# EFFECTS OF DROUGHT DYNAMICS ON VEGETATION COVER AND WATER RESOURCES IN MARIGAT SUB-COUNTY, BARINGO COUNTY, KENYA

BY

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## ABSTRACT

Drought is a natural phenomenon that exists when precipitation is significantly below normal, affecting land resource production systems. In the arid and semi-arid areas, where pastoralism is the main source of livelihood, droughts adversely affect vegetation cover and water resources which are the key resources for pastoralism. The effects posed by every drought episode vary depending on drought intensity and duration. Thus, there is need to a certain drought intensity and duration to enable effective drought preparedness by both the inhabitants and other stakeholders. Studies carried out have put less emphasis on specific dynamics of drought and their associated impacts. This study examined the effects of drought dynamics on vegetation cover and water resources in Marigat Sub-County. The Specific objectives of study were to establish drought dynamics between 1980 and 2012; to examine the effects of drought intensity and duration on vegetation cover; and to examine the effects of drought intensity and duration on water resources. The study adopted cross sectional descriptive design since both quantitative and qualitative data for a period of 33 years was obtained at once The unit of analysis was the households. Proportionate random sampling was used to select 368 households from a total study population of 9,160 households Three Focus Group Discussions (FGDs) were conducted and five Key Informants were selected using purposive sampling. Both primary and secondary data was collected and analyzed. The results were presented in textual outlines, tables, charts, graphs, percentages and description. The study used Landsat images which was processed using ERDAS IMAGINE Version 2011 and resulting maps were analyzed using GIS ArcMap Version 10.1 software. Hydrological data for 6 years for River Perkerra was analyzed using Pearson's Product Moment Correlation Coefficient (r). The study established that droughts in Marigat Sub-County varied in both intensity and durations. The intensity ranged from 0.1 to 57.8 percent below the long term mean while durations ranged from 1 to 5 years. The effects of these droughts on vegetation cover and water resources were intensity and duration dependent. Low Normalized Drought Vegetation Index (NDVI) values characterized high intensity and prolonged droughts. NDVI values were higher when droughts were of lower intensity and shorter durations. The intense drought of the year 2000 recorded an NDVI value of -0.07, an indication that most parts of the study area were bare ground devoid of vegetation cover due to the drought whereas the less intense drought of the year 1994 recorded an NDVI value of 0.08. Vegetation cover during the 1994 drought was adequate with few pockets of bare grounds Similarly, the effects of droughts on water resources were intensity and duration dependent. The effects were more severe with increasing drought intensity and duration. The size of Lake Baringo varied from 39.9 km$^2$ to 51.3 km$^2$ to 62.2 km$^2$ during the 2002, 2000 and 1984 droughts. The intensities of the droughts were: 57.8% below the long term mean in 2002, 54.4% in 2000 and 52% in 1984. During the prolonged drought of 2000-2004, all water pans and seasonal rivers dried up. The study established a negative relationship between drought intensity and River Perkerra discharge, correlation coefficient (r) was -0.9. This study is useful to the inhabitants, policy makes and other stakeholders in placing appropriate coping measures in order to minimize losses and forms a basis of drought action and preparedness plans for effective drought management and mitigation plans in the Arid and Semi-Arids Land (ASALs) of Kenya.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background to the Study

Drought is a relative rather than absolute, a condition that should be defined for each region. Each drought differs in intensity and duration (Vetter, 2009). There are perspectives on drought for instance; meteorological and hydrological. Meteorological drought is usually defined by the measure of the departure of precipitation from the normal whereas hydrological drought deals with surface and subsurface water supplies (Gathara et al., 2006). Precipitation has been used as an indicator for determining drought. UNEP (1998) and Ngaira (2005) define drought as natural phenomenon that exists when precipitation is significantly below 500-650mm affecting land resource production systems. Ericksen et al. (2013) used rainfall data for a period of 30 years to depict drought years in Kajiado district, Kenya. They noted that most parts of the districts received annual rainfall of 200mm to 300mm.

Precipitation data has been used to quantify drought intensity and duration. Ramazanipour et al. (2011) analyzed drought intensity and duration using percent of normal precipitation index which is based on the precipitation deviation from the mean for a given period. Onyango (2014) analyze meteorological drought using standardized Precipitation Index (SPI) to examine the duration of drought in North Eastern, Kenya. Savatia (2009) indicated that the use of percent of normal precipitation is effective measurement of rainfall for a single region especially a location represented by one meteorological station.

Droughts occur in all climates but more predominant in the drylands. Their modes of occurrence vary in terms of duration and intensity affecting land cover at varied magnitudes (http://www.isws.illinois.edu/hilites/drought, 2011). Owrangi et al. (2011) and Rouault and Richard (2005) observed that the intensity of droughts has been increasing in most parts of the world. Similar observations have been made by Ericksen et al. (2013) in Sub-Saharan Africa and Rouault and Richard (2005) in southern Africa where increased periods of prolonged widespread droughts have been experienced. Dragovic et al. (2001) observed that for a period of five decades drought occurrence in Eastern Serbia accounted for 86 percent. Two categories of droughts have been identified by United Nations (1977), the short-term and the long-term droughts. The short-term droughts cause periodic stress to the vegetation cover and water resources while long-term droughts lead to significant changes in land use patterns. Changes in vegetation cover and water resources are mainly caused by altered land use practices triggered by climatic event such as droughts (Auschka, 2003). These studies have highlighted on droughts and their varying mode of occurrences. Since the effects of drought are determined by its dynamics that is duration and intensity. There is need for investigation on drought dynamics and their specific effects, and particularly in Africa where such studies remains relatively scanty. This study therefore, examined drought duration and intensity in Marigat Sub-County, a study which was the first of its kind.

Globally, Eldridge et al. (2011) observed that vegetation composition in the arid and semi-arid grasslands and savannahs of the world has been changing. Droughts are among the major contributors of these changes such as with tropical forests as observed by Parolin (2010).

According to Owen (2008) a 15-month drought between 2002 and 2003 across Arizona and New Mexico led to loss of Ponderosa pine and Pinon-juniper ecosystem with over 90 percent of Pinon trees being lost. Godfree et al. (2011) observed that the 2006-2007 extreme drought in Southeastern Australia led to destruction of temperate grasslands resulting in decline of grassland species. These studies have demonstrated that droughts have negatively affected tree and grassland species. Although the effects of droughts are not uniform across a given area depending on drought characteristics, these studies have investigated areas of large spatial extent. Such vast areas experience drought of varying characteristics and subsequently varied effects on vegetation cover. This study investigated the variations in drought duration and intensity in an area of a smaller spatial extent, covering 1,346 square kilometers, and the associated effects of each drought event.

Water resources are equally affected by the dynamics of droughts. In Southwest China, Yang et al. (2011) observed that the 2009-2010 drought led to serious shortages in domestic water causing loss of about 11.7 million heads of livestock. In western and southeastern United States the 2007 drought led to decrease in water levels in various reservoirs particularly rivers and lakes (Kimmell & Veil, 2009; Lettenmaier et al. 2008). Droughts alter both the accessibility and demand for water as observed by Waggoner (1990) where the severe drought of 1976-1977 in California led to increased demand for water from the Colorado River System. The above studies revealed that droughts affect water resources. However, little efforts have been put to investigate how specific effects of drought of varying dynamics affect water resources differently. This study focused on analyzing drought intensity and duration in Marigat Sub-County and how variations in the intensity and duration affect surface water resources such as water pans, dams, streams, springs, ponds, lakes and rivers. Thus, this study highlights the specific effects on surface water resources based on variations in intensity and duration of droughts, an aspect that has not been investigated in Marigat Sub-County.

Africa is the most affected continent by droughts, having experienced 382 events between 1960 and 2006 (Gautam, 2006). The aftermath of the droughts has been degraded physical environment and unprecedented human suffering. Vetter (2009) observed that droughts are responsible for loss of perennial shrubs and grasses causing increased bare ground cover and soil erosion in the rangelands of South Africa. In Northern Afar rangelands Ethiopia, Tsegaye et al. (2010) observed that massive loss of woodlands occurred due to the drought of 1973-1974 and 1984-1985. In Ghana, the drought of 2001 led to severe reduction of vegetation cover (Opoku-Duah et al., 2013).

Decline in Lake Chad area from 10,000 square kilometers in 1998 to 1,500 square kilometers in 2010 has been attributed to frequent droughts since 1970s (Urama and Ozor, 2010). The studies revealed that droughts have resulted in shrinking of lake sizes especially Lake Chilwa and Lake Chad. Regionally, studies have demonstrated that droughts affect vegetation and water resources. However, most of these studies have focused on droughts in general without investigating the effects of varying characteristics of droughts. Whereas the effects of droughts are specific to drought characteristics, researches carried out in Marigat Sub-County, like in most other parts of Kenya, have examined droughts from a general perspective without being specific. This study specifically examined drought dynamics in relation to duration and intensity and their effects on vegetation cover and water resources. Such an approach has never been used to investigate droughts and their effects in Marigat Sub-County in Baringo County.

Kenya, which has about 88 percent of her landmass falling under arid and semi-arid climates, is prone to drought of varying characteristics resulting in negative impact on the environment and natural resources such as vegetation cover and water resources (Kandji, 2006). In these ASALs, where pastoralism is the main source of livelihood, vegetation and water are the most important resources. Unfortunately, droughts which are inherent in these areas, have been identified as the major contributors to loss of rangeland resources, particularly pasture and water (Urama and Ozor, 2010; Huho and Ngaira, 2011). Even though the studies on vegetation and water resources in relation to droughts have been carried out in the ASALs of Kenya, most studies have been carried out at large spatial extents in different localities. However, this study focused on establishing drought intensity and durations between 1980 and 2012 and assessed how these drought dynamics affected vegetation cover and water resources within small spatial extent which is Marigat Sub-County.

Marigat Sub-County experience frequent droughts and since different droughts episode have different effects within locality, understanding droughts of varying intensity and durations and their associated effects on vegetation cover and water resources is crucial towards enhancing sustainable pastoral livelihoods in the sub-county. There is need for monitoring and predicting with high precision the effects of droughts to enable the inhabitants to identify measures and opportunities that may cushion them against droughts. Unfortunately, this practice has not been undertaken in the sub-county since most studies have only been based on ground observation inhibiting monitoring and long term assessment of drought episodes. This study integrated ground observation and use of remote sensing and Geo-Information Systems (GIS) technology to assess the effects of drought dynamics, an in particular intensity and duration, on vegetation cover and water resources in Marigat Sub-County of Baringo County, Kenya and provide database for future monitoring.

## 1.2 Statement of the Problem

Marigat Sub-County falls under ASALs of Kenya and thus experiences prolonged droughts which adversely affected vegetation cover and water resources. The effects vary from one drought event to the other depending on drought characteristics. The scenario affects vegetation abundance and even diversity, and water resources both surface and underground in terms of quantity and quality. Few studies in ASALs such as Ngaira (1999) and Kandji (2006) have focused on rainfall variability on physical environment and noted that droughts resulted in water scarcity and loss of rangeland resources. These studies focused on drought from a general perspective but not specific characteristics of drought and their effects on key natural resources in ASALs. Studies carried out in Marigat Sub-County have concentrated on the effects of droughts on crop production and food security (Johansson and Svensson, 2002; Saina et al., 2012). Monitoring and ability to predict with precision droughts of varying durations and intensities is critical since it enhances planning and preparedness against drought risks and disasters. It is against this background that this study assessed the effects of drought dynamics, that is, intensity and duration on vegetation cover and water resources between 1980 and 2012 in Marigat Sub-County of Baringo County, Kenya.

## 1.3 Objectives of the Study

The main objective of the study was to assess the effects of drought dynamics on vegetation cover and water resources in Marigat Sub-County of Baringo County.

Specific objectives were to:

1. Establish drought intensity and duration between 1980 and 2012 in Marigat Sub-County.
2. Examine the effects of drought intensity and duration on vegetation cover between 1980 and 2012 in Marigat Sub-County.
3. Examine the effects of drought intensity and duration on water resources between 1980 and 2012 in Marigat Sub-County.

## 1.4 Research Questions

1. What had been drought intensity and duration between 1980 and 2012 in Marigat Sub-County?
2. What were the effects of drought intensity and duration on vegetation cover between 1980 and 2012 in Marigat Sub-County?
3. What were the effects of drought intensity and duration on water resources between 1980 and 2012 in Marigat Sub-County?

## 1.5 Justification of the Study

Marigat Sub-County falls under ASALs areas of Kenya and it is categorized with aridity index of 50 percent which implies that it is has potential to support pastoralism and agro-pastoralism. However frequent droughts affect vegetation cover and water resources. Since droughts occurrence within one locality are not uniform and therefore poses different effects on vegetation cover and water resources, it is important to monitor different drought episodes to understand their associated effects. This study analyzed rainfall data for a period of 33 years (1980-2012) to meet World Meteorological Organization (WMO) requirements that climatic data should be analyzed for a period between 30 and 35 years to give viable results.. The study used GIS and remote sensing (RS) to enable long term assessment and mapping of areas with varying vegetation cover and water resources within Marigat Sub-County. The study examined the effects of droughts with different intensities and durations on vegetation cover and water resources. Drought duration and intensity are drought characteristics which have severe impacts on vegetation cover and water resources. Similar studies can be carried out in other ASALs of Kenya since they are also affected by droughts which threaten the livelihoods. This study therefore, aimed at providing useful information to decision makers, policy makers and other stakeholders in formulating policies on drought management plans on monitoring, prediction and mitigation in order to cushion the inhabitants of Marigat Sub-County and other ASALs in Kenya.

### 1.6 Scope and Limitations of the Study

The study was undertaken in Marigat Sub-County and two key resources; vegetation cover and water resources were investigated. Among the resources which the study examined included; surface water and vegetation cover. The study used precipitation as climatic indicator to depict droughts years in the study area. The years which had total annual rainfall below the calculated long term mean rainfall of 563.7mm for the period under study (1980-2012) were considered drought years. The study examined two characteristics of drought which included; drought duration and intensity.

The study area (Marigat Sub-County) was recently created under the new demarcation of boundaries in the country and getting the data for many years became a problem. There was insufficient data in some offices thus it was to be collected from the former offices, this was inconveniencing in terms of time and cost.

Data which was not available in the sub-county offices was obtained from the former Baringo District headquarter offices. Data from all the former divisions including Marigat was kept there. Data obtained from these offices included: hydrological data for water discharge for River Perkerra and water level for Lake Baringo.

### 1.7 Assumptions

1. The households identified drought with respect to years and not seasons. Thus the study assumed that analysis of annual drought will clearly show how droughts of varying characteristics affects vegetation cover and water resources. Annual precipitation was therefore used in depicting droughts.
2. That vegetation cover in the study was affected by droughts
3. The study assumed that *Prosopis juliflora,* which is not affected by drought, was not responsible for the loss of vegetation cover in the study area.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

This chapter reviews the literature on drought dynamics and its effects on vegetation cover and water resources in various parts of the world.

## 2.2 Drought Dynamics (Intensity and Duration)

Drought dynamics refers to the changes in various characteristics of droughts. Owrangi et al. (2011) observed that both the frequency and intensity of droughts are increasing in a number of regions in the world. However, the intensity vary from one drought event to the other with some occurring rapidly but short lived while others develop slowly but persist for a long time (Smith, 2011). In Russia the 2010 drought was long and intensive not only covering vast areas but also led to serious damages to the environment (Kogan et al., 2012). In relation to duration, Australia experienced a drought which lasted for 10 years between 1958 and 1968 (Lake, 2011) and a 12-year drought in the southern and eastern parts of Australia between 1996 and 2008 (Kogan et al., 2012).

Africa, like other continents, has been experiencing droughts of varied characteristics. Between 1970 and 2006 droughts accounted for 20% of the natural disasters affecting over 80% of the entire African population (Huho and Mugalavai, 2010). The intensity, frequency, duration and severity of droughts vary from one locality to another during any particular drought event or during separate drought episodes. For instance, whereas the 1982-1983 drought in Mozambique and Botswana was the severe in 50 years (http://www.blueplanet.nsw.edu.au/Comparison-of-Australian-Impacts-with-Southern and Eastern Africa, 2013), the 1991-1992 drought was the most severe and extensive in South Africa (Sheffield et al., 2009). In 1973 and 1984 Africa experienced severe droughts where most of countries suffered reduced rainfall affecting millions of people in the Horn of Africa, the Sahel and Southern Africa (AWDR, 2006).

Kenya is a drought-prone country with the effects felt by livestock based economies and livelihoods in the ASALs (ILRI, 2010). UNDP (2008) observed that the frequency and intensity of droughts is increasing in Kenya with ASAL areas experiencing droughts almost on an annual basis. Among the severe droughts that have been noted in Kenya include: 1983/84, 1991/92, 1995/96, 1999/2001, 2004/05, 2008/09 and 2010/2011 (Urama and Ozor, 2010; Serna, 2011). The 1999-2001 drought was amongst the longest and severest droughts on record in Kenya. According to Murungaru (2003) the severity and frequency of droughts in the country seems to be increasing over time. In the ASALs of northern Kenya, the frequency has increased from once in every 10 years in the 1970s; once in every 5 years in the 1980s; once in every 2 to 3 years in the 1990's and now annually since the year 2000 (Howden, 2009). For instance, Turkana and Laikipia Districts have experienced recurrent and prolonged drought between 1991 and 2011 (Huho and Ngaira, 2011). Terrence (2010) observed that the 2008-2009 drought was the most severe in Kajiado and Laikipia Districts. These studies have provided vital evidence that droughts occurrences are increasing in terms of frequency and severity in ASALs areas of the world and their associated effects negatively affect agriculture production and food security. However, most of these researches focused on drought in general perspective but not on specific characteristics of the drought. This current study investigated two major characteristics of drought; intensity and duration and examined their effects on vegetation and water resources in order to unearth precise effects of a given drought on pastoral livelihoods.

## 2.3 Effects of Drought Intensity and Duration on Vegetation Cover

Droughts trigger major changes in vegetation cover and their adverse impacts depend on their intensity and duration (Vetter, 2009; Smith, 2011; USDA, 2012). Ribot et al. (2005) observed that prolonged drought delay re-establishment of vegetation cover and also lead to over exploitation of rangeland and forest vegetation resources as pastoralists seek alternative sources of livelihood (Mongabay, 2010). Sheffield et al. (2009) analyzed the effects of drought on US forests by use of remote sensing and observed that forests response to drought especially those located in the driest regions are more sensitive to drought occurrence. According to Serrano (2012) forests are sensitive to prolonged and intense droughts but may be non-sensitive to short droughts. In southwestern Amazonia, the 2005 severe drought led to tree mortality in approximately 70,000 hectares (Saatchi et al., 2012). Whereas the 1997-1998 droughts reduced Net Primary Productivity of the Amazon forests by 20-30 percent. In Southern Nevada the drought of 1997 led to loss of herbaceous perennials and the shrubs (Lei, 1999; Nepstad et al., 2004). Similarly, the 2002-2003 droughts in southeastern Australia resulted in high reduction of primary productivity in woody native vegetation cover (McAlpine et al., 2007). Childs (2013) observed that short-term droughts cause wilting, leaf scorch, and some defoliation whereas long-term droughts of greater intensity and duration cause stunted growth, branch die-back and death in trees and shrubs.

