THE IMPACT OF CLIMATE VARIABILITY ON PASTORALISM:

Forage Dynamics and Trends in Cattle Population in Kajiado County, Kenya

BY

OMBOGO MESHACK OPOLE

Research Project submitted in partial fulfillment for the requirement of Masters of Arts Degree in Climatology in the Department of Geography and Environmental Studies, University of Nairobi.

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DECLARATION

This research Project is my original work and has never been submitted for a degree award in any University.

____________________________ Date:………………/2013

Meshack Opole Ombogo

(C50/73762/09)

This Research Project has been submitted for examination with my approval as the University Supervisor.

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Mr. Isaac J. Ndolo

Department of Geography and Environmental Studies

University of Nairobi

Date:…………../2013

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ABSTRACT

The study was conducted to determine the influence of climate variability on pastoralism in Kajiado County of Kenya. Since pastoralism encompasses several components, the research limited its focus only to two aspects namely; forage and cattle production – further narrowed to cattle population. Rainfall data from Ngong Divisional Office, Mashuru and Magadi Soda Works Meteorological Stations were factored in as climate variability parameter. Specifically, the project aimed to; determine the existence and level of climate variability in Kajiado County, identify forage change and examine the change dynamics relative to rainfall characteristics, and determine the relationship between climate variability and cattle population in the study area.

Input data were organized in excel and analyzed using Statistical Package for Social Scientists (SPSS). Standard deviation, mean, range and coefficient of variation (C.V.) were calculated for rainfall data for the three Meteorological stations over the period 1964 - 2011. Data on annual cattle population gathered from Kajiado District Veterinary Office for the period 1979 – 2009 was regressed and correlated against annual rainfall totals over the same period. Data on forage levels for the period 1982 – 2004 was processed in the form of Normalized Differential Vegetation Index (NDVI) for sampled areas within the four ecozones. Time series of these data were then averaged into dekadal means and annual averages then regressed and correlated with corresponding rainfall data at lags 0 and 30days.

Findings for this research suggested that rainfall over Kajiado had overtime revealed high variability both spatially, seasonally and inter-annually. Spatial variations revealed that Mashuru to the East had exhibited higher variability (C.V. = 26%) compared to areas around Ngong in the North (C.V. = 24%) and areas around Lake Magadi in the West (C.V=21%). Similarly, there was higher variability during the short-rain seasons as compared to long-rain seasons over the three stations. The results indicated that forage indices were strongly related to rainfall amounts at Magadi Soda Works Meteorological Station, accounting for 74% of forage at onset and 92% at peak vegetation performance, while at Mashuru Meteorological Station it accounted for

48% at onset and 89% at its peak. Annual Cattle population was found not to have significant association with annual rainfall amounts at the three stations thus annual rainfall totals alone was concluded not to be a good predictor of annual cattle performance.

The study was limited by unavailability of daily rainfall data for the three stations. It was also limited by unavailability of cattle population statistics – available only on annual census. The project thus recommended more frequent periodical livestock census, more weather monitoring infrastructure be installed, formulation of policy based pastoral management system, and enhanced climate and pastoral education.

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LIST OF ACRONYMS

IPCC	- Intergovernmental Panel on Climate Change
WMO	- World Meteorological Organization
GOK	- Government of Kenya
AR4	-Fourth Assessment Report
WG2	-Working Group II
TLU	- Tropical Livestock Unit
NDVI	- Normalized Differential Vegetation Index
NIR	- Near Infra- Red
ILCA	- International Livestock Centre for Africa
ASARECA	- Association of Strengthening Agricultural Research in Eastern and Central Africa
C.V	- Coefficient of Variation
ENSO	- El'Nino Sothern Oscillation
PANESA	-Pasture Network for Eastern and Southern Afric

