your **PATNER**?	1= None	
		2= Primary (std 1-4)	
		3= Primary (std 5-8)	
		4= Secondary	
		5= Higher Education	
		6= Don't know	
1.7.	Indicate the household type you belong to	1= Male headed	
		2= Female headed	
		3= Youth headed	
1.8.	What is your **MAIN** occupation?	1= farming	
		2= livestock keeping	
		3= Salaried employment	
		4= Self employed (Business)	
		5= No employment	
		6= Others (Specify)	

		....	
1.9.	How long have you lived in this community?	Years.................Months...	
1.10.	Indicate which type of housing you have	1= Mud walled grass thatched	
		2= Semi permanent with iron sheet	
		3= Stone walled (permanent)	
		0thers (specify)	

SECTION 2: RESOURCES OWNERSHIP AND UTILIZATION			
2.1	What is the size of your land?	1= < one acre	
		2= 2.5 acres	
		3= > 5 acres	
		4= Don't know	
2.2	How do you utilize the land	1= farming	
		2= livestock keeping (if livestock jump to 3.0)	
		3=commercial farming	

		4=mixed farming	
		5= others (specify)	
2.3	What food crop do you grow?	1= Maize	
		2= Beans	
		3= Millet	
		4= Cassava	
		5= Other (specify)	
2.4	Do you produce enough food to feed your family?	1= Yes	
		2= No	
2.5	If **yes**, what crops do you sometimes produce as surplus for sale? *(multiple responses allowed)*	1= Maize	
		2= Beans	
		3= Millet	
		4= Cassava	
		5= Other (specify)	
2.6	If no, how many foods deficient months do you experience in a year?	1= Less than 3 months	
		2= 4-5 Months	
		3= More than 5 months	
2.7	What are the reasons for low	1= Drought	
		2= Floods	

	crop production? (*multiple responses allowed)*	3= Lack of farm input	
		4= land not enough	
		5= Others (specify)	
2.8	What are the possible solutions to these problems? *(multiple responses allowed)*	1= conservation of flood water	
		2= Irrigation of land during drought	
		3= Provision of farm input by government	
		4= growing drought resistant crops	
		5=Don't know	
2.9	What kind of livestock do you own and in what numbers?	1= Cattle	
		2= Goats	
		3= Donkeys	
		4= Sheep	
		5=Others (Specify)	
2.10	What is the **major** problem regarding livestock rearing in this community?	1= Lack of pasture	
		2= Lack of water	
		3= Inadequate grazing land	
		4= Livestock disease	
		9= Others (Specify)	
2.11	How do you cope with these major problems (*Multiple*		

	answers allowed)		
2.12	Do you experience droughts, famine or prolonged droughts?	1= yes	
		2= no	
		3= don't know	
2.13	What do you think is the cause of droughts, famine or prolonged droughts?	1= changing climate	
		2= deforestation	
		3= water resource drying up	
		4=changing land use	
		5= others (specify)	
2.14	How common are the droughts, famine or prolonged droughts as compared to other years?	1= common	
		2= not common	
		3= no significant change	
		4= don't know	
		5= others (specify)	

SECTION 3: WATER RESOURCES			
3.1	What are your major sources of water	1= rivers and streams	
		2= boreholes	
		3= water pans/dam	

		4=water harvesting at home	
		5= others (specify)	
3.2	What are your major uses of water?	1= farming	
		2= domestic use	
		3= livestock	
		4=others Specify	
3.3	How far is the nearest water source?	1= < 1km	
		2= 1.2 km	
		3= 3-5km	
		4= > 5km	
		5= Don't know	
3.4	Are your sources of water permanent or seasonal?	1= permanent	
		2= seasonal	
		3= others (specify)	
3.5	What problems do you experience in accessing water?	1= Long distance	
		2= Dirty water	
		3= Scarcity of water	
		4= Conflict with neighbouring communities	
		5= Don't know	
3.6	How do you think the above problems	1= Construct wells	
		2= protect water sources	

	can be solved?	3= Encourage roof catchment	
		4= Promote water storage during rainy season	
		5= Promote community awareness on water resources	
		5= Don't know	
3.7	What are some of the changes that have occurred in relation to accessibility to water sources in the last 10 years?	1= Rivers have dried up	
		2= Dams have dried up	
		3= water everywhere due to floods	
		4= Others (specify)	
3.8	What do you attribute these changes to? (*multiple responses allowed)*	1= Changes in rain patterns	
		2= Prolonged drought	
		3= Failure to protect rivers	
		4= Destruction of catchment areas	
		5= Others (specify)	

SECTION 4: CLIMATIC CHANGES			
4.1	What significant	1= Unpredictable rains	

	changes in weather have you observed in the community over the past 10 years?	2= Prolonged drought	
		3= Very hot seasons	
		4= Very wet seasons	
		5= Others (specify)	
4.2	In your opinion, what have been the causes of these changes?	……………………………………………… ……………………………………………… ………………………………………………	
4.3	What have been the major effects of these changes to the community?	1= Crop failure	
		2= Flooding	
		3= Human disease outbreak	
		4= Animal disease outbreaks	
		5= Famine	
		6= Disruption in settlement	
		7= Others (specify)	
4.4	do you have access to early warning information on droughts and famine	1= yes	
		2= no	
		3= don't know	
4.5	If yes above where from?	1= government offices	
		2= NGO	
		3=Radio/ TV	
		4=others (Specify)	

4.6	Do you follow the warnings or information given	1=yes	
		2=no	
		3= don't know	
4.7	Are they effective?	1= yes	
		2= no	
		3= don't know	
4.8	Do you have or know any traditional early warning systems? *(Multiple answers accepted)*	....	
4.9	Please explain the changes the climatic change has had on each of the following:	1= Farming	
		2= livestock keeping…	
		3= Settlement patterns	
		4= water resources	
4.10	What measures have you put in place to cope with the above changes?	1= farming	
		2= livestock keeping	
		3= water resources	

4.11	What are your doing to adapt to other climatic changes effects on other sectors (socio-economic)	....
4.12	What are the traditional methods of coping, adapting to prolonged droughts and famine?	....

THAT WAS THE LAST QUESTION. THANKYOU