The semi-arid regions of Africa are characterized by limited or discontinuous natural vegetation cover such as shrubs, scrubs and grasses. Although vegetation growing in these regions is well adapted to extreme conditions, the ecosystems are vulnerable to environmental degradation due to recurrent drought events. For instance, Leeuw and Reid (1995) observed that frequent droughts have led to severe degradation of vegetation cover in many parts of Sub-Saharan Africa. In Zimbabwe, the 2000-2003 severe drought led to reduction of plant biomass in dryland ecosystem resulting in high mortality rate of grazing animals due to poor pastures. Analysis of vegetation cover in the semi-arid of Tunisia using GIS and remote sensing by Amri et al. (2011) established that the drought of 2000-2001 affected three forms of land cover i.e. pasture, annual agriculture and olive trees.

In Kenya, drought is the main recurring natural disaster which has led to degradation of rangelands in the ASALs regions (ILRI, 2010). The 1979-80 and 1991-2011 severe droughts in Turkana District led to massive loss of rangeland resources affecting the livelihood of pastoralists (Terrence, 2010; Huho and Ngaira, 2011). For instance, the 2009 drought led to over-exploitation of pasture by livestock. In Laikipia District, the 2003-2006 droughts resulted in the destruction of riverine vegetation through overgrazing and felling trees for charcoal burning by inhabitants as alternative source of livelihood (Http:// www.acted.org/en/kenya, 2013). The massive felling of Acacias trees for charcoal burning by the community in 2009 was occasioned by the 2008-2009 extreme drought (Terrence, 2010). The referred to studies above revealed that droughts affect vegetation cover. However, literature on the effects of varying drought characteristic on vegetation cover remains scanty as little has been documented prior to this study.

**2.4 Effects of Drought Intensity and Duration on Water Resources**

The availability of water in the dryland is a function of rainfall performance. Droughts result in declining amounts of both surface and groundwater due to inadequate amounts of rainfall to

Laikipia District. Two springs; Ngaboli and Ildupata springs dried up and never rejuvenated again. Similarly, all water points such as boreholes, water pans and dams in Wajir and Mandera dried up following a prolonged drought of 2010-2011 (Serna, 2011). The studies have demonstrated that frequent and prolonged droughts affect water resources. However, little research relates the duration and intensity of different drought episodes and their associated effects on surface water. Since droughts have both short term and long term effects on surface water resources, there is need to examine the effects of different droughts episodes with varying duration and intensity on surface water sources which formed the basis of this study.

## 2.5 Gap Identified from the Literature Review

Studies on the effects of droughts on vegetation cover and water resources are not new phenomena (Travis, 2006; Urama and Ozor, 2010 and Owrangi et al., 2011). Most of the research focuses on drought in general but not on specific characteristics of the droughts. Although few studies, have investigated specific aspects of droughts and their effects on livelihoods. Huho (2011) investigated the effects of drought severity on subsistence agriculture but little has been done on the effects of drought dynamics on vegetation cover and water resources. This study investigated two major characteristics of droughts - intensity and duration - and their effect on vegetation and water resources. These are the key resources for livestock farmers in Marigat Sub-County and yet no research data exists.

## 2.6 Theoretical framework

This study was based on the theory of desertification which states that "desertification is a condition of land degradation that occurs in arid, semi-arid and dry sub-humid regions and leads to persistent decline in economic productivity of useful biota related to land use or a production system" (Jagdish et al., 2000). Zeng et al. (1999) linked climate variability to desertification and observed that pasture in the Sahel region had changed resulting to overgrazing. Vlek (2003) observed that surface water resources such as dams, water pans, streams and rivers in Sub-Saharan Africa dried up as a result of desertification. Kassas (1995) asserted that mortality of tree cover species, shrubs and grasses in Northern Sudan was as a result of desertification. The studies above show the relationship between climate variability and desertification. The studies revealed that depletion of vegetation cover and surface water resources in the ASALs area are contributed by climate variability.

## 2.7 Conceptual Framework

The main land resources in the ASALs are vegetation and water. Unfortunately, these resources are affected by drought of varying intensity and duration. For instance, drought leads to mortality in perennial grasses and shrubs, reduce percentage cover of grasses, shrubs and trees, destruction of riverine tree cover and shrubs, pasture degradation due to overgrazing. In addition, it leads to drying up of water pans, dams, springs, ponds, swamps and streams, reduce volume of water flowing from perennial rivers, decline in water volume in lakes and dams, drying up of seasonal rivers resulting in the degradation of vegetation cover and water resources.

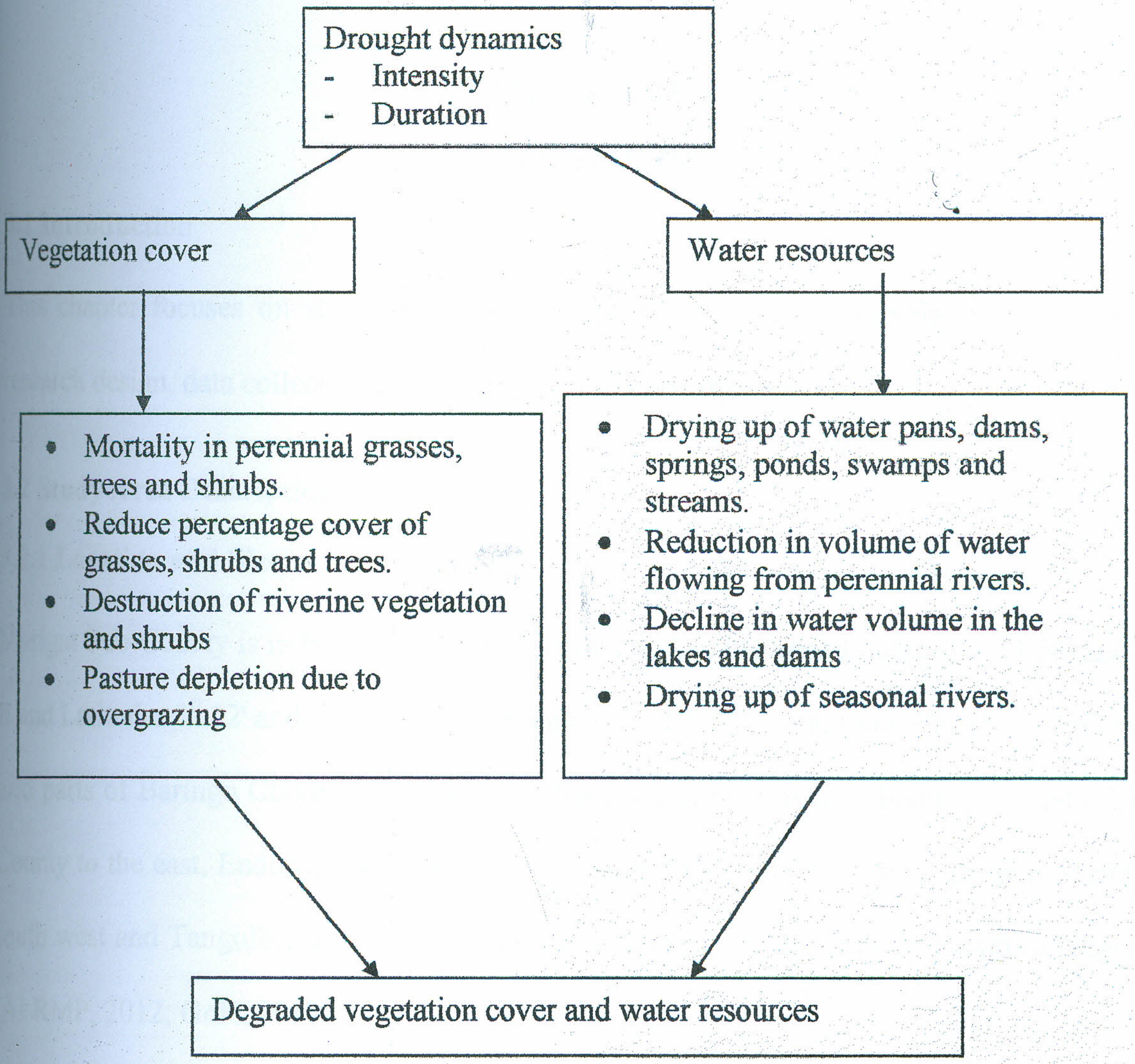



**Figure 2.1: Conceptual Framework**
**(Source: Researcher, 2013)**

# CHAPTER THREE

# METHODOLOGY

## 3.1 Introduction

This chapter focuses on study area, population characteristics and explains the methods: i.e. research design, data collection techniques, analysis and presentation.

## 3.2 Study Area Description

### 3.2.1 Location and Size

Marigat Sub-County is in Baringo County Kenya; and lies between Longitudes $35^0 36'$ and $36^0 30'$ E and Latitudes $0^0$ 12' and $1^0$ 36' N. It covers an area of 1,346 square kilometers. It is in the semi-arid parts of Baringo County. Pastoralism is the main source of livelihood. It borders Laikipia County to the east, Endoros and Tenges to the south, Mochongoi to the south east, Sacho to the south west and Tangulbei to the north. The sub-county is divided into 11 locations (Figure 3.1) (ALRMP, 2012; GoK, 2012).

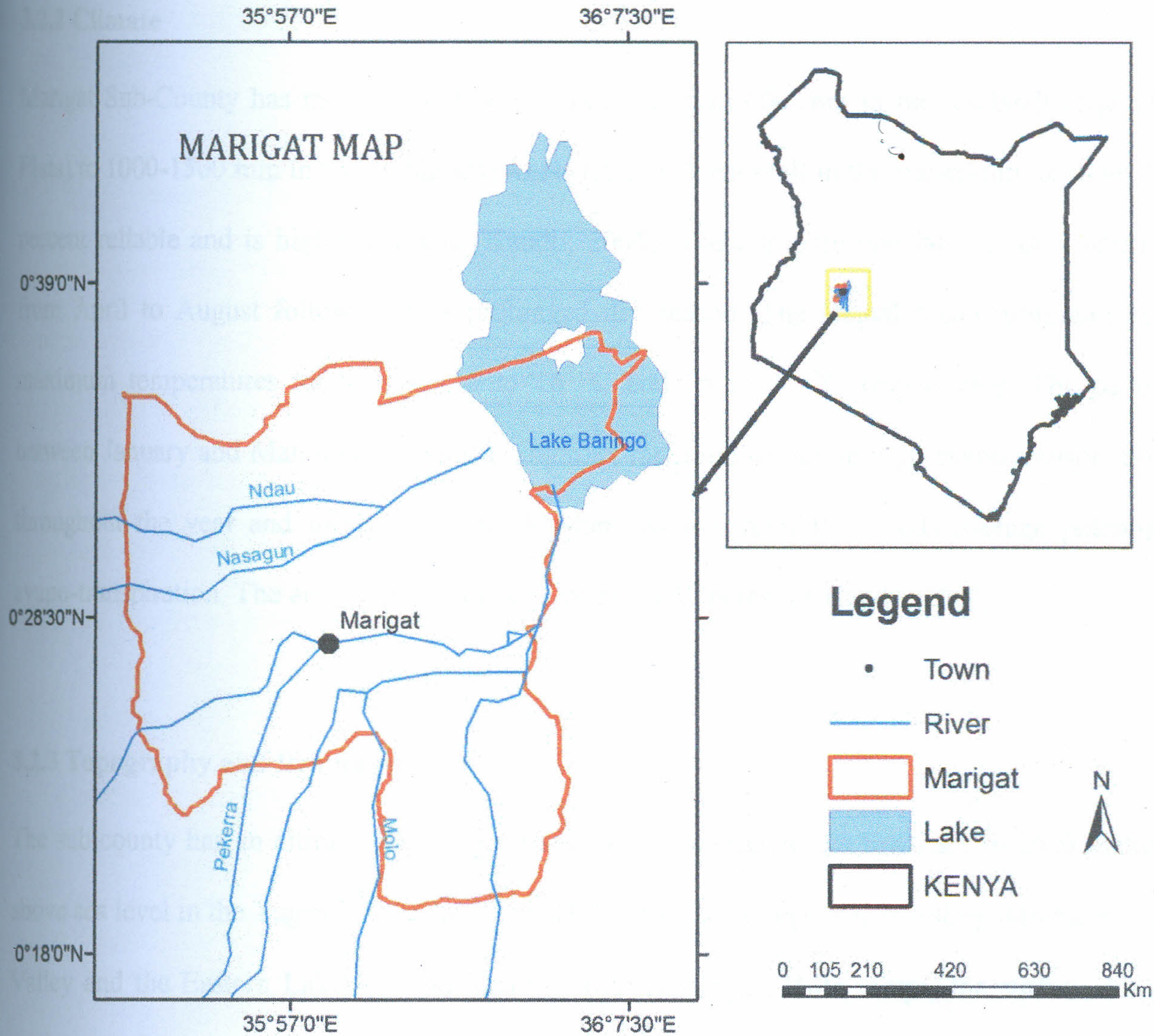



**Figure 3.1: Map of Marigat Sub-County**

### 3.2.2 Climate

Marigat Sub-County has mean annual rainfall ranging from 600 mm in the lowlands (Njemps Flats) to 1000-1500 mm in the highlands (ALRMP, 2012). Rainfall in the sub-county is about 50 percent reliable and is highly variable (Kandji, 2006). There is only one rainy season starting from April to August followed by a prolonged dry season. The annual mean minimum and maximum temperatures range from 16 to 18 °C and 25 to 30 °C respectively. The period between January and March is the hottest. High net radiation results in high evapo-transpiration throughout the year and there is no month when average rainfall exceeds average potential evapo-transpiration. The aridity index for sub–county is 50 percent ( Kandji, 2006).

### 3.2.3 Topography and Drainage

The sub-county has an altitude that ranges between 752 metres in the lowlands to 2600 metres above sea level in the Tugen Hills. The Tugen Hills splits the Gregory Rift Valley into the Kerio Valley and the Eastern Lake Baringo Valley. From the Tugen Hills scarps, the surface drops steeply through a foothill zone of complex topography to the Tugen Plateau at 1100 to 1300 metres above sea level (ALRMP 2012). This forms the western boundary of the Lake Baringo trough. Lake Baringo is bounded by the Njemps Flats which are in turn bounded by a series of fault scarps which rise to the Laikipia plateau at close to 2000 metres above sea level (GoK, 2012).

The sub-county is characterized by different topographical features namely; river, valleys and plains, the Tugen hills, lakes, plains, and volcanic rocks. The floor of Rift Valley as a result of tectonic and volcanic disturbances is aligned towards Lake Baringo and Lake Bogoria. Tugen Hills forms an important source of seasonal rivers in the sub-county (Wasonga et al., 2011).

### 3.2.4 Water Resources in the Study Area

The major permanent rivers in the sub-county are Rivers Perkerra and Molo together with their tributaries (GoK, 2012). River Perkerra is formed by the union of several radial streams from Lembus forest highlands and has several seasonal tributaries on the western flanks of the Tugen Hills. River Molo drains from the Mau Hills near Molo and Elburgon through its own head-waters and and some seasonal. There are also several seasonal rivers in the study area which include the following; Endao, Loboi, Weseges, ol Arabal and Chemeron (ALRMP, 2012).

### 3.2.5 Vegetation

The vegetation and its primary production are considerably poorer than would be expected from an area receiving an average rainfall of 600 mm (ALRMP, 2012). The sub-county is too dry to support forests. Few scattered acacia species, tufts of bushes and short thorny bush with grass scattered all over the area. Both the productivity and palatability of forage have fallen over the years. There is emergence of non-palatable grass species. Some of non-palatable woody species in the grazing land are *Acacia nilotica, Acacia brevis pica, Euphorbia tirucali.* Non-palatable grass species are *Bothriochloa insculpti and Melinis minutejlora* (Mwangi and Swallow, 2005). The lowland part of the sub-county (Njemps flats) is vegetated with grasses and the tall Acacia woodland species including; Thermeda, Tortillis and Senegal. In the highlands, trees are short less than 10 metres high (Kandji, 2006). Dense vegetation is found along both permanent and seasonal rivers (Wasonga et al., 2011).

### 3.2.6 Land Use Activities

There are three main land use activities in Marigat Sub-County. These include; pastoral, agro-pastoral and farming (crop cultivation). About 52 percent of the land in the sub-county is still under communal. Large Crop farming is practiced through irrigation in Perkerra Scheme and in smallholdings of 1-3 acres by residents living along the rivers. The inhabitants rely heavily on vegetation and water for their livestock. The inadequacies of these resources force them to move beyond borders with their animals searching for these key natural resources (Kandji, 2006).

### 3.2.7 Population Characteristics

According to the Kenya Population Census 2009, Marigat Sub-County had a population of 41,780 persons comprising of 20,826 males and 20,954 females with 9,160 households. The population density of the sub-county is 53 persons per square kilometers (Table 3.1). The population increased by 36 percent from the 1999 census which had a total population of 26,923 with population density of 44 persons per square kilometers (KNBS, 2009)

**Table 3.1: Population Totals, Households and Population Density for Marigat Sub-County**

| Location | Male | Female | Total | Households | Density (Person/Sq.Km) |
|---|---|---|---|---|---|
| Ilchamus | 1613 | 1734 | 3347 | 669 | 81 |
| Kapkuikui | 547 | 533 | 1080 | 215 | 14 |
| Kimondis | 689 | 668 | 1357 | 332 | 40 |
| Elwalel Soi | 699 | 667 | 1366 | 322 | 19 |
| Kimalel | 2141 | 2121 | 4262 | 1046 | 28 |
| Ling'aarua | 1282 | 1281 | 2563 | 473 | 321 |
| Marigat | 6470 | 6520 | 12990 | 3289 | 86 |
| Loboi | 1087 | 1058 | 2145 | 446 | 29 |
| Sandai | 1262 | 1318 | 2580 | 456 | 53 |
| Salabani | 2342 | 2422 | 4764 | 963 | 60 |
| Ngambo | 2694 | 2632 | 5326 | 949 | 104 |
| **Total** | **20826** | **20954** | **41780** | **9160** | **Average-53** |

(Source: KNBS, 2009)

### 3.3 Research Design

This study adopted cross sectional descriptive design since all data was collected at once. Although the data collected was between 1980 and 2012, this data was obtained at the same time without visiting the field several times at intervals. The design was used to obtain information through the use of interviews and questionnaires and also enabled examining of relationships among variables. The design was appropriate for this study since the study sought to establish historical occurrences of drought of varying intensity and duration and the effects associated with each drought episode on vegetation cover and water resources in Marigat Sub-County. The study also involved use of in-depth interviews to the key informants and household questionnaires to a sample size of 368 households in the study area to obtain data on drought occurrence and their effects on vegetation cover and water resources. The unit of analysis for this study was the households.

### 3.4 Sampling Procedures

The sample size for this study was computed using Fishers et al., (1983) sample size formula as shown below. This was the most appropriate sample size formula for the study since the target population size was 9,160 households.

$$nf = \frac{n}{1 + n/N}$$

Where nf= the desired sample size (when the target population is less than 10,000)

n=384

N= the estimate of the target population size (9,160)

$$nf = \frac{384}{1 + 384/9160} = 368 \text{ households}$$

The sampling procedures used in the study were purposive and proportionate random sampling. Purposive sampling is the selection of a group of subjects (a sample) from a larger group (a population) for study based on the judgment of the researcher as to which subjects best fit the criteria of the study. This was therefore used in selecting five key informants and three groups of Focus Group Discussants (FGD) each comprising of members between five and eight. The five key informants included: one sub-county agricultural officer (livestock department), one hydrologist, one local NGO leader, one group ranch leader and one self-help group leader. The three groups of FGD were: i) pure pastoralists ii) Agro-pastoralists and iii) A self-help group dealing with dry land crop and livestock farming.

Proportionate random sampling was used in selecting 368 households that were interviewed in the whole sub-county. In every household selected, the head of the household and in absence of the head of household, a person in the family who had been brought up in the study area for more than thirty years was interviewed. Marigat Sub-County is divided into 11 locations; proportionate random sampling was done based on the number of households in each location (Table 3.2).