CHAPTER ONE

1.0. INTRODUCTION

1.1. Study Background

Climate Change and variability creates risks in many climate sensitive sectors such as agriculture, vegetation, livestock, water resources and health, with its extremes affecting mostly the welfare and livelihoods of rural populations. While Climate Change is defined as the difference between long term mean values of a climate parameter of statistics - where the mean is taken over a specified interval of time; usually a number of decades, climate variability includes the extremes and differences (usually termed anomalies) of monthly, seasonal and annual values from the climatically expected value (temporal mean), World Meteorological Organization 1988. Among the climate parameters that have exhibited a shift in both short and long-term trends are rainfall and temperatures. These two have impacts upon the terrestrial waters, atmosphere, cryosphere, and biosphere resulting into phenomena such as the abnormal rainfall regimes, droughts, floods and changes in species composition in various ecosystems. These changes have lead to competition among organisms and human adjustments in a bid to cope. Confirming this, Intergovernmental Panel on Climate Change (IPCC 2001) noted: '*Present recording of an increase in drought, flood, windstorms and other extreme climate phenomena will negatively affect water resources through reduced freshwater availability*'. '*For the afflicted populations, competing needs for water for domestic livestock and crops will further exacerbate access to dwindling supplies from degrading water catchments, drying underground reserves, and declining precipitation*'.

Developing countries are among the high climate variability risk prone nations. Their vulnerability to climate change and variability comes both from being predominantly located in the tropics, and from various socioeconomic, demographic, and policy trends limiting their capacity to adapt to change (Forton 2007). Arid and Semi-Arid Lands (ASALs) are particularly vulnerable because of the dominance of pastoralism and rain-fed rather than irrigated agricultural food production systems, and if the conditions continue as they are, then the impacts of increased temperature from global warming and reduced and variable precipitation resulting from climate change and variability are expected to further depress marginal land that is currently under crop production and livestock grazing. In Africa, high levels of vulnerability and low adaptive capacity have been linked to factors such as limited ability to adapt financially and institutionally, low per capita gross domestic product (GDP) as well as high poverty rates. And although there are uncertainties about the future climate, it is necessary to explore how sensitive environmental and social systems and economically valuable assets are to climate change (Hulme *et al.*, 2001).

Pastoralists constitute about 13% of Kenya's 30 million people (Government of Kenya, 1999 population census), with livestock as their major source of livelihood and food security. As reported by Kenya Food Security Steering Group (2009) , Livestock production contributes 50 percent of all household incomes in Kenyan ASAL districts compared to marginal farming which contributes 30 percent. Davis (2007) breaks down this figure at 90% of employment in ASALs and more than 95% of family incomes and livelihood security. He notes in his economic valuation of pastoralism, that the system goes far beyond simple mode of livestock production, but also encompasses consumption systems that support a large global population and are natural resource management systems that support a wide range of services and products that are globally valued, such as bio diversity protection, tourism and raw materials.

In Kenya, pastoralists are found in all the arid districts and in some of the semi-arid – including the Southern Rangelands (Kajiado, Narok and Transmara), West Pokot and parts of Laikipia (Government of Kenya, Ministry of State for Development of Northern Kenya and Other Arid Lands, 2009). They (Pastoralists) provide a significant share (70%) of livestock to the country's market (GOK, 2009). The pastoralists herd their livestock in the ASALs, which constitute about 80% (ASAL National Vision and Strategy, 2005) of the country's landmass. These areas are home to extreme droughts. Rainfall variability largely drives vulnerability to climate change as it affects forage availability, livestock production and ultimately the livelihood of pastoralists. The increasing vulnerability of pastoralists' livelihoods to climate change results from the interaction of ecological, socio-economic and socio-political factors. An example not far from the study area as reported by Welfare Monitoring Survey in 2003 is that increasing poverty levels exacerbates drought vulnerability in pastoralist areas of northern Kenya (specifically in Turkana and Mandera districts) experiencing greatest poverty levels of 65%.