**Table 3.2: Proportionate Households Sample in the Sub-County**

| Location | Study Households | Sample Households |
|---|---|---|
| Ilchamus | 669 | 27 |
| Kapkuikui | 215 | 9 |
| Kimondis | 332 | 13 |
| Elwalel Soi | 322 | 13 |
| Kimalel | 1046 | 42 |
| Ling'aarua | 473 | 19 |
| Marigat | 3289 | 132 |
| Loboi | 446 | 18 |
| Sandai | 456 | 18 |
| Salabani | 963 | 39 |
| Ng'ambo | 949 | 38 |
| **Total** | **9160** | **368** |

List of households in the locations containing names of heads of households were obtained from the area chiefs. The names in each list were allocated numbers. The questionnaires were then administered randomly to the households in the sub-county.

Interviews schedules were used to collect data on drought occurrence and its effects on vegetation cover and water resources. The information obtained was used to supplement information obtained through rainfall data, satellite images, focus group discussions and key informants on drought and its effects.

## 3.5 Data Collection Methods

Data was collected from both primary and secondary sources.

### 3.5.1 Primary Data

The primary data was collected through; household questionnaire interviews, key informant interviews, Focus Group Discussions and observation checklist

**Household Questionnaire Interviews**

The questionnaire was designed to collect data on the occurrence of drought and its effects on vegetation cover and water resources between 1980 and 2012 in the study area. It was administered to 368 heads of households who had inhabited the study area for more than thirty years.

Questions were put into three thematic areas namely (i) drought occurrence, intensity and durations - this was to get the respondents understanding on droughts and the frequency of occurrence over the decades under the study, it was also to know how they considered the duration of long term and short term droughts, (ii) drought effects on vegetation – the questionnaire sought information about the existence of vegetation which the livestock depend on in the area as well as the status of vegetation during any drought episode in the study area and (iii) drought effects on water resources -. This was to get the main sources of water and how drought of varying durations and intensities affect these resources in the study area. The researcher administered the questionnaire to the respondents and for those who did not know how to read, the researcher read the question to the interviewee and wrote down the responses.

**Key Informant Interviews**

This technique involved in-depth qualitative interviews with people with specific knowledge about the subject in question. Key informants included one livestock officer, one hydrologist, one local NGO leader, one self-help group leader and one group ranch leader. In each category, the key informant was purposively sampled. The study selected the head of the group. From livestock officer, interviews were used in obtaining drought dynamics and their effects on vegetation cover and surface water. From hydrologist, data on surface water was obtained. Local NGO, self-help group and group ranch leaders' interview, data was collected on drought dynamics over the years and the associated effects on vegetation cover and water resources.

**Focus Group Discussions (FGDs)**

Focus Group Discussion is a data collection method that gathers together people with similar backgrounds or experiences in order to discuss a specific topic of interest. Discussants were purposively sampled. The study selected three groups of Focus Group Discussants, each group comprising between five and eight members of the community with similar experiences. Three groups (categories) of discussants selected included: (i) pure pastoralists - the discussion with this category revolved around the breed and the number of livestock they kept, where they graze, if they had experienced livestock deaths as a result of drought and the effects of different droughts on vegetation in the study area. (ii) Agro-pastoralists – this group involved inhabitants who engaged in both livestock keeping and crop cultivation in the study area. Discussions with this category was to get information on number of livestock they kept, the acres of land they cultivated, where they abstracted water for farming and how droughts of varying durations and intensities affect their livelihoods.(iii) Members of self-help group dealing with dry land crop and livestock farming. The study considered gender and age in each FGD. The study involved discussants who were 30 years and above since the period under study was 33 years. The study examined droughts over the period of 3 decades: 1980s, 1990s and 2000s thus a discussant with 30 years and above was able to give information on decades under the study. The researcher guided the discussions while the research assistants noted down the responses. Discussion revolved around drought occurrence, intensity and durations and the effects of drought dynamics on vegetation cover and water resources and eventually livelihood sources.

**Observation Checklist**

This technique was used in the field and went hand in hand with photography. Observation checklist was prepared to guide the researcher while in the field. The researcher observed various types of vegetation and spatial variations in vegetation density. Different sources of water were observed and recorded. In addition, the researcher observed indicators of environmental impacts of drought dynamics. This information was used to supplement data collected through household questionnaires, FGDs and key informant interviews.

### 3.5.2 Secondary Data

This involved collection of published data which included rainfall data, remotely-sensed data, hydrological data, documented data and maps.

**Rainfall Data**

Rainfall data used in analyzing drought years was obtained from Kenya Agricultural and Livestock Research Organization (KALRO) - Perkerra Meteorological Station. The meteorological station was selected because it is located in Marigat Sub-county. Other rainfall stations in Baringo County were located in different agro ecological zones from the ones in Marigat Sub-county. Thus rainfall data obtained from KALRO-Perkerra Meteorological Station was considered representative for the whole sub-county. KALRO-Perkerra Meteorological Station had a continuous monthly rainfall data for a period of 33 years (1980-2012). Monthly rainfall data was used in calculating total annual rainfall and long term mean rainfall from which drought years were established alongside drought intensity and duration. The computed long term mean rainfall for the period under the study was 563.7mm. Years which received total annual rainfall below the long term mean of 563.7mm were considered drought years.

**Remotely- Sensed Data**

Cloud free satellites Landsat images for the selected drought years between 1980 and 2012 was downloaded from United States Geological Survey (USGS) (http://glovis.usgs.gov/, 2014). The study used Landsat 5 Thematic Mapper (TM) images (path/row: 168/29) with spatial resolution of 30 metres and Landsat 7 Enhanced Thematic Mapper plus (ETM+) (path/row: 168/29) with spatial resolution of 30 metres. Landsat 5 TM was used to provide satellite images between 1982 and 1999, whereas Landsat 7 ETM+ which is currently in use provided the satellite images between 2000 and 2012. Based on the rainy season in sub-county, the study analyzed satellite images which were acquired during the months of September and October; the satellite images during these months could give clear state of vegetation cover and water resources because the sub-county has only one rainy season which starts from April to August (Table 3.3).

**Table 3.3: Landsat Image Specifications**

| Date Acquired | Satellite | Sensor |
|---|---|---|
| 28/09/1984 | Landsat 5 | TM |
| 03/10/1994 | Landsat 5 | TM |
| 01/10/2000 | Landsat 7 | ETM+ |
| 22/09/2002 | Landsat 7 | ETM+ |

(Source: http://glovis.usgs.gov/, Downloaded on: 21/11/2014)

The selected satellite images were downloaded as separate TIF files and were combined using the layer stacking function of ERDAS Imagine Version 2011 software. The initial image classification was made using unsupervised method to give classes which was then combined to 5 classes by using ground truth verifications (Table 3.4)

**Table 3.4: NDVI Classification**

| NDVI Values | Land cover type |
|---|---|
| 0.0 to Negative Values Approaching -1 | Free Standing Water |
| 0.0 to 0.1 | Bare Soils and Rocks |
| 0.1 to 0.2 | Sparse Vegetation |
| 0.2 to 0.3 | Shrub and Grassland |
| 0.3 to 0.8 | Dense Vegetation |

(Source: http://simwright.com/downloads/SimWright_NDVI.pdf, 2014)

The Normalized Difference Vegetation Index (NDVI) calculation was then performed to produce NDVI values and images using ERDAS Imagine software Version 2011. NDVI calculation is made by using ETM's band 3 and 4, the ratio of two wavelengths, near-Infrared (NIR) and visible bands (VIS) of Advanced Very High Resolution Radiometer (AVHRR), by examining their difference in wavelength absorption and reflection, the health of the vegetation is determined.

The study used four Landsat satellite images acquired in 1984, 1994, 2000 and 2002. Based on drought intensities, these years had drought intensity of 50 percent rainfall below the long term mean rainfall except the year 1994 which had drought intensity of 0.1 percent below the long term mean rainfall. For NDVI analysis, the 1994 was considered as the base year. In analyzing effects of drought dynamics on water resources, 1984 was used as a base year. These images were digitally classified using ERDAS Imagine 2011 and the resulting maps extracted using GIS ArcMap Version 10.1 software. The images were used to identify the changes in vegetation cover and delineate a section of Lake Baringo falling under Marigat Sub-County. they were also used to show how different drought episodes affected the vegetation cover, size of the lake as well as the vegetated riparian areas

**Hydrological Data**

Hydrological data was obtained from Water Resource Management Authority (WRMA) Regional office, Nakuru and Perkerra Irrigation Scheme office, Marigat. The daily River Perkerra discharge data for gauging station (2EE7B Marigat Bridge Station) was analyzed to show the average water discharge of River Perkerra during drought episodes of varying durations and intensities. A continuous data for 6 years between 2006 and 2012 was available. The daily data was used to compute annual mean for the river discharge.

**Documented Data**

This data was obtained from reviewing drought-related literature from texts, newsletters, papers from professionals, journals and internet. The following resource centers were used in obtaining documented data; Maseno University library, Regional Centre for Mapping Resources Development and Drought Monitoring Centres. The information obtained gave background information on drought intensity and durations and its effects on vegetation and water resources in the ASALs areas.

**Maps**

The study area map was extracted from the map of Kenya with a scale of 1:250,000. ArcMap software was used to extract the Marigat Sub-County map.

### 3.6 Data Analysis and Results Presentation

Quantitative data which included rainfall data obtained from KALRO Perkerra Meteorological Station and household quantitative data obtained from household questionnaires were analyzed using descriptive statistics i.e. mean, standard deviation and percentages. The mean was used in calculating the mean annual and long term mean rainfall for 33 years (1980-2012).The mean was calculated as shown below:

$$\bar{X} = \frac{\sum x^1 n}{n}$$ Where: $\bar{x}$ =Mean

$x^1$ =Observed variables

n =Total number of observed variables

(Source: Mugenda and Mugenda, 1999)

The long term mean rainfall for 33 years in Marigat Sub-county was 563.7mm.

$$\bar{x} = \frac{18602.20}{33}$$

$$= 563.7mm$$

Standard deviation was computed using MS Excel software and was used in calculating the spread of annual rainfall around the long term mean rainfall.

Drought intensity was calculated by subtracting the long term mean rainfall for the 33 years (1980-2012) from the total annual rainfall for a given year and was expressed as a percentage.

$$DI = \frac{X - \overline{X}}{\overline{X}} * 100\%$$

Where: DI=Drought intensity

x =Total annual rainfall for a given year

$\bar{x}$ =Long term mean rainfall for the study period

(Source: McKee et al.,1993)

Drought duration was considered as any year or consecutive years with rainfall below the mean. For example, two consecutive years with rainfall below mean was termed as a 2-year drought.

Household questionnaire data was entered and analyzed in statistical package for social sciences (SPSS). This data was presented using textual outlines, tables, charts and graphs.

Qualitative data obtained from household questionnaires, FGD guide and key informant interviews were analyzed by assigning codes and organizing of data into themes and sub-themes to enable emergence of the answers from these categories. This data was presented in description.

The Normalized Difference Vegetation Index (NDVI) was used to do time series analysis of vegetation cover health for the identified drought years between 1980 and 2012.

The NDVI derived from satellite images was expressed as follows:

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

Where: NDVI= Normalized Difference Vegetation Index

NIR= near infrared band

VIS= visible band

(Source: http://earthobservatory.nasa.gov/features, 2009)

The NDVI dataset was derived from remotely sensed images whereby the raw data was processed using ERDAS IMAGINE Version 2011 software and the resulting maps were analyzed using Arc Map Version 10.1 software. This data was presented in form of images and maps.

Hydrological data for River Perkerra discharge was analyzed using Pearson Product Moment correlation coefficient. This was to show the relationship between drought intensity and river discharge flow.

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

## 4.1 Introduction

This chapter entails presentation of results and discussions of the findings from the field. The study analyzes drought intensity and duration and examines their effects on vegetation cover and water resources in Marigat Sub-County of Baringo County.

### 4.1.1 Household Characteristics of the Study Population

**Duration of Stay in the Sub-County**

The study revealed that most households in Marigat community live as a clan therefore they have inhabited the place for many years. The household data in Table 4.1 shows that 86.6 percent of the respondents had lived in the study area for more than 30 years while 13.4 percent had lived the community between 21 and 30 years. The reason for long duration of stay in the study area is because of traditional settlements pattern of the Marigat community whereby typically large circle of 10 to 20 houses composed of members of several lineages lived adjacent to each other and shared herding tasks. Similarly, Le Houerou (2012) asserted that long duration of stay of Fulani pastoralists in Abet area, Nigeria was as a result of initial settlement pattern by their forefathers whereby a homestead includes several households living together and sharing tasks.

**Table 4.1: Number of Years that Respondents Have Lived in Marigat Sub-County (N=368)**

| Years | Frequency | Percent |
|---|---|---|
| 21–30 | 65 | 13.4 |
| 31 – 40 | 176 | 47.8 |
| 41 – 50 | 78 | 21.1 |
| > 50 | 49 | 17.7 |
| **Total** | **368** | **100.0** |

The duration of stay in the study area made sampled household relevant since the time spent in the sub-county enabled them have enough experiences on drought dynamics and their effects on vegetation and water resources. Similarly, Ferreri (2011) made observation that the settlement patterns of Karamojong pastoralists in Karamoja region of north eastern Uganda reflect the long duration of stay in the region and indicates their experience in transformation of pastoral livelihoods over time.

### Gender of the Respondents

The household data revealed that in terms of gender, the number of male respondents was higher than female respondents. About 62 percent of the interviewed respondents were male whereas 38 percent were female. This implies that majority of the households in the community were male headed. In the absence of male head the female headed the household (Figure 4.1).

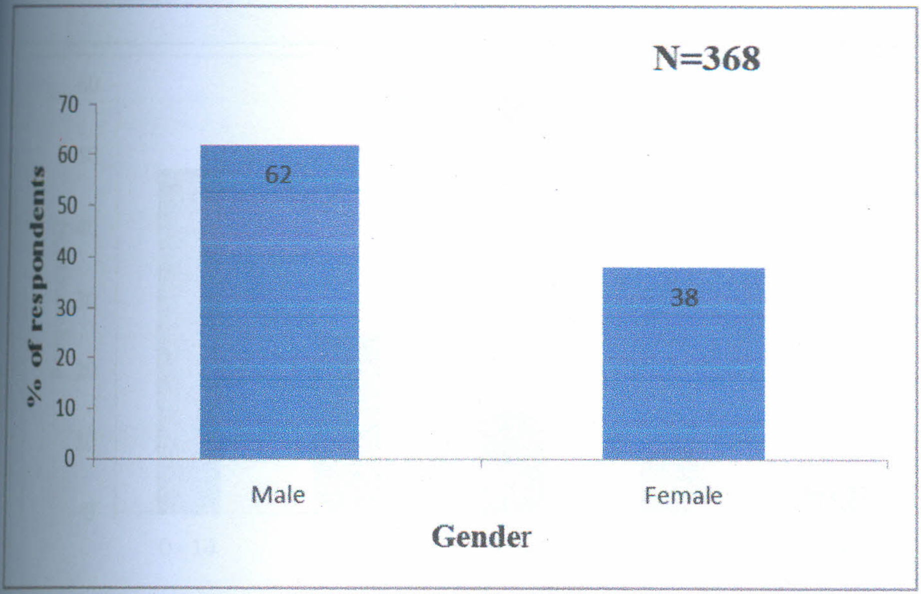



**Figure 4.1: Percentage Distributions of Respondents by Gender in Sub-County**

The study established that men dominated the leadership in the household because of culture and ownership of the properties. Livestock keeping is the most common activity in Marigat community and men are entitled with the ownership of the livestock, women only become in charge of livestock and headed the households in absence of a man in that household. This agrees with Wasonga et al. (2011) assertion that livestock is the major asset to the inhabitants of Marigat community which is owned and highly valued by men.

**Age Category of Household Members in the Sub-County**

Data from household survey showed that 48 percent of the inhabitants were aged between 0 - 14 years. The households 15-60 years comprised of 48 percent and the aged, above 60 years, formed 4 percent of the population (Figure 4.2).

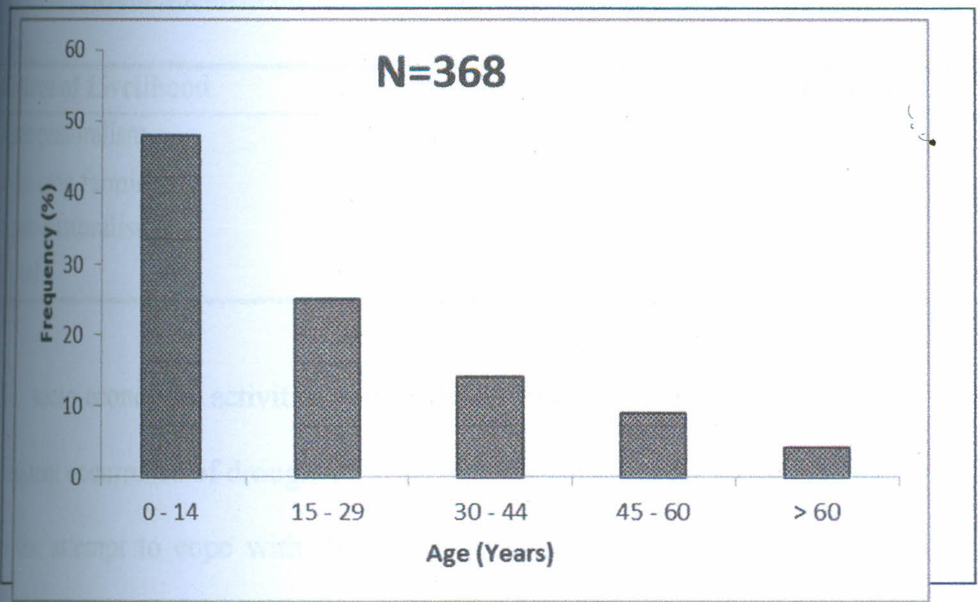



**Figure 4.2: Distribution of Households by Age in Marigat Sub-County**

Data from Figure 4.2 revealed that about 52 percent of the population was dependent with 48 percent comprising of young population and 4 percent aging. Almost half of the population provided labour force. This means that the rate of dependency in the sub-county is high since half of the population depends on the other half of the population. This finding agrees with KNBS (2012) observation that the sub-county has a child rich population structure where 0-14 years old constitute 49 percent of the total population.

**Socio-Economic Activities**

The household data revealed that the main socio-economic activity in the sub-county was agro-pastoralism. Table 4.2 shows that 65 percent of the respondents stated agro-pastoralism as the main economic activity practiced in the sub-county, pure pastoralism accounted for 26 percent of the respondents whereas pure crop farming accounted for 9 percent of the respondents.

Table 4.2: **Main Socio-Economic Activities in Marigat Sub-County (N=368)**

| Source of Livelihood | Frequency | Percent |
|---|---|---|
| Pure pastoralism | 96 | 26 |
| Pure crop farming | 33 | 9 |
| Agro-pastoralism | 239 | 65 |
| Total | **368** | **100** |

All socio-economic activities were dependent on rainfall performance. Unfortunately, the frequent occurrence of droughts of varying intensity and durations had led to changes in land use in the attempt to cope with drought dynamics. As a result, there was a shift towards agro-pastoralism from pastoralism. The findings agree with that of Kandji (2006) who pointed out that the sources of livelihood in Baringo County were affected by drought episodes.

## 4.2 Drought Occurrence in Marigat Sub-County

The study used annual rainfall for a period of 33 years (1980-2012) to depict droughts years in the study area. Years with total annual amount of rainfall below calculated long term mean of 563.7mm were considered as drought years for the period under study. Marigat Sub-County recorded 18 droughts which occurred in 1980, 1984, 1986, 1992, 1994, 1995, 1996, 2000, 2001, 2002, 2003, 2004, 2006, 2008, 2009, 2010, 2011 and 2012 (Table 4.3).

**Table 4.3: Drought and Non-Drought Years in Marigat Sub-County (1980 – 2012)**

| Year | Total Annual Amount of Rainfall | Drought/Non Drought |
|---|---|---|
| 1980 | 427.5 | Drought |
| 1981 | 692.1 | Non Drought |
| 1982 | 666.7 | Non Drought |
| 1983 | 703.3 | Non Drought |
| 1984 | 270.5 | Drought |
| 1985 | 714.4 | Non Drought |
| 1986 | 510.6 | Drought |
| 1987 | 587.0 | Non Drought |
| 1988 | 892.9 | Non Drought |
| 1989 | 842.0 | Non Drought |
| 1990 | 590.5 | Non Drought |
| 1991 | 667.5 | Non Drought |
| 1992 | 562.0 | Drought |
| 1993 | 654.9 | Non Drought |
| 1994 | 563.4 | Drought |
| 1995 | 500.1 | Drought |
| 1996 | 539.7 | Drought |
| 1997 | 780.8 | Non Drought |
| 1998 | 760.4 | Non Drought |
| 1999 | 637.6 | Non Drought |
| 2000 | 256.9 | Drought |
| 2001 | 411.2 | Drought |
| 2002 | 237.6 | Drought |
| 2003 | 275.4 | Drought |
| 2004 | 275.8 | Drought |
| 2005 | 626.6 | Non Drought |
| 2006 | 529.3 | Drought |
| 2007 | 926.8 | Non Drought |
| 2008 | 452.4 | Drought |
| 2009 | 486.3 | Drought |
| 2010 | 550.7 | Drought |
| 2011 | 510.2 | Drought |
| 2012 | 496.1 | Drought |

**Mean=563.7 mm ± 14.9**

**(Source: KALRO Perkerra Meteorological Station, 2014)**

The analyzed Meteorological Data (Table 4.3) revealed that droughts in Marigat Sub-County have been increasing in frequency of occurrence. In 1980-1989 decade, 3 out of 10 years (30%) were drought years (Figure 4.3)

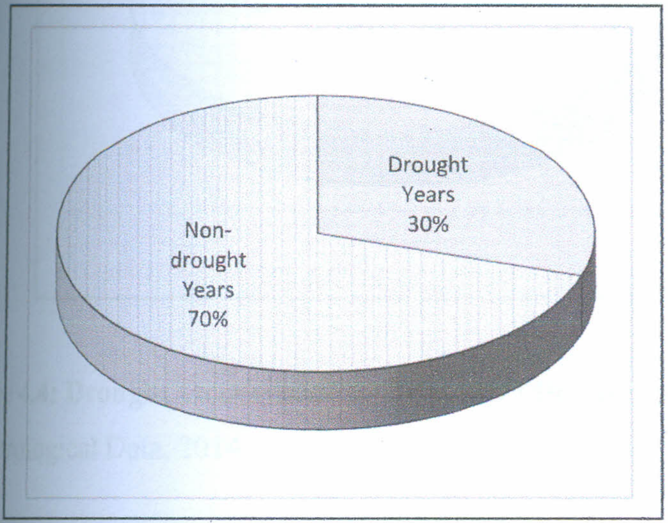



Figure 4.3: **Drought Occurrence in 1980-1989 Decade** (Source: Analyzed KALRO-Perkerra Meteorological Data, 2014)

The 1980s droughts occurred in 1980, 1984 and 1986. The frequency increased to 4 in every 10 years (40%) in 1990s (Figure 4.4)

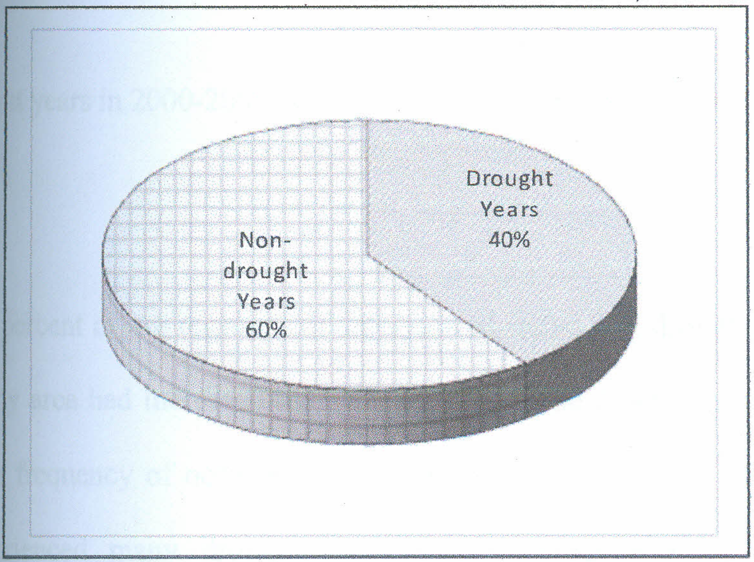



**Figure 4.4: Drought Occurrence in 1990-1999 Decade** (Source: Analyzed KALRO-Perkerra Meteorological Data, 2014)

The droughts in 1990s occurred in 1992, 1994, 1995 and 1996. In 2000s, 8 out of 10 years (80%) were drought years (Figure 4.5).

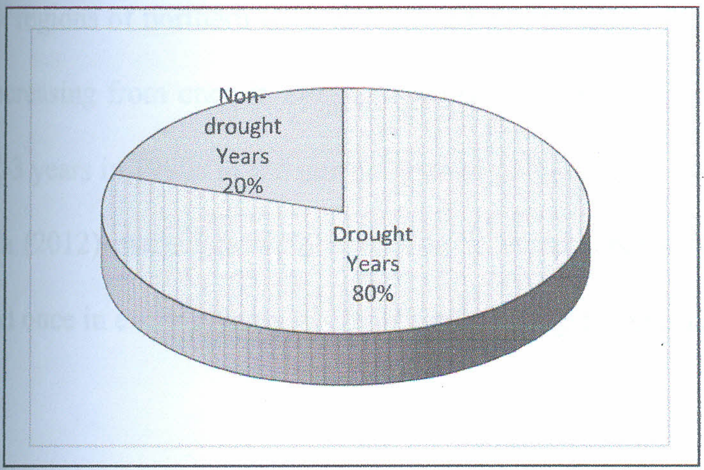



**Figure 4.5: Drought Occurrence in 2000-2009 Decade** (Source: Analyzed KALRO-Perkerra Meteorological Data, 2014)

The drought years in 2000-2009 decade included: 2000, 2001, 2002, 2003, 2004, 2006, 2008 and 2009.

About 97 percent of the respondents interviewed stated that droughts occurrence and frequency in the study area had increased over the decades while 3 percent stated that there had been no changes in frequency of occurrence. The respondents stated that during the 2000-2009 decade they experienced many droughts compared to 1990-1999 and 1980-1989 decades. The observation confirmed the analyzed meteorological data whereby 80 percent of 2000-2009 decade was characterized by drought whereas 40 percent and 30 percent of 1990-1999 and 1980-1989 decades were drought years respectively (Figures 4.3, 4.4 and 4.5). The study revealed that the frequency of drought occurrences had been increasing in Marigat Sub-County. Similarly, increasing frequency in drought occurrence had been observed in most dry lands of the world. In the vast regions of northern Kenya, for example, droughts frequency had been observed to have been increasing from once in every 10 years in 1970s, once in every 5 years in 1980s, once in every 2-3 years in 1990s to the current annual phenomenon starting from 2000s (Howden, 2009). Mekuria (2012) made similar observation in eastern parts of Ethiopia that in 1990s droughts occurred once in every 2 years while in 2000s droughts occurred almost on an annual basis.

### 4.2.1 Drought Duration

Drought duration refers to the length of time drought episode persist in the area. Interviews with the respondents showed that droughts in the study area occurred as either short-term or long-term droughts. About 74 percent of the respondents considered the drought durations to be short-term if it lasted for less than one year, 18 percent considered short-term drought as one that lasted between 1 to 2 years, 6 percent considered to last between 3 to 4 years and 2 percent considered to last for more than 4 years (Table 4.4).

**Table 4.4: Durations for Short-Term Drought (N=368)**

| Duration | Frequency | Percent |
|---|---|---|
| <1 year | 272 | 74.0 |
| 1-2 years | 66 | 18.0 |
| 3-4 years | 22 | 6.0 |
| Above 4 years | 8 | 2.0 |
| Total | **368** | **100.0** |

The household data from Table 4.4 above revealed that short-term drought was considered to persist for a period less than 2 years by 92 percent of the respondents. The respondents stated that during short-term droughts there was less migration since vegetation and water resources were not severely affected and they were able to cope with such droughts. This implied that droughts were considered to be short term when their associated effects less affect the key resources and when the inhabitants were able to cope with them. Similar observation was noted by Yawitz (2012) in Midwestern States whereby 12 months without rainfall was considered as short term because the impacts to the forests, water supplies and agriculture were not severe. In northern Kenya, Serna (2010) asserted that there was less livestock and human migration during the 18 months drought of 1998-1999 in the region.

For the long-term droughts, about 69 percent of the respondents interviewed stated that long term drought lasted for a period between 3 to 4 years, 26 percent stated that it lasted between 5 to 6 years and 5 percent stated above 6 years (Table 4.5).

Table 4.5: **Durations for Long-Term Drought (N=368)**

| Duration | Frequency | Percent |
|---|---|---|
| 3-4 years | 254 | 69.0 |
| 5-6 years | 96 | 26.0 |
| Above 6 years | 18 | 5.0 |
| Total | **368** | **100.0** |

The household data revealed that 95 percent of the respondents considered long-term drought to persist for a period between 3 to 6 years (Table 4.5). The respondents associated long term drought with displacement and movement of livestock because water resources dried up completely and vegetation was completely depleted. For example, the 2000-2004 prolonged droughts in the study area led to mass movement of livestock beyond borders. The observation agrees with Stewart (2009) who noted that the 1983-1985 and 1986-1991 prolonged droughts in Western United States were considered long term which resulted in death of livestock as a result of starvation and drying up of major water reservoir in the region. The findings also agree with Hendy and Morton (2013) assertion that the 6-year drought of 2007-2012 in northern Kenya led to mass movement of livestock across the borders of Ethiopia, South Sudan and Uganda in search of fresh pasture. During such drought episodes the pastoralists travelled long distances to access water from Tana River.

The analyzed meteorological data revealed that drought duration in the study area differed from one drought event to the other, with the durations ranging from 1 to 5 years. The study established that in 1980s droughts had shorter durations extending for one year. In 1990s the droughts ranged from 1 to 3 years. A one-year drought occurred in 1992 while between 1994 and

1996 the sub-county experienced a 3-year drought. The longest drought duration was experienced in 2000-2009 decade spanning for up to 5 years between 2000 and 2004. In addition, the decade also experienced a 1-year and 2-year droughts in 2006 and 2008-2009 respectively. The analyzed 3 years of 2010 decade revealed that the sub-county experienced a 3-year drought period between 2010 and 2012 (Table 4.6).

**Table 4.6: Decadal Drought Duration**

| Decade | Drought Year | Total Annual Amount of Rainfall (mm) | Drought |
|---|---|---|---|
| | 1980 | 427.5 | Drought |
| 1980 | 1984 | 270.5 | Drought |
| | 1986 | 510.6 | Drought |
| | 1992 | 562.0 | Drought |
| 1990 | 1994 | 563.4 | |
| | 1995 | 500.1 | Drought |
| | 1996 | 539.7 | |
| | 2000 | 256.9 | |
| | 2001 | 411.2 | Drought |
| | 2002 | 237.6 | |
| | 2003 | 275.4 | |
| 2000 | 2004 | 275.8 | |
| | 2006 | 529.3 | Drought |
| | 2008 | 452.4 | Drought |
| | 2009 | 486.3 | |
| | 2010 | 550.7 | |
| 2010 | 2011 | 510.2 | Drought |
| | 2012 | 496.1 | |

**Long term mean rainfall from 1980-2012 = 563.7mm ± 14.9**

(Source: Analyzed KALRO - Perkerra Meteorological Station data, 2014)

The analyzed meteorological data in Table 4.6 revealed that drought duration had been increasing over time, with the 2000-2009 decade recording droughts that spanned up to 5 years. The 1990-1999 decade had the second longest drought spanning up to 3 years while 1980-1989 decade had droughts that lasted for only one year. This observation confirmed 90 percent of the respondents' assertion that 2000-2009 decade was the driest and had the longest drought compared to 1980s and 1990s. About 10 percent of the respondents stated that the 1990-1999 and 2000-2009 decades had equally prolonged droughts compared to 1980s. Similar observations have been noted in other parts of the world. For instance, in the Sool Plateau, Sanaag regions of Somalia the 2000-2009 decade experienced prolonged droughts compared to 1980s and 1990s. During this period for instance, a 5-year drought was experienced between 2000 and 2004 while the longest drought in the 1990s was a 2-year drought which occurred between 1995 and 1996 (StClair, 2009). Schwabe and Connor (2010) made observation on their study that over the past 4 decades in the Southwestern United States and California, drought duration had increased by approximately 3.5 percent and 6.4 percent respectively. Akhtar and Qureshi (2008) findings agree with the observation that in 2000-2009 decade Balochistan and Sindh Provinces in Pakistan experienced a 5-year drought which occurred between 2001 and 2005, while in 1990-1999 decade the longest drought experienced in the regions was a 3-year drought of 1997-1999. Increasing drought duration over the decades had also been noted in southern and eastern parts of Australia. Kogan et al. (2012) asserted that in 1990s the region experienced a prolonged drought between 1996 and 1999 whereas in 2000s the drought extended from 2000 to 2008.

**4.2.2 Drought Intensity**

The study analyzed rainfall data to establish drought intensities for the study area by using the formula below and as demonstrated using the 1980 drought.

$$DI = \frac{X - \overline{X}}{\overline{X}} * 100\%$$

DI=Drought intensity

$x$=Total annual rainfall for a given year

$\bar{x}$=Long term mean rainfall for the study period

(Source: McKee et al, 1993)

$$DI = \frac{427.5 - 563.7}{563.7} * 100\% = -24.16\%$$

The negative sign for the calculated drought intensity indicates the percentage of total annual rainfall for a specific year below the calculated long term mean rainfall (Trotman et al, 2007). This implies that drought intensity for 1980 was 24.16% below the long term mean rainfall of 563.7mm (Table 4.7)

Table 4.7: **Drought Intensity for the Identified Drought Years (1980-2012)**

| Drought Year | Total Annual amount of rainfall (mm) | $DI = \frac{X - \overline{X}}{\overline{X}} * 100\%$ Drought intensity (%) | % below the long term mean rainfall $DI = \frac{X - \overline{X}}{\overline{X}} * 100\%$ |
|---|---|---|---|
| 1980 | 427.5 | -24.2 | 24.2 |
| 1984 | 270.5 | -52.0 | 52.0 |
| 1986 | 510.6 | -9.4 | 9.4 |
| 1992 | 562.0 | -0.2 | 0.2 |
| 1994 | 563.4 | -0.1 | 0.1 |
| 1995 | 500.1 | -11.3 | 11.3 |
| 1996 | 539.7 | -4.3 | 4.3 |
| 2000 | 256.9 | -54.4 | 54.4 |
| 2001 | 411.2 | -27.1 | 27.1 |
| 2002 | 237.6 | -57.8 | 57.8 |
| 2003 | 275.4 | -51.1 | 51.1 |
| 2004 | 275.8 | -51.1 | 51.1 |
| 2006 | 529.3 | -6.1 | 6.1 |
| 2008 | 452.4 | -19.7 | 19.7 |
| 2009 | 486.3 | -13.7 | 13.7 |
| 2010 | 550.7 | -2.3 | 2.3 |
| 2011 | 510.2 | -9.5 | 9.5 |
| 2012 | 496.1 | -12.0 | 12.0 |

**Long term mean=563.7mm ± 14.9**

(Source: Analyzed KALRO-Perkerra Meteorological Station Data, 2014)

Analysis using data in Table 4.7 revealed that drought intensity in Marigat Sub-County ranged from 0.1 to 57.8 percent rainfall below the long term mean rainfall. This implies that droughts occurring in the same area vary in terms intensity. The greater the negative variations from the long term mean, the higher the drought intensity. In this case, the 1994 drought where annual rainfall was 0.1 percent rainfall below the long term mean rainfall was of lesser intensity compared to the 2002 drought where annual rainfall was 57.8 percent below the long term mean rainfall. Actually, the 2002 drought was the most intense drought in the study area for the period under the study. The 2002 drought also affected others parts of the world. For instance, San Diego in California recorded 51.1 percent rainfall below the long term mean rainfall whereas Quad cities in the US recorded 59 percent rainfall below the long term mean rainfall in the year 2002 (Gathara et al., 2006). In Ethiopia, North Afar zones, the 2002 drought was considered the worst and intense in human memory even worse than 1984-1985 droughts due to combination of high loss of animals and yields (Mekuria, 2012). In contrast, the interviews with the respondents revealed that the 2000 drought was the most intense drought in 2000-2009 decade. The reason for the respondents' assertion was that the respondents measured drought intensity with the effects associated with every drought episode on vegetation and water resources in the study area. The study revealed that there was a noticeable change in vegetation and water resources in the year 2000, unlike the preceding years whereby the respondents stated that there was plenty rainfall.

Respondents categorized the intensity of drought by their effects on vegetation and water resources as well as livestock in the study area. Table 4.8 shows the drought effects that amounted to intense droughts according to the respondents. About 25 percent of the respondents stated depletion of vegetation, 23.1 percent stated drying up of water resources, 22.6 percent stated migration of livestock and 29.3 percent stated death of livestock.

Table 4.8: **Effects Posed by Intense Drought in the Community (1980-2012) (N=368)**

| Effects of **Drought in the Community** | **Frequency** | **Percent** |
|---|---|---|
| Depletion of vegetation | 92 | 25.0 |
| Drying up of water resources | 85 | 23.1 |
| Migration of livestock | 83 | 22.6 |
| Death of livestock | 108 | 29.3 |
| Total | **368** | **100** |

According to the interviews in Table 4.8, the intense drought affected vegetation, water resources and livestock. This implies that the higher the drought intensity, the higher the rate of depletion of the key resources in the sub-county. As a result, the inhabitants coped by migrating with their livestock to other places where pasture was available. Savatia (2009) asserted that direct impact of intense drought in the ASALs region of Northwestern Kenya had drying up of water sources and declining forage resources for the livestock which led to transhumance.

Interviews revealed that major droughts that had occurred in the study area were still remembered by both pastoralists and agro-pastoralists. For instance, in 1980-1990 decade majority of the respondents (73 percent) mentioned the 1984 drought to be the most intense drought in that decade (Table 4.9).

Table 4.9: **The Driest Years in 1980-1989 Decade (1980-2012) (N=368)**

| Year | Frequency | Percent |
|---|---|---|
| 1980 | 66 | 18.0 |
| 1984 | 269 | 73.0 |
| 1986 | 33 | 9.0 |
| Total | **368** | **100.0** |

The responses from respondents revealed that the 1984 drought was referred as "*Rubetab Kiagik*" meaning the drought which swept livestock. The respondents reported that during this drought period many households in the sub-county lost their livestock, this was due to lack of pasture and water for the livestock and also drought-related diseases. These findings confirmed Conway (2000) observation that two-thirds of the households in north east Ethiopian highland lost their livestock during the 1984 drought as a result of starvation and drought related diseases. The respondents also reported that vegetation was cleared in Kimalel, Salabani, Elwalel-Soi and Kimondis Locations resulting to massive migration of livestock to other districts. For example, the pastoralists moved as far as Kapnarok in Kabarnet, part of Turkana and Laikipia Districts (Kandji, 2006). Similarly, studies in Mali showed that during the 1984 drought, vegetation was completely depleted in the eastern parts of Mali leading to massive movement of livestock to the North-West areas of Mali (Fransen, 2009).

According to the interviews, in 2000-2009 decade majority of the respondents (90 percent) mentioned the 2000 drought to be the most intense drought in the 2000s (Table 4.10).

Table 4.10: **The Driest Years in 2000-2009 Decade (1980-2012) (N=368)**

| Year | Frequency | Percent |
|---|---|---|
| 2000 | 331 | 90.0 |
| 2002 | 15 | 4.0 |
| 2008 | 7 | 2.0 |
| 2009 | 15 | 4.0 |
| Total | **368** | **100.0** |

The respondents indicated that during the 2000 drought, vegetation was completely depleted and many surface water reservoirs dried up in the study area. Depletion of the key resources led to human displacement and mass movement of livestock in the sub-county. This means that the livelihood sources of the inhabitants were severely affected by the intense drought compared to years of lesser drought intensity. The abrupt decline in the key resources forced them to look for places with sufficient pasture and water. The 2000 drought was experienced in other ASALs areas in the country and posed similar effects on vegetation and water resources. For example, in the semi-arid areas of Laikipia District, Kenya, most surface water resources and pasture dried up resulting to migration of animals and Maasai pastoralists beyond borders (Huho, 2011).

The study established that droughts affected vegetation either directly or indirectly.

### 4.3 Direct Effects of Droughts on Vegetation Cover

Interviews from the respondents showed that the current state of vegetation cover in the study area had reduced compared to the past. Figure 4.6 shows the state (the percentage change) in vegetation cover as noted by respondents.

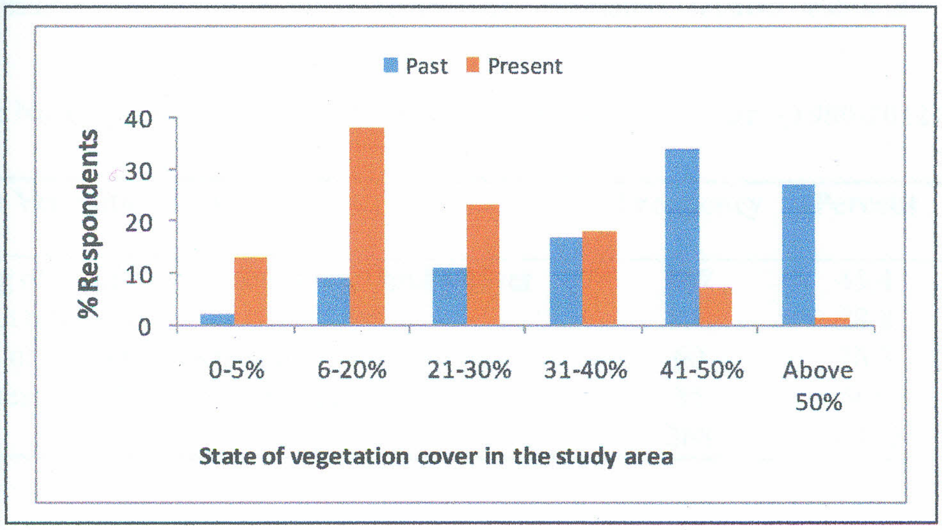



**Figure 4.6: Past and Present State of Vegetation Cover in the Study Area**

Figure 4.6 shows that about 78 percent of the households indicated that over 30 percent of Marigat Sub-County had adequate vegetation cover in the past compared to 22 percent who asserted that the area had over 30 percent of vegetation cover at present. This implied that vegetation cover had reduced over time. The reduction was attributed to changes in land use activities due to changes in climatic patterns which had resulted to variations in drought intensity and durations. Vulnerability of vegetation cover in the study area increased in response to changes in land use. These findings agrees with Lake (2011) observation that the loss of vegetation in Australia was associated with climate change which resulted in changes in farming systems to shift cultivation in the region.

The direct effect of drought on vegetation in the study area included slow regeneration, drying up of vegetation and destruction of wetland vegetation depending on the intensity or duration of the drought.. Respondents mentioned the following as noted changes in vegetation cover in the sub-county (Table 4.11). Mingyuan et al. (2012) had similar findings and noted that droughts reduce or delay re-establishment of grasslands, scrublands, shrublands and also bushlands.

**Table 4.11: Noted Changes in Vegetation Cover in the Sub-County (1980-2012) (N=368)**

| Changes in Vegetation Cover | Frequency | Percent |
|---|---|---|
| Diminishing of grasslands pastures and shrubs cover | 167 | 45.4 |
| Reduction in tree cover | 106 | 28.8 |
| Destruction of wetland vegetation | 60 | 16.3 |
| Overall increased in bare ground cover | 35 | 9.5 |
| **Total** | **368** | **100.0** |

Table 4.11 above, show that 45 percent of the respondents reported that grasslands pastures (annual grasses) and shrubs had diminished in the study area between 1980 and 2012. Since they were more sensitive to both high and low drought intensity compared to tree cover and wetland vegetation. Thus, different types of rangeland vegetation are affected differently by droughts of varying characteristics. With the loss of annual grasses and shrubs, which livestock dependent on majorly, the inhabitants experienced loss of livestock. These observations confirms Mwangi and Swallow (2005) assertions that in 1980 and 1990 decades, most areas of Kimalel, Kimondis, Elwalel-Soi, Salabani, parts of Kapkuikui and Marigat Locations were dominated by annual grasses and shrubs which have now declined tremendously. Similar effects of droughts on vegetation has been observed in Australia by Michalk et al, (2013) who noted that the recurrent droughts between 1984 and 2006 resulted in the decline of rangeland grasses and shrubs lead ing to reduced vegetation cover. The findings were also in line with Auken (2000) observation that

prolonged droughts experienced in the semi-arid of North America between 1987 and 1999 led to 54 percent decline of grasslands and 32 percent decline of shrub lands in the region respectively.

Reduction in tree cover was mentioned by 28.8 percent of the household respondents. The most notable change was the decline in Acacia tree species especially in the lowland parts of the sub-county which comprised of Marigat, Il-Chamus, Iling'arua and Ngambo Locations. This was attributed to extensive use of Acacia tree for charcoal burning (Figure 4.7) as a coping strategy during droughts. Increasing trend in the number of charcoal bags (25-30 kg standard bag) sold form the sub-county indicated high rates of tree felling.

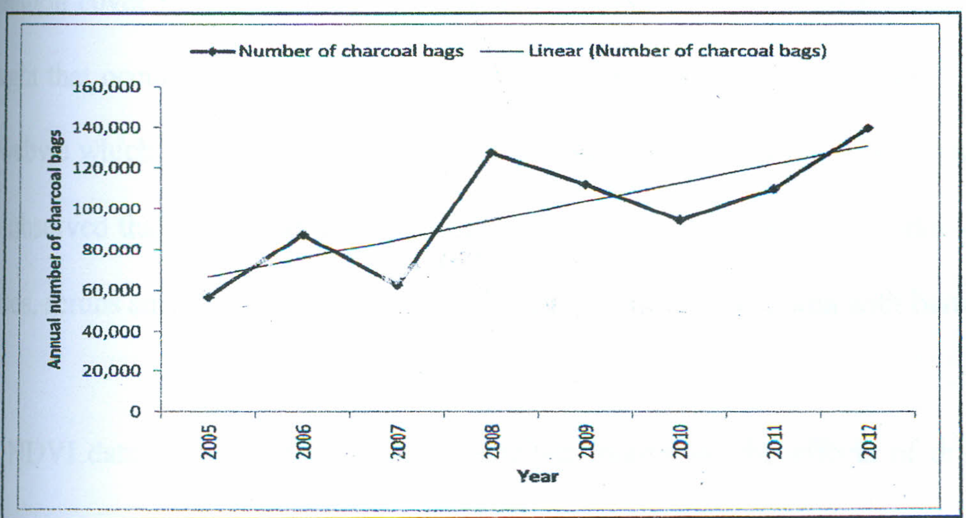



**Figure 4.7: Increasing Trend in Number of Charcoal Bags Produced in the Study Area**

The household data in Table 4.11 revealed that 16.3 percent of the respondents stated that they have noted destruction of wetlands vegetation in the study area. The riverine vegetation along Perkerra and Molo Rivers and wetland areas in Loboi and Marigat Locations were reported to have increased drastically since the year 2000. Probably as a result of intense and long durations droughts experienced in the study area leading to conversion of wetland to farmland by local residents. In Dodoma District in Tanzania prolonged droughts has caused destruction of bush lands and diminishing of tree cover (Schechambo et al., 1999). In Hararghe eastern parts of Ethiopia bush lands had been encroached for establishment of a new settlement (Guinand, 2000).

Increased in bare ground was another noted change in vegetation cover in the study area which was reported by 9.5 percent of the respondents. The intense and prolonged droughts that were experienced during the 2000-2009 decade led to increase in bare ground area in most rocky parts of Kimalel, Salabani, Kimondis and Elwalel-Soi locations. This was triggered by drying up of vegetation cover following the 5-year drought that occurred from 2000 – 2004, and the 2-year drought that occurred from 2008 - 2009. This was similar to a 4-year drought of 2000-2003 in Zibwabwe which led to increased bare ground area (Terrence, 2010). Biradar and Sridhar (2009) also observed that the 3-year drought of 2001-2003 in Karnataka, south India led to depletion of grasses, scrubs and shrubs in the region leaving some parts of the area with bare ground.

The NDVI data analyzed from Landsat satellite images on the effects of droughts of varying characteristics on vegetation cover supported the observations made by the respondents in the study area. The NDVI data showed variations in amount of plant biomass during droughts of different intensities and durations. Droughts of high intensity resulted to low mean NDVI values compared to droughts of low intensity as shown in Table 4.12 and Plates 1a, 1b and 1c.

Table 4.12: **Mean NDVI Values for 1984, 1994 and 2000 Images and Respective Drought Intensities**

| Drought Year | Mean NDVI Values | Drought Intensity (%) Below Long Term Mean |
|---|---|---|
| 1984 | 0.03 | 52.0 |
| 1994 | 0.08 | 0.1 |
| 2000 | -0.07 | 54.4 |

(Source: Analyzed Meteorological Data, 2014 and http://glovis.usgs.gov, Downloaded on 21/11/2014)

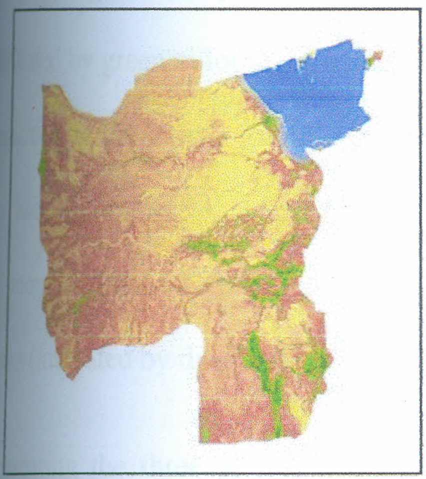


Plate 1a: 1984 NDVI image

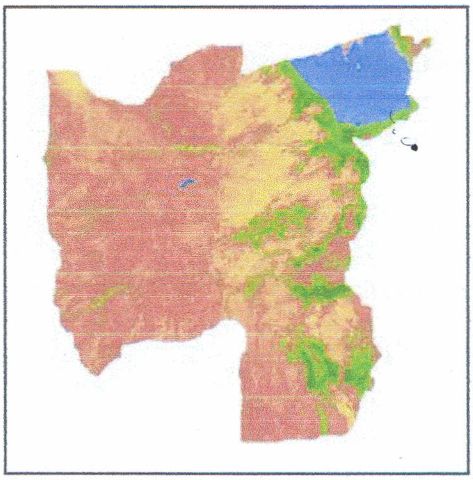


Plate 1b: 1994 NDVI image

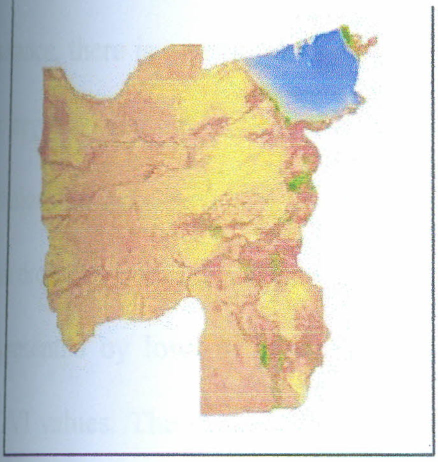
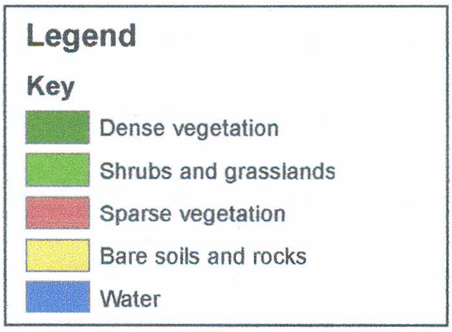


Plate 1c: 2000 NDVI image




**Plates 1a, 1b and 1c: Vegetation Cover in Marigat Sub-County During 1984, 1994 and 2000 Droughts** (Source: http://glovis.usgs.gov/, Downloaded on: 21/11/2014)

Analysis using data in Table 4.12 and Plates (1a, 1b and 1c) revealed that droughts of different intensities can drive significant changes on plant biomass in an area. For instance, the NDVI image for the 1994 (Plate 1b) when the intensity was lower (0.1) there was a higher mean NDVI value (0.08), the study area had more concentration of shrubs and grassland vegetation (as indicated by green colour). In addition, most of the area was covered with sparse vegetation (as indicated by the brown colour). On the other hand, the NDVI images for 1984 and 2000 (plates 1a and 1c respectively) when drought intensities were high, vast areas of the study area (Kimondis, Salabani, Elwalel-Soi and Kimalel locations) was characterized by bare soils and rocks (indicated by diminishing green colour and increase in yellow colour).

Comparing the three plates, there is pronounced changes in vegetation cover as a result of changes in mean NDVI values. This may be in response to varying drought intensity. For instance, there is a noticeable change in vegetation cover between Plates 1b and 1c, as revealed by negative changes in mean NDVI values from 0.03 in 1994 to -0.07 in 2000 (Table 4.12). The relationship between drought intensity and mean NDVI values could be explained by the fact that droughts with high intensity affect vegetation cover resulting to bare soils and rocks which is represented by low mean NDVI values whereas less drought intensity represents high mean NDVI values. The observation was in line with Travis (2006) findings in San Antonio region, Texas, who observed changes in NDVI images of 1999 and 2002. The mean NDVI values were noted to change from 0.195 in 1999, the year which recorded a drought of high intensity to 0.361 in 2002, the year with low drought intensity.

## 4.4 Indirect Effects of Drought on Vegetation Cover

The study established that droughts exacerbated some factors which resulted in depletion of vegetation cover. Table 4.13 shows factors which were perceived by the households as indirect effects of drought on vegetation in the sub-county. In a multiple response frame majority of respondents (80%) stated overgrazing as a factor attributed by drought which affect vegetation, 70% of the respondents stated charcoal burning, while 68% of the respondents stated change in land use activity.

**Table 4.13: Factors Perceived to be Exacerbated by Drought Indirectly (1980-2012)**

| Factors Perceived by the Respondents | Total Number of Respondents | Percent |
|---|---|---|
| Over-grazing | 294 | 80 |
| Charcoal burning as an alternative source of livelihood | 258 | 70 |
| Change in land use activity | 250 | 68 |

Data in Table 4.13 shows that about 80 percent of the household respondents stated that overgrazing in the study area mostly occurred during dry periods. This suggests that droughts expose vegetation cover into intensive grazing as a result of the number of livestock exceeding the carrying capacity of pastures. Similarly, Macharia and Ekaya (2005) observed that overgrazing in the semi-arid areas of Kenya had influence rangeland conditions leading to degradation of vegetation cover. The respondents mentioned that, during dry seasons both pastoralists and agro-pastoralists take their livestock to grazing fields in Arabel and Perkerra Scheme in Marigat location, Loboi Swamp in Loboi location, Kaptich and Lpunyaki Forests in Marigat and Nga'mbo locations respectively and Lake Baringo shores. However, these dry-season grazing fields were affected during droughts of high intensity and long durations. This was emanated from high concentration of livestock from within and outside the sub-county.

The findings from the local livestock officer revealed that the prolonged and intense drought of 2000-2004 led to concentration of livestock along Rivers Perkerra and Molo and the wetland areas of Loboi Swamp. This resulted into destruction of riverine vegetation (Table 4.14).

Table 4.14: **The Action Taken by the Inhabitants during Droughts of Varying Characteristics in the Sub-County**

| Drought Year(s) | Effects on Dry-Season Grazing Fields/ End Result to the Livestock | Action Taken |
|---|---|---|
| 1984 | Complete depletion of vegetation in all dry-season grazing fields, many households loss the livestock | Migration of livestock beyond borders. For instance Kapnarok in Kabarnet and neighbouring district i.e. parts of Turkana and Laikipia |
| 1996 | Depletion of vegetation along the rivers and forests | Migration of livestock to Lake Baringo shores |
| 2000-2004 | Complete depletion of vegetation in all dry-season grazing fields, loss of livestock | Migration of livestock beyond the borders i.e West Pokot, GoK provide feeds (hay) for the livestock |
| 2008-2009 | Destruction of vegetation in Perkerra scheme and Arabel and deaths of livestock | GoK provide feeds (hay) for the livestock, migration of livestock beyond the borders. |

(Source: Sub-county Livestock Office, 2014).

Depletion of vegetation in dry-season grazing fields in the study area was dependent on the intensity and duration of drought. This means that the action taken by the inhabitants as drought coping strategies vary depending on the effects of drought. For instance, a 1-year drought of 1984 led to complete depletion of vegetation in all dry-season grazing fields and loss of livestock. Further the 1-year drought of 1996 led to depletion of vegetation along rivers and forests but there were no livestock lost (Table 4.14). This shows that drought in the same region could be of the same duration but poses different effects depending on intensity. Similarly, in other ASALs areas of the world, vegetation in the preserved dry-season grazing fields is affected during drought episodes. For example, in Isiolo District, Kenya, the 2002 drought led to massive destruction of vegetation in the hilly areas in the district (GoK, 2005). In northern Tanzania, vegetation in the slopes of Mt. Kilimanjaro was severely depleted as a result of 1991-1993 drought (Mkangi, 1996). Personal communication with one of the key informant who is an agropastoralist from Ngambo Location revealed that over-grazing in the study area led to a decrease in vegetation cover which in turn had led to an increased pressure on the land.

The study used satellite images for 1984, 1994 and 2000 to show how drought of varying intensities affected the riverine vegetation along Lake Baringo shores. From the satellite images the areas with red color represents the riverine vegetation in the identified areas (Plates 2a, 2b and 2c).

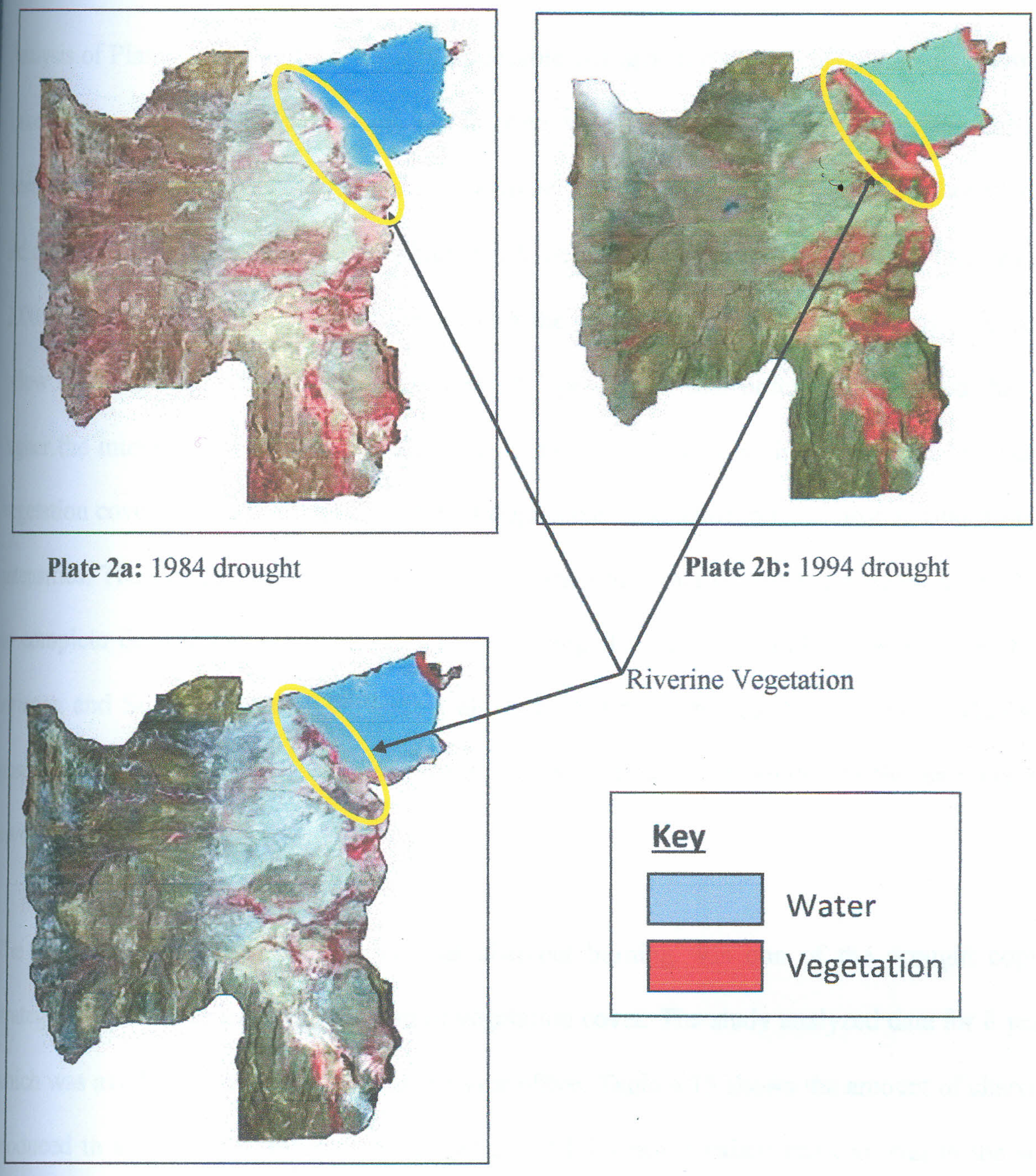



**Plate 2a:** 1984 drought

**Plate 2b:** 1994 drought

**Plate 2c**: 2000 drought

**Plates 2a, 2b and 2c: Destruction of Riparian Vegetation along Lake Baringo Shores**
(Source: http://glovis.usgs.gov/, Downloaded on: 21/11/ 2014)

Analysis of Plates 2a, 2b and 2c revealed noticeable changes in riverine vegetation cover around Lake Baringo shores. Depletion of the riverine vegetation was dependent on the drought intensity. From Plate 2b, there was relatively higher amount of riverine vegetation (indicated by red colour) during the 1994 drought which had lower intensity compared to 1984 (Plate 2a) and 2000 (Plate 2c) droughts. Drought intensities for the years 1984, 1994 and 2000 were 52 percent below the long term mean, 0.1 percent and 54.4 percent in that order. This implied that the higher the intensity, the higher the rate of depletion. The relatively similar amount of riverine vegetation cover during the 1984 and 2000 droughts can be explained by almost similar drought intensities. The finding agrees with Jacob (2011) who noted that the intense drought of 2002 led to complete destruction of riverine vegetation along the shores of Lake Powell in Northern Arizona and Southern Utah. The finding also was in line with Urama and Ozor, (2010) who observed that the riparian vegetation in Lake Chad extremely responded to the extreme and severe drought of 2002 in the region.

The household respondents indicated that charcoal burning was one of the drought coping strategies which have led to destruction of vegetation cover. The study analyzed data for 8 years which was available from Kenya Forest Service office. Table 4.15 shows the amount of charcoal produced in a year, with different prices per 25-30 kilogram standard charcoal bag in the sub-county.

Table 4.15: Changes in Charcoal Production and Prices in Marigat Sub-County

| Year | Drought/ Non- Drought | Number of 25-30 kg Bags Produced in a Year | Price Per 25-30 kg Bag (Ksh) | % Increase/ Decrease in Price |
|---|---|---|---|---|
| 2005 | Non Drought | 56,814 | 450 | - |
| 2006 | Drought | 87,509 | 300 | -33.3% |
| 2007 | Non Drought | 62,378 | 500 | +40.0% |
| 2008 | Drought | 127,473 | 300 | -40.0% |
| 2009 | Drought | 111,668 | 350 | +14.3% |
| 2010 | Drought | 94,216 | 370 | +5.4% |
| 2011 | Drought | 109,647 | 400 | +7.5% |
| 2012 | Drought | 139,443 | 400 | 0.0% |

(Source: Kenya Forest Service Office, Marigat, 2013)

The data from Table 4.16 revealed that during non-drought years, the prices of charcoal per 25-30-kilogram bag were high and the number of 25-30 kilogram bags produced was less compared to drought years. For instance, in 2005 and 2007 non-drought years, a total number of 62,378 and 56,814 bags were produced retailing at Kshs 450 and 500 respectively. But during the 2008 drought, increased charcoal burning activity led to production of 127,473 bags which retailed at Kshs 300, 40% lower than the price in the preceding non drought year. This was attributed to the high number of inhabitants who engage in charcoal burning activity during drought periods. As a result of high production, the prices in the market fall due to increased supply against demand. The observation agrees with Savatia (2009) assertion that over 70 percent of the pastoralists in the semi-arid areas of Northwestern Kenya engaged in charcoal burning and selling during the 2008 drought.

The respondents indicated that over the decades, 1980s, 1990s and 2000s there have been changes in land use practices in Marigat Sub- County. Figure 4.8 show how the three main land use activity have changed over the decades.

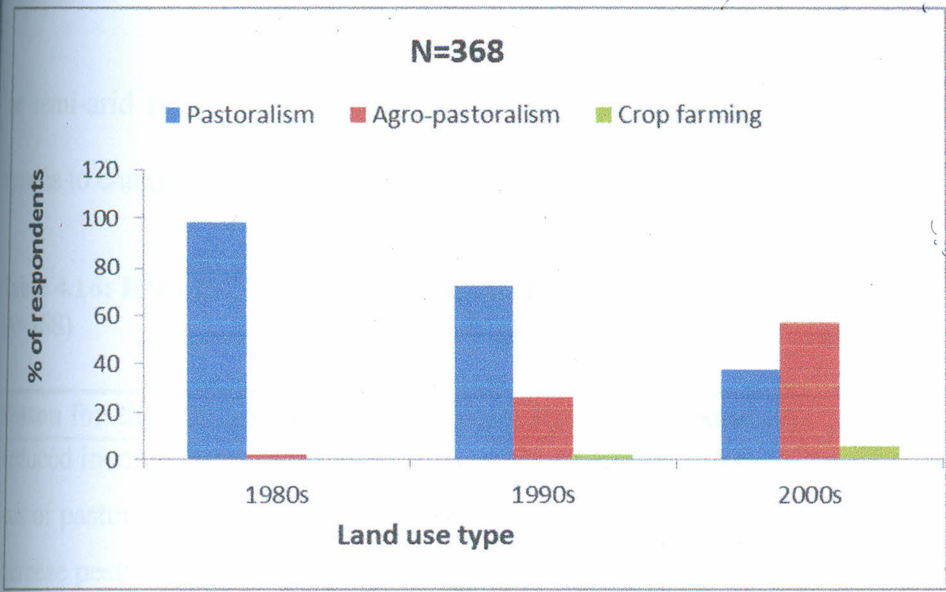



**Figure 4.8: Changes in Land Use Activity over Decades**

In the 1980s, pastoralism predominated accounting for 98 percent with only two percent of the households practicing agro-pastoralism. Household practicing pure crop farming emerged in 1990s accounting for two percent. In 2000s, agro-pastoralism predominated accounting for 57 percent of the households. Pastoralism and pure crop farming accounted for 38 and 5 percent in that order. Currently about 65 percent of the households practice agro-pastoralism and about 10 percent practice pure crop farming. Pastoralism has been on decline over the decades from 98 percent in 1980s to 38 percent in 2000s. This could be in response to the growing population and climate change i.e. increasing drought occurrences in the sub-county. These findings are consistent with those of Abdi et al. (2012) who also reported that population pressure and recurrent drought occurrences are the main driving forces of change in land use activity in the Semi-Arid of East Kordafan of Western Sudan. Studies by Kioko and Okello (2010) also associated climate change and population increase to the drastic changes in land use activity in the semi-arid rangeland of Southern Kenya. Interviews revealed that respondents gave some reasons to changes in land use activity from pastoralism to agro-pastoralism (Table 4.16).

**Table 4.16: Reasons for Change in Land Use Activity in the Sub-County (1980-2012) (N=368)**

| Reason for the Change in Land Use Activity | Frequency | Percent |
|---|---|---|
| Reduced income from livestock | 96 | 26 |
| lack of pasture due to prolonged dry periods | 162 | 44 |
| Increase pests and diseases | 58 | 16 |
| Loss of livestock | 52 | 14 |
| **Total** | **368** | **100** |

From Table 4.16 above, about 44 percent of the respondents shift from pastoralism to agro-pastoralism and pure crop cultivation due to prolonged dry periods which led to inadequate pasture and consequently reduced income from and/ or loss of livestock. However, 26 percent attributed reduced income only while 14 percent stated loss of livestock. About 16 percent stated increase in pests and diseases. This suggests that drought, unreliable and variable rains which are recurring problem affect the key resources in the sub-county. Therefore, the inhabitants have opted to change from pastoralism to agro-pastoralism because their main source of livelihood had been affected over time. However, the community still holds cattle for their cultural values thus they incorporated livestock keeping and crop farming. Similarly, a study by Mwakaje (2013) also noted that recurrent drought has affected livestock productivity in Ngorongoro District, Tanzania as a result the pastoralists are gradually adopting crop farming. The findings also agrees with Terrence (2010) who asserted that frequent and severe droughts occurrence in northern Kenya has led to migration of the inhabitants looking for arable areas to incorporate crop farming to their main source of livelihood.

Personal communication with one of the pastoralists from Kimalel Location revealed that the intense drought of 1984 triggered diversification of livelihood source for most of the pure pastoralists. As a result, inhabitants started practicing crop cultivation as he reported.

*"I almost lost all livestock during the 1984 drought. My livestock starved to death. Pasture was depleted completely forcing the community to move to higher lands in search of palatable grasses and leaves from trees such as Koloswa, Lokoywo and Kilimbil. Since the 1984 drought, I reduced my herd to an average of 50 livestock and started engaging in crop farming though at very small-scale. Since the year 2000, most of the inhabitants here have incorporated crop farming into livestock keeping due to prolonged and intense droughts affecting the sub county. Crop farming was an adaptive strategy against livestock farming."*

Similar observation were made by Guliye et al. (2007) whose findings showed that the declined livestock products mainly meat and milk forced the pure pastoralists in arid and semi-arid areas of northern Kenya to adopt agro-pastoralism activity as the alternative source of livelihood. Shifting from pastoralism to crop farming led to clearance of vegetation to pave way for agriculture. Respondents argued that loss of vegetation cover, particularly in the wetlands, has been triggered by increasing number of household engaging in crop cultivation.

## 4.4 Effects of Drought Intensity and Duration on Water Resources

### 4.4.1 Water Resources in the Study Area

The sources of water in the study area included rivers and streams, lakes, dams, water pans, ponds, springs and swamps. The household data show that, over half of the households (54.4 percent) relied on water from the rivers and streams for their livestock and domestic use. Also

17.2 percent depended on dams, 14.7 percent on water pans, 6.5 percent on lakes, 5.6 percent on swamps, 0.9 percent on springs and 0.7 percent on ponds (Figure 4.9).

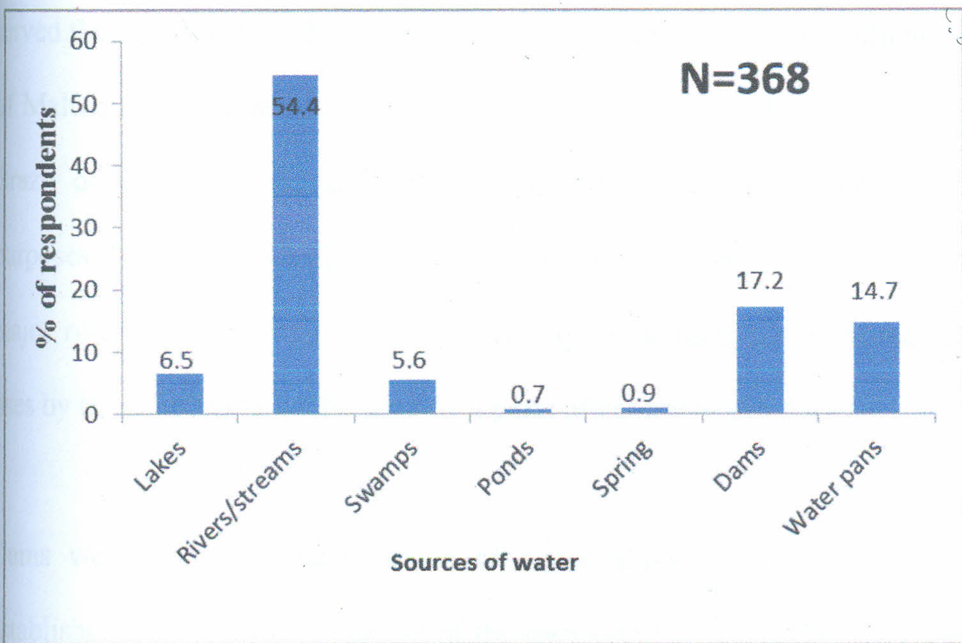



**Figure 4.9: Water Resources in Marigat Sub-County and Frequency of Use**

The household data revealed that rivers and streams were the main source of water in the study area for households, livestock use and irrigation. There were 13 rivers and 4 streams in the study area which included Perkerra, Molo, Endao, Loboi, Weseges, Ol Arabel, Mukutani, Darajani, Chemeron, Subukia, Kapiswa, Loturo and Kapcheburet. The four streams were Cheptugen, Perkerra, Loboi and Endao. Whereas all other rivers are seasonal, Rivers Perkerra and Molo are the perennial draining into Lake Baringo. Interviews revealed that about 54.4 percent of the respondents depended on the rivers and streams mainly for irrigation purposes as well as livestock and domestic use. The most reliable source of water was from Rivers Perkerra and Molo because they were permanent. River Perkerra traverse and serve the inhabitants of Marigat, Iling'arua, Ilchamus, Ngambo, Loboi and Sandai Locations while River Molo served inhabitants of Sandai, Loboi and Ng'ambo Locations. River Endao which originates from Tugen Hills served the inhabitants of Marigat and Salabani Locations. These findings are consistent with that of Maltchik and Medeiros (2006) who reported that the inhabitants of semi-arid north-eastern Brazil depend on rivers and streams for livestock and domestic uses as well as irrigation purposes. Woyessa et al. (2006) made similar observation that many seasonal rivers and the two major rivers Limpopo and Orange are greatly relied upon for livestock, domestic and irrigation uses by the inhabitants of the semi-arid parts of central South Africa

Dams were very important source of water although they served few people. Interviews established that about 17.2 percent of the respondents depended on dams as their main source of water for irrigation purposes, domestic use or watering of livestock. In total, the study area had 10 dams namely Chemeron, Lowal, Ruotik, Chelaba, Sirinyo, Kimorok, Kirandich, Sandai, Endao and Ndambul. The largest dam was Chemeron which was constructed later in 1984 after the intense 1984 drought and is located in Marigat Location. The dam served lower parts of Marigat and Kimalel Locations. About 14.7 percent of the respondents indicated that they dependent on water pans. There were 5 water pans in the study area namely Kinyach, Chebowen, Mollem, Kokchatenin and Iti. Respondents indicated that water pans were constructed in Kimondis, Elwalel-Soi, Kapkuikui and Kimalel Locations to harvest water during the rainy season for the purpose of livestock use. These locations were served by very few rivers and streams. Similarly, in the ASALs areas of the world, thousands of dams are still constructed to store water and make it available during dry periods. The observation made by Ngaira (2009) confirmed these findings that construction of surface water reservoirs i.e. dams and water pans in

Baringo District of Kenya store water for livestock use during dry periods. Studies by Woyessa et al. (2006) also noted that construction of the largest dam Gariep on the Orange River play a very important role in serving irrigation projects in the region.

Despite Lake Baringo and Lake 94 being the largest surface water resources in the area, they only served 6.5 percent of the respondents who hailed from Salabani and Ng'ambo locations because of their proximity to the lakes. Lake 94 formed during the 1997-1998 El Nino rains when River Molo changed its course forming a new lake in Molo Swamp. To date, the Lake has not been gazetted by the government of Kenya. Other sources of water included swamps, springs and ponds. The study area had four swamps namely Loboi, Kiborwach, Serian and Arabel which serves inhabitants of Loboi, Marigat, Ng'ambo, IlChamus and Salabani Locations. The study established residents depended on the swamps for both pasture and water which acted as dry-season grazing fields during drought events. In addition, the agro-pastoralists practiced crop farming in the riparian areas of the swamps. Springs and ponds served about 0.9 and 0.7 percent of the inhabitants respectively. There were two springs, Bogoria and Lorwai located in Loboi Location. These springs served inhabitants of Loboi, Sandai and Kapkukui Locations. Salabani Location had two ponds namely Elmaine and Flower which served the inhabitants from Salabani and Ngambo Locations.

### 4.4.2 Direct Effects of Drought on Surface Water Sources in Marigat Sub-County

The study established that droughts of varying intensities and durations had different direct effects on surface water sources in the study area. Some of the effects included drying up or reduction in volume of the water source (Figure 4.10).

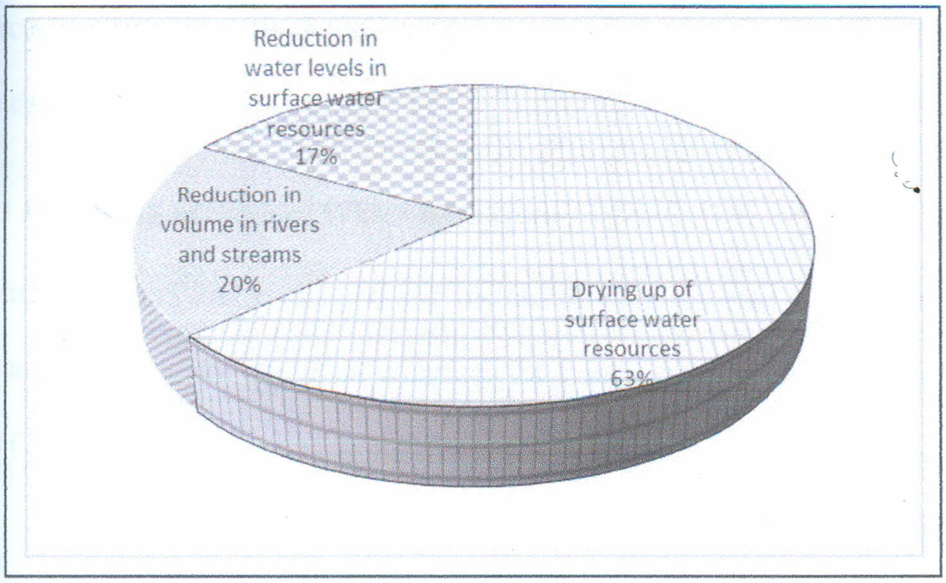



**Figure 4.10: Direct Effects of Droughts on Surface Water Resources in Marigat Sub-County**

The study revealed that drought episodes were accompanied by drying up and reduction in surface water resources. About 63 percent of the respondents stated that water resources dried up. Respondents indicated that seasonal rivers, streams and springs, dams, water pans and ponds also dried up quickly during drought episode. The rate of drying up depended on the size of the reservoir, the intensity and the duration of the drought. About 37 percent indicated that they experienced reduction in water levels. Out of the 37, 20 percent of the respondents observed reduction in rivers and streams levels while 17 percent of the respondents noted reduction in water levels in lakes and dams. This may explain that the effects of droughts either drying up or reduction in surface water resources largely depend on the storage capacity of the reservoirs. Where the reservoir was large, water levels reduced instead of drying up. This was the case of Lake Baringo and Lake 94 and Chemeron Dam and Rivers Perkerra and Molo. This observation was in line with Wehrmann (1992) findings who noted that effects of drought on surface water resources in Illinois greatly depend on the source of supply as well as the intensity and duration of the drought.

#### 4.4.2.1 Drying up of Surface Water Resources

The study revealed that prolonged and intense drought affected surface water resources in the study area. Drying up was most common for rivers, streams, springs, water pans, dams and ponds (Table 4.17).

##### 4.4.2.1.1 Surface Water Resources: Rivers, Streams and Springs

From the household data in Table 4.17, the study revealed that seasonal rivers, streams and springs dried up during the intense and prolonged droughts.

**Table 4.17: Effects of Droughts of Varying Characteristics on Rivers, Streams and Springs (1980 - 2009)**

| Drought Year(s) | Drought Duration (No of Years) | Average Drought Intensity(% Below the Long Term Mean) | Type of Water Resources Affected | | |
|---|---|---|---|---|---|
| | | | No. of Rivers | No. of Streams | No. of Springs |
| 1980 | 1 | 24.4 | 9 | 3 | 1 |
| 1984 | 1 | 52.0 | 11 | 4 | 2 |
| 1986 | 1 | 9.4 | 7 | 2 | 1 |
| 1992 | 1 | 0.2 | 4 | 1 | 0 |
| 1994-1996 | 3 | 5.2 | 5 | 4 | 1 |
| 2000-2004 | 5 | 48.3 | 11 | 4 | 2 |
| 2006 | 1 | 6.1 | 5 | 3 | 1 |
| 2008-2009 | 2 | 16.7 | 6 | 4 | 2 |

The respondents pointed out that the intense and prolonged droughts of 1984 and 2000-2004 led to drying up of about 100 percent of seasonal rivers, streams and springs in the sub-county. Therefore severe effects posed by drought of high intensity either directly or indirectly to the livelihood negatively affect seasonal rivers, streams and springs. This could be as a result of natural threats by drought directly to these resources or the pressure by inhabitants as a result of water scarcity in the sub-county. For instance, interviews revealed that during the 5-year drought of 2000-2004 and 1-year drought of 1984 all seasonal rivers which included Rivers Endao, Loboi, Weseges, Ol Arabel, Mukutani, Darajani, Chemeron, Subukia, Kapiswa, Loturo and Kapcheburet dried up. In addition, all the four streams namely; Cheptugen, Perkerra, Loboi and Endao dried up. The two springs Bogoria and Lorwai also completely dried up. During the 2008–2009 drought, about 54.5 percent of all seasonal rivers dried up. This included Rivers Loboi, Subukia, Kapiswa, Loturo, Mukutani and Darajani and all the four streams and springs dried up. This observation agrees with Marsh et al, (2007) assertion that in England and Wales, a 4-year drought of 2000-2003 led to drying up of many flowing rivers in the regions. Similarly, Qureshi and Akhatar (2004) noted that Helmand River in Helmand Province of Afghanistan dried up for the first time during the prolonged and intense drought of 1999-2001.

The study revealed that the effects of drought were majorly determined by the intensity of a drought. For instance, a 1-year drought of 1984 with drought intensity of 52.0 percent led to complete drying up of all seasonal rivers, streams and springs in sub-county compared a 1-year drought of 1992 with drought intensity of 0.2 percent which led to drying up of only four rivers which included Rivers Subukia, Kapiswa, Loturo and Mukutani, Loboi stream and there was no spring which dried up (Table 4.17). The study established that the 1984 drought not only affected water resources in the study area but also in the different parts of the country. In Laikipia District, Mukogodo Division Huho (2011) made an observation that the 1984 drought led to drying up of Ildupata and Ngaboli springs which had never rejuvenated again.

#### 4.4.2.1.2 Surface Water Resources; Dams, Water Pans and Ponds

The study established that man-made reservoirs such as dams, water pans and ponds were also affected by drought of varying intensities and durations in the study area. The respondents reported that over the decades (1980s, 1990s and 2000s) they have experienced drying up of dams. Table 4.18 shows the number of dams which dried up over the 3 decades.

**Table 4.18: The Number of Dams Dried up between 1980 and 2009**

| Drought Year(s) | Drought Duration | Drought Intensity | Dams that Dried up | Total Number of Dams in a Decade |
|---|---|---|---|---|
| 1980 | 1 | 24.4 | Sirinyo, chelaba | |
| 1984 | 1 | 52.0 | Sirinyo, Chelaba, Ruotik, Lowal, | 4 |
| 1986 | 1 | 9.4 | Ruotik, Lowal | |
| 1992 | 1 | 0.2 | Sirinyo, Chelaba, Ruotik, Lowal | |
| 1994-1996 | 3 | 5.2 | Ruotik, Lowal, Sirinyo, Chelaba, Kirandich, Ndambul, | 6 |
| 2000-2004 | 5 | 48.3 | Sirinyo Chelaba, Ruotik, Lowal, Kirandich, Ndambul, Sandai, Endao, Kimorok | |
| 2006 | 1 | 6.1 | Ruotik, Lowal | 9 |
| 2008-2009 | 2 | 16.7 | Sirinyo, Chelaba, Ruotik, Lowal, Kirandich, Ndambul, Sandai, | |

The household data revealed that more dams dried up in 2000-2009 decade compared to 1980s and 1990s. In 1980-1989 decade on average, 4 dams dried up. The number rose to 6 and 9 in 1990-1999 and 2000-2009 decades respectively. This suggests that the longer the drought persists, the more the water level in the reservoir reduced and finally dries up. The reason behind this could be as a result of cumulative effects associated with every drought episode by which at the end, some significant effects would be greatly noted in the reservoir. For instance, in 1980s, the intense drought of 1984 led to drying up of 4 dams which included: Sirinyo, Chelaba, Ruotik and Lowal dams. In 1990s a 3-year drought of 1994-1996 led to drying up of 6 dams. These were

Ruotik, Lowal, Sirinyo, Chelaba, Kirandich and Ndambul dams. In 2000 decade a 5-year drought of 2000-2004 led to drying up of up to 9 dams in the study area. The most affected dams were Sirinyo, Chelaba, Ruotik, Lowal, Kirandich, Ndambul, Sandai, Endao and Kimorok dams. The study revealed that drying up of the dams in the study depended on duration of the drought. For example, a 5-year drought of 2000-2004 led to drying up of 9 dams compared to a 3-year drought of 1994-1996 which led to drying up of 6 dams. Similarly, in India, a 4-year drought of 1987-1990 led to completely drying up of 40 dams whereas a 2-drought of 1983-1984 led to partial drying up of 20 dams causing severe water shortage for livestock herders (Nathan, 2001).

The water pans and ponds in the study area were also vulnerable to all notable droughts that were mentioned by the respondents. El-Maine and Flower ponds situated in Salabani location dried up during dry periods. The respondents attributed to soil sediments accumulated in these water bodies especially during every drought episode as a result of many livestock surrounding the water point. This means that ponds are reservoirs with low storage capacity and are not protected such that during drought the animals access them. Mogaka et al. (2006) asserted that capacity storage of water reservoirs in ASALs areas in Kenya were affected by sedimentation resulting from constant livestock trampling around the water point during dry periods.

The household data revealed that drought of high intensity and long duration in the sub-county led to complete drying up of water pans whereas drought of low intensity and short duration led to partial drying up of water pans. Table 4.19 show the effects of droughts of varying intensity and duration on the water pans in the study area.

**Table 4.19: Effects of Drought of Varying Characteristics on Water Pans in Sub-County (1984 -2009)**

| Drought Year | Drought Duration (No. of Years) | Drought Intensity(% Below the Long Term Mean | Complete Drying up of Water Pans | Partial Drying up of Water Pans |
|---|---|---|---|---|
| 1984 | 1 | 52.0 | Kinyach, Chebowen, Mollem, Iti and Kokchatenin | None |
| 1994-1996 | 3 | 5.2 | Chebowen, Mollem, and Kokchatenin | Kinyach and Iti |
| 2000-2004 | 5 | 48.3 | Kinyach, Chebowen, Mollem, Iti and Kokchatenin | None |
| 2008-2009 | 2 | 16.1 | Chebowen, Mollem, Iti and Kokchatenin | Kinyach |

Analysis using the data from Table 4.19 revealed that a 3-year drought of 1994-1996 drought with an average drought intensity of 5.2 percent below the long term mean led to partial drying up of Kinyach and Iti water pans while a 5-year drought of 2000-2004 with an average drought intensity of 48.3 percent below the long term mean led to complete drying up of all water pans in the study area. This is attributed to significance changes in water pan reservoirs with the cumulative effects of different drought episode which persisted in the study area. This could be explained that water pans in the study area dried up when a drought of very high intensity was followed by another drought of high intensity. This agrees with Serna (2010) assertion that a 2-year drought of 2008-2009 in northern parts of Kenya led to drying up of about 99 percent of the water pans in the region. Similarly, In California, Fall (2012) asserted that a 4-year drought of 2000-2003 with an average intensity of 51.1 percent below long term mean led to complete drying up of water pan reservoirs in the region resulting in increased demand of water from Colorado River System.

The study established that not only the prolonged drought of high intensity resulted in drying up of all water pans in the sub-county but also a short duration drought of high intensity. For instance the 1-year drought of 1984 with drought intensity of 52.0 percent below the long term mean resulted in drying up of all 5 water pans in the sub-county namely; Kinyach, Chebowen, Mollem, Iti and Kokchatenin. This implies that a drought could be very intense such that its associated effects might be equally the same as for drought which persisted for a very long time. The finding agrees with Schwabe and Jeffery (2010) observation who noted that the intense and severe drought of 2002 led to 90 percent of water pan reservoirs in the semi-arid region of Arkansas.

#### 4.4.2.2 Water Levels in Surface Water Resources

The household data revealed that 17 percent of the respondents mentioned reduction in water levels as one of the effects of drought on surface water resources in the sub-county (Figure 4.9). The study established that water levels and size of section of Lake Baringo falling under Marigat Sub-County reduced during different drought episode. This was attributed to persistence of droughts resulting to drying up of rivers feeding the lake. The respondents mentioned Rivers; Ol Arabel, Darajani, Mukutani and Weseges that they drained directly into the lake whereas Rivers; Loboi, Kapiswa Chemeron, Endao, and Subukia, and streams; Cheptugen, Perkerra, Endao and Loboi feed Rivers; Perkerra and Molo. Drying up or decrease flow in these rivers leads to decrease in lake size and water levels. The findings agrees with Coe and Toley (2001) observation that the prolonged drought of 1997-2000 led to reduction in water levels in Lake Chad following the drastic decrease flow of River Chari and River Logone which provide the largest percentage to the lake water. Similarly, in northern slopes of Zomba and Mulenje Massif, Malawi, where the 3-year drought of 1983-1985 affected all seasonal rivers and streams in the region resulting to gradual discontinuous flow of all perennial rivers draining to Lake Chilwa (DeBano, 1999).

The study analyzed satellite images for selected years, these years were selected because their drought intensities were more than 50 percent rainfall below the long term mean rainfall. The drought year 1984 was considered as a base year for comparing with the drought years of 2000 and 2002 (Table 4.20).

**Table 4.20: Drought Intensities for the Selected Drought Years 1984, 2000 and 2002**

| Drought Year | Drought Intensity(% Below the Long Term Mean) |
|---|---|
| 1984 | 52.0 |
| 2000 | 54.4 |
| 2002 | 57.8 |

(Source: Analyzed Meteorological Data, 2014)

The data in Table 4.20 together with the satellite images for the years 1984, 2000 and 2002 (Plates 3a, 3b and 3c respectively) revealed that the effects of drought on the Lake Baringo shores vary with the drought intensity. Plates 3a, 3b and 3c show sections of the lake shores where lake water had receded during droughts of different intensities.

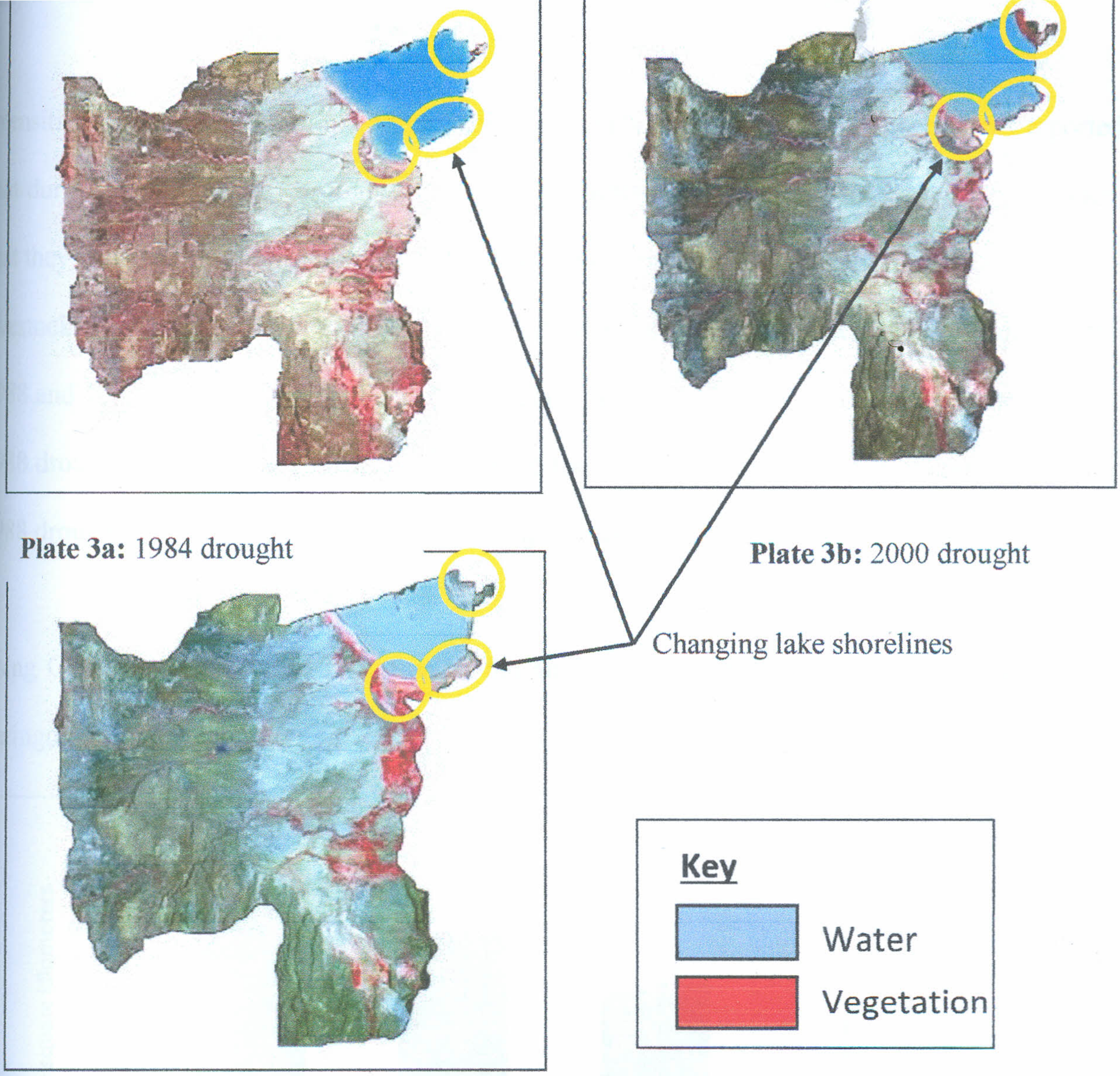



**Plate 3a:** 1984 drought

**Plate 3b:** 2000 drought

**Plate 3c:** 2002 drought

**Plates 3a, 3b and 3c: Changes in Lake Shorelines during Drought of Varying Durations**
(Source: http://glovis.usgs.gov/, Downloaded on: 21/11/ 2014)

The study used false color composite in the above satellite images in the presentation of the land cover. For example, red color represents vegetation while blue color represents water. Analysis using the satellite images revealed that the lake shorelines changed from one drought event to the other. The waters receded with increasing drought intensity. More recession was experienced during the 2002 drought (Plate 3c) when the drought intensity was 57.8 percent rainfall below the long term mean rainfall compared to 2000 (plate 3b) and 1984 (Plate 3a) droughts when the intensities were 54.4 percent and 52 percent respectively (Table 4.20). The respondents reported that during the 2000-2004 drought, the amount of water in Lake Baringo reduced to an extent that they could move about 1 kilometer from the lake shoreline into the lake to get water for their livestock. In Malawi, DeBano (1999) observed changes in Lake Chilwa shoreline during the 1988 and 1992 drought. During the 1992 drought which was considered to be more extreme than 1988 drought, the distance from the shoreline to the water in the lake increased compared to the 1988 drought which showed insignificant change in distance.

Using GIS ArcMap Version 10 software, the study delineated the size of the section of Lake Baringo that was falling under Marigat Sub-County (Figure 4.11).

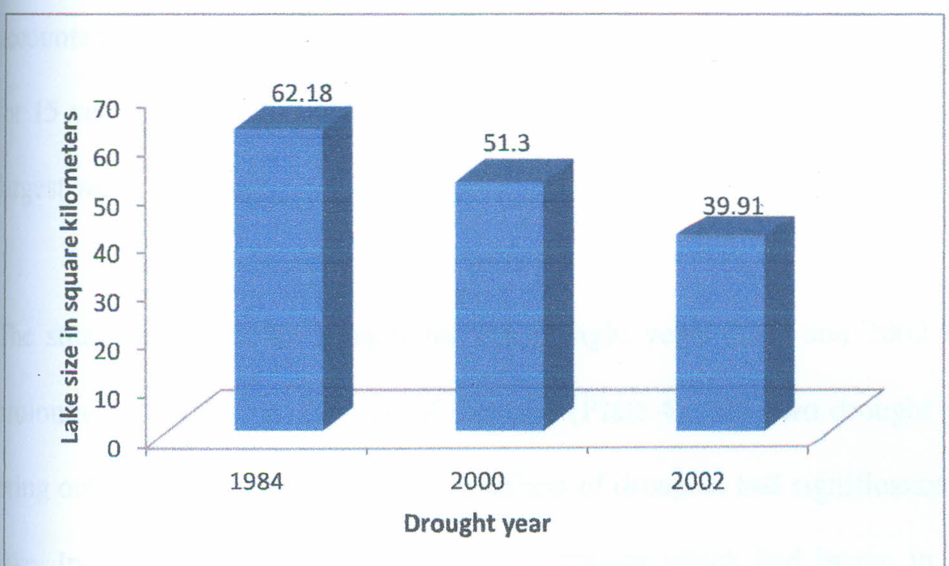



**Figure 4.11: Changes in Lake Baringo Size during Different Drought Years**

(Source: Delineated Landsat Images; http://glovis.usgs.gov/, Downloaded on: 21/11/ 2014)

The study revealed that the reduction in the size of Lake Baringo was determined by the intensity of the drought. For instance, during the 1984 drought with drought intensity of 52 percent below the long term mean the size of the lake was 62.18 square kilometers (Figure 4.11). During the

2002 drought with drought intensity of 57.8 percent below the long term mean the size of the lake was 39.91 square kilometers (Figure 4.11). This implies that the higher the drought intensity, the more the size reduction of the lake. In this case, the lake experienced a size reduction of 35.8 percent between 1984 and 2002. This study indicates that the lake size had been decreasing over the decades. The most probable reason for the decline in lake size could be frequent occurrence of high intensity droughts and abstraction in rivers for irrigation uses draining into the lake. These findings were in line with Coe and Toley (2001) observation made on Lake Chad that between 1966 and 1975 the lake decreases by 30 percent, out of this percentage, abstraction of water for agricultural purposes accounted for 5 percent while droughts accounted for 25 percent. Similarly, Pang (2014) analyses NASA satellite images for Lake Mead for 15 years and pointed out there was a dramatic change in water levels and size of America's largest water reservoir.

The study used satellite images for the drought years 2000 and 2002 to show the effects of prolonged droughts on the size of the lake (Plate 4). The two drought years were selected to bring out the scenario that cumulative effects of droughts had significance impacts on the size of lake. In this case, by the year 2002, the drought which had begun in 2000 had lasted for 3 consecutive years and noticeable changes in the lake size could be recognized.

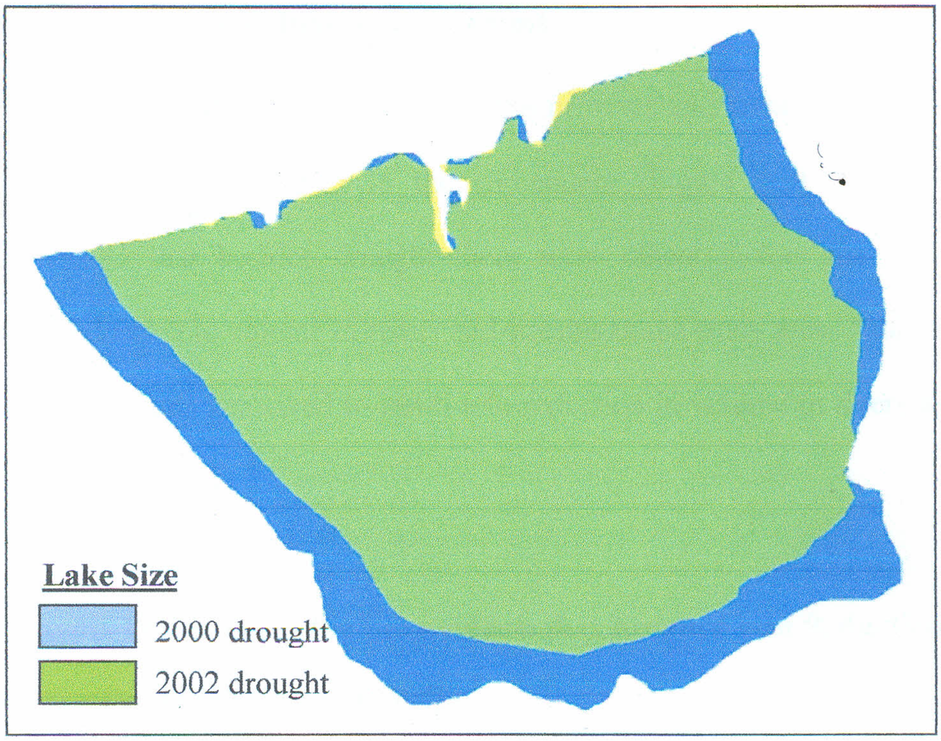



**Plate 4: Lake Baringo Sizes During the 2000 And 2002 Droughts** (Source: http://glovis.usgs.gov/, Downloaded on: 21/11/ 2014)

Analysis using plate 4 revealed that the images of 2000 (drought intensity of 54.4%) and 2002 (drought intensity of 57.8%) demonstrated a noticeable reduction (of about 22.2 %) in the lake sizes from 51.3 square kilometers in the year 2000 and to 39.91 square kilometers in year 2002. This explains that the more the drought of high intensity prolonged, the more the significant effects are noted i.e. the size of the lake here is clearly seen to have declined within the 3 consecutive drought years of 2000-2002. The findings were in line with Urama and Ozor, (2010) observation on decline in Lake Chad lake size from 10,000 square kilometers in 1998 to 1,500 square kilometers in 2010 about 85 percent reduction in the lake size. The decline was attributed to prolonged droughts experienced between 1998 and 2010 in North central parts of Africa.

### 4.4.2.3 Reduction in Volume in Rivers and Streams

The respondents indicated that reduction in volume in rivers and streams is one the effects of drought on surface water resources in the sub-county (Figure 4.9). Interviews with the respondents revealed that besides drought there were others factors that the respondents attributed to the reduction in volume in rivers and streams in the study area. Table 4.21 show the factors that the inhabitants perceived to result into reduction in volume in rivers and streams in the sub-county.

**Table 4.21: Factors Perceived by the Respondents that Resulted into Reduction in Volume in Rivers and Streams (1980-2012) (N=368)**

| Factors Resulting into Reduction in Volume in Rivers and Streams | Frequency | Percent (%) |
|---|---|---|
| Drought | 132 | 36 |
| Siltation | 59 | 16 |
| Increased in water demand for irrigation | 114 | 31 |
| Destruction of catchment areas | 63 | 17 |
| **Total** | **368** | **100** |

The household data in Table 4.21 revealed that 36 percent of the respondents perceived drought to be one of the factors that led to the reduction in volume in rivers and streams in the sub-county. The respondents indicated that the volume flow of River Perkerra depends on the seasonal rivers such as Endao, Kapiswa and Chemeron, and streams including Cheptugen and Perkerra which feds it. The respondents pointed out that during droughts especially the prolonged droughts the seasonal rivers and streams in the sub-county dried up resulting into the low flow of River Perkerra which in turn affects the water levels in Lake Baringo. For instance, the 5-year drought of 2000-2004 led to drying up of all 11 seasonal rivers and 4 streams in the sub-county. This means that seasonal rivers and streams in the study area are affected by severe and prolonged droughts. Similarly, in other parts of the world, droughts have been noted to reduce the flow of the perennial rivers. For instance, the drought of 2000-2004 in United States led to low flow of the Colorado River which drains into Lake Powell (Jacobs, 2011). In North America, the recession of Lake Mead by 20 percent of its former volume was attributed to the extreme drought of 1984-1985 which resulted into low flow of the rivers draining into the lake (Pang, 2014)

The assertions made by the respondents were confirmed by the analyzed hydrological data for River Perkerra discharge. Analysis using water discharge for the last 6 years of continuous data from Marigat Bridge Station (2EE7B) (WRMA, 2014) revealed that drought of varying intensity resulted in different discharge flow of the river (Table 4.22).

**Table 4.22: The Relationship between Drought Intensity and River Discharge**

| Year | Drought Intensity | River Perkerra Discharge (cusec) |
|---|---|---|
| 2006 | 6.1 | 9.16 |
| 2008 | 19.7 | 1.18 |
| 2009 | 13.7 | 0.56 |
| 2010 | 2.3 | 13.51 |
| 2011 | 9.5 | 4.76 |
| 2012 | 12 | 6.67 |

Correlation Coefficient (r) = -0.90

Pearson's Product Moment Correlation Coefficient (r) was used to analyze the relationship between drought intensity and river discharge of River Perkerra. The study established a negative relationship. The correlation coefficient (r) was -0.90. The negative correlation coefficient value showed that the higher the drought intensity, the lower the river discharge flows. Further calculations of Coefficient of Determination ($R^2$) revealed that a reduction of 81 percent in river flow could directly be as a result of increase in drought intensity whereas 19 percent could be attributed by other factors increased in water demand for irrigation, siltation and destruction of catchment areas.

Data from Table 4.22 revealed that droughts of high intensity resulted to very low river discharge compared to the droughts of less intensity. For example, during 2008 drought of drought intensity (19.7 percent rainfall below the long term mean rainfall), the river discharged 1.18 cusec compared to 2010 drought of drought intensity (2.3 percent rainfall below the long term mean rainfall) which resulted in river discharge of 13.51 cusec. The study also established that cumulative effects of drought affect the river discharge. For instance, though the drought intensity of 2009 was less than the 2008 drought intensity, the river recorded lower discharge in 2009 compared to the 2008 drought; this was as a result of cumulative effects from the preceding year. This suggests that permanent water sources relatively respond to the long-term droughts compared to response to the drought of high intensity. This is because as the drought persists its effects accumulate and finally changes can be noted in the permanent water sources.

The analyzed hydrological data showed similar results with the major River Missouri in North America, the low river discharge during 2000 drought which was considered as less intense compared to the 1999 drought was attributed to the previous severe impacts following the 1999 drought (MDRP, 2002). These findings are also consistent with Vliet and Zwolsman (2008) findings that during the year 2003, there was extremely low discharge in River Meuse in Western Europe as a result of continuous drought which began on 2001-2003 compared to the year 2001 which was characterized by high intensity but the river discharged was relatively higher than the year 2003.

Siltation was one of the factors perceived by the respondents resulting in reduction in volume in rivers and streams. The respondents reported that water point areas such as along River Perkerra, Arabel and Loboi Swamps and the shores of Lake Baringo in the sub-county suffer from siltation. This scenario could be attributed to the excessive trampling of livestock near the water points during dry season which will result into lose soils that can easily be swept by wind into surface water sources. The finding agrees with Mwandera (1997) that surface water reservoirs such as rivers in Borena, Ethiopia were silted as a result of livestock grazing in the water point areas. Similarly, Leeuw and Reid (1995) pointed out that overgrazing in water point areas adversely affects soil properties which results in reduced infiltration, accelerated run-off and soil erosion.

Increased in water demand for irrigation was also one of the factors resulting into volume reduction in rivers and streams in the study area. The respondents pointed out that Community-Based Irrigation Projects had increased in number over the decades. Table 4.23 shows the number of Community-Based Irrigation Projects established during the 2000 decade and 1990s and 1980s.

**Table 4.23: Existing Community-Based Projects in the Study Area**

| Decade(s) | Community-Based Irrigation Projects | Total Number |
|---|---|---|
| 1980s and 1990s | Eldume, Sandai, Kapkuikui, Salabani and Kamoskoi | 5 |
| 2000s | Eldume, Sandai, Kapkuikui, Salabani, Kamoskoi, Embosses, Musiro, Ilmaine and Nyoro | 9 |

Data in Table 4.23 shows that the number of Community-Based Irrigation Projects increased from 5 in the 1980s and 1990s to 9 in the 2000 decade. The respondents reported that the Community-Based Irrigation Projects entirely depend on surface water resources for irrigation in the sub-county. Such increased of Projects increased the water demand for irrigation. The study established that many of the projects were established in Marigat, Ilingarua, IlChamus, Loboi, Sandai, Kapkuikui and Ngambo Locations. The respondents reported that they abstract water for irrigation form Rivers Perkerra, Loboi, Molo, Subukia and Chemeron. The rise in number of Community-Based Irrigation Projects could be due to increased drought occurrences in the study area. Therefore, the inhabitants are adopting farming as alternative source of livelihoods as a result surface water sources are negatively affected. Similarly, in most ASALs areas of the world, reduction in volume in rivers and lakes are strained by demand of agriculture as droughts forced people to practice agriculture through irrigation. Venot et al. (2007) asserted that reduction in flow volume of water in Rivers; Yarmouk, Zarqa and Jordan in the ASALs areas of Hashemite Kingdom of Jordan resulted from 80 percent irrigated agriculture in the region. Akivaga et al, (2010) observed that River Perkerra in Baringo County had experienced low flow as a result of current abstractive uses in Perkerra Irrigation Scheme and other self- projects.

Destruction of water catchment area was another factor perceived to result in reduction in volume in rivers and streams. The respondents reported that most of the rivers in the sub-county originate from highlands where cultivation is the main source of land use activity. This means that land use activities in the upper catchment negatively affect the flow of rivers and streams in the lower catchment area. A study by Wasonga et al. (2011) also noted that rivers flows in the lower catchment of River Perkerra (which drains a catchment area of 1207 kilometers) decreased as a result of over-abstraction of water for irrigation in the upper catchment areas. These findings also agree with Vagheti et al. (2013) findings that there was a significant low flow of rivers and streams in the lowland parts of southeastern Australia, as a result of unregulated water abstraction for crop spraying and irrigation in the upper parts of the region.

The effect of droughts on water resources in the sub-county was measured on the distance travelled by the inhabitants to access water for both domestic and livestock use. Table 4.24 shows the average distance covered by the inhabitants during droughts of varying characteristics.

**Table 4.24: Distance Travelled by Inhabitants during Different Droughts Episodes (1980-2012)**

| Drought Year(s) | Drought Duration (No of Years) | Average Drought Intensity | Average Distance Travelled to Water Points (km) |
|---|---|---|---|
| 1980 | 1 | 24.4 | 20 to 30 |
| 1984 | 1 | 52.0 | 20 to 30 |
| 1986 | 1 | 9.4 | 5 to 10 |
| 1992 | 1 | 0.2 | Less than 5 |
| 1994-1996 | 3 | 5.2 | 5 to 10 |
| 2000-2004 | 5 | 48.3 | 20 to 30 |
| 2006 | 1 | 6.1 | 5 to 10 |
| 2008-2009 | 2 | 16.7 | 10 to 20 |

Data from Table 4.24 shows that the distance to the water point increased with increase in drought intensity and duration. For instance, data from the household interviews revealed that during the 5-year drought of 2000-2004, inhabitants of Kimalel, Kimondis and Elwalel-Soi Locations travelled an average distance of 20-30 kilometers to access water in River Perkerra where there was still water for their animals and parts of Lake Baringo unlike during rainy season where they travelled less than 2 kilometers to access water in their respective locations. This means that droughts of low intensity and short duration result in short distance travelled by the pastoralists to access water whereas droughts of high intensity and long duration result in long distance travelled by the pastoralists to access water for their livestock. Observation from other parts of the country indicate that pastoralists in the semi-arid of northern Kenya were forced by a 2-year drought of 2008-2009 to trek more than 20 kilometers to secure water for their livestock were in line with the findings (Serna, 2010).

# CHAPTER FIVE

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Summary

Droughts in Marigat Sub-County are historic events which have been occurring over the years. The effects of droughts are determined by its dynamics, for instance duration and intensity. To understand the effects of drought dynamics on vegetation cover and water resources, the study examined the effects of drought duration and intensity in Marigat Sub-County of Baringo County, Kenya.

The findings of this study were analyzed based on decadal period. For instance, the 1980-1989, 1990-1999 and 2000-2009. Droughts years alongside duration and intensity were depicted from rainfall data collected from Kenya Agricultural and Livestock Research Organization (KALRO) Perkerra Meteorological Station. Marigat Sub-County being located in the ASALs areas of Kenya, frequent occurrence of droughts of different intensities and durations are experienced in the area. Between 1980 and 2012, the sub-county recorded 18 drought years out of 33 years. The intensities and durations of these droughts varied from year to year. Drought intensity ranged from 0.1 to 57.8 percent rainfall below the long term of 563.7mm rainfall in the sub-county whereas drought duration ranged from 1 to 5 years.

Vegetation cover mainly comprised of trees of different acacia species, grasses and shrubs. In the highlands parts of Tugen Hills, vegetation cover are sparse while in the lowlands (Njemps flats), vegetation cover are dense along River Perkerra, Kaptich and Ilupunyaki forests. The rate of vegetation cover had been noted by the inhabitants to have changed over the decades. Droughts of varying intensities and durations have both direct and indirect effects on vegetation. Direct effects of drought on vegetation cover led to depletion of grasses, tree cover and shrubs. Indirect effects exacerbated by droughts included: overgrazing, charcoal burning as alternative source of livelihood and change in land use activity these have led to depletion of vegetation cover in the sub-county. The prolonged and intense drought of 2000-2004 in the study area led to increased bare ground in most parts of the sub-county especially where the surface of the earth was largely rocky.

Surface water was the main sources of water in the study area. Most households accounting for 54.4 percent relied on rivers and streams for both households and livestock. Surface water resources in the sub-county were also affected by droughts of varying intensities and durations. Droughts led to drying up of surface water resources such as seasonal rivers and streams, dams, ponds, water pans, springs and swamps, reduction in volume of water in River Perkerra and Lake Baringo. Alongside droughts, there were other factors perceived by the respondents to be exacerbated by drought affecting the water resources. These included; siltation, increased demand of water for irrigation and destruction of catchment area. Abstraction of water for irrigation had increased over decades. Since the year 2000 several Community-Based irrigation Projects and self-farms irrigation have been established in the sub-county resulting to usage of water in both seasonal and permanent rivers.

## 5.2 Conclusions

Drought duration in Marigat Sub-County showed increase in terms of persistence. The 1980s droughts lasted for one year while 1990s recorded droughts spanned up to 3 years and 2000s droughts spanned up to 5 years. The intensities of the analyzed drought years revealed that drought intensity varied from one drought episode to the other. For instance it ranged from 0.1 percent below the long term mean in 1994 to 57.8 percent below the long term mean in 2002.

Vegetation cover in Marigat Sub-County was drought intensity and duration dependent. The higher the drought intensity and the longer the duration the more the vegetation cover depleted and vice visa. The use of acquired satellite images for different drought years with varying intensities and durations revealed that vegetation cover in sub-county respond depending on magnitude of these characteristics. The study also revealed that droughts indirectly exacerbated other factors such as: over-grazing, change in land-use activity and charcoal burning as alternative source of livelihoods. These factors led to depletion of vegetation cover in the study area.

Water resources were also affected by drought of varying intensities and durations. The study concluded that permanent Rivers Perkerra and Molo, Lake Baringo and Chemeron dam which is the largest man made reservoir in the study area reduced in amount water volume whereas seasonal rivers and other surface water sources dried up during drought of high intensity and long duration.

## 5.3 Recommendations

1. Proper understanding of specific effects of drought of varying durations and intensities should be precondition for drafting drought policy to enhance planning strategies and preparedness that are applicable, reliable, sustainable and cost effective.
2. The relevant research institutions to develop more palatable grasses which are drought tolerant, in case of intense and prolonged droughts they are quick to regenerate.
3. Due to high rate of evapotranspiration, sand dams should be enhanced in the sub-county.

## 5.4 Areas for Further Research

The study suggest further research on suitable grasses that are drought tolerant and usefulness of sand dams in Marigat Sub-County.

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