1.2. Statement of the Problem

Climate variability manifestations of fluctuating precipitation resulting to droughts and flooding have become more and more frequent in the recent past in Kenya, with pastoralists being the highest victims of this harsh natural calamity. As reported by mongabey.com on September 17, 2009; one good example is the 2008-2009 droughts in which pastoralists lost over 150,000 herds of cattle and close to 10 million people starved, a catastrophic event which gave Kenya a great focus during the Cop 15 (Fifteenth Conference of Parties) convention in Copenhagen in December 2009 as it was noted to be the most severe in 50 years (Stockholm Environmental Institute, Project Report-2009). An oscillation of the two extremes of droughts and floods in a repeated pattern leads to longer lasting effects of climate variability such as loss of biodiversity and desertification and their consequential impact on livestock and other forms of livelihoods. To make matters even more worrying is the observation that drought frequencies of one in four or five years have become common under current climatic conditions (Orindi *et al*., 2007).

Pastoralism plays an important role not only in the economies of the practicing societies, but also in the national economy as a whole. Pastoralists have practiced transhumance which was made possible by the abundance of land and low population levels of both human and livestock (Mung'ong'o and Mwamfupe, 2003), making it an effective way of utilizing these large tracts of land while maintaining its productivity through seasonal balancing of graze/browse thereby giving time for vegetation regeneration. This has made the system in-tune with the ecological realities of drylands where rainfall and grazing are subject to high risk of seasonal variability. This practice is however losing its sustainability as forage easily succumbs to forces of climate variability and change.

Kajiado County has always been affected by climate variability manifestations such as high fluctuations in rainfall amounts that have repeatedly hit the country in the past, and pastoralism as the main form of livelihood being affected most. Despite literature on livestock and forage response to climate variability increasing, most impact studies have not used time series data at the micro-spatial level to design an appropriate mitigation and/or adaptation model to counter the impacts. This situation thus calls for a proactive step by different stake holders to review pastoral management and sustainability aspects right from international, regional, national and down to district level. For this reason, this study aimed to assess the impacts of climate variability and change on pastoralism in Kajiado County where its main focus was to determine the level of climate variability and relate it to forage dynamics. To achieve this, the study attempted to answer the following research questions:

1) Is climate variability experienced in Kajiado County and what is the magnitude?
2) Are there changes in forage levels in response to climate variability?
3) How does cattle population respond to climate variability?

1.3. Research Objectives

The broader objective of this study was to determine the level of climate variability in Kajiado County and examine how it impacts on forage and cattle population. To achieve this, three specific objectives were formulated;

1) To determine the existence and magnitude of climate variability in Kajiado County.
2) Identify the forage change and examine the change dynamics relative to rainfall characteristics.
3) To determine the relationship between climate variability and cattle population in the study area.

1.4. Hypothesis

Out of the Research Questions and Objectives, the researcher formulated the following three hypotheses:

1) Climate variability does not exist in Kajiado County.
2) Forage does not change in response to climate variability in Kajiado County.
3) There is no significant relationship between climate variability and cattle population in Kajiado County.

1.5. Significance of the study

Africa is the most vulnerable to impacts of climate change and variability, IPCC (2007). In order therefore to mitigate and adapt to these effects, nations and societies have to identify and focus on the major sectors and regions within their territories in which vulnerability is high. Generally, ASALs fall in the category of ecosystems that are most fragile and that which may respond much to the negative if the phenomenon continues unabated. In Kenya, such lands form over 80% of the country and are inhabited by ten million people (ASAL National Vision and Strategy, 2005) - presenting enough basis for conducting this study, with Kajiado as a case. Back in the years, livestock populations in Kajiado rose sharply from the 1940s to the 1960s, due to increased availability of water and veterinary services (Western, 1986). However, there has been no further increase since the late 1960s due to a saturation of grazing lands. Rather, livestock populations have fluctuated with downward trends due to increased drought frequencies and desertification resulting from climate change, variability, and overstocking (Western, 1986).

This study is an essential step among the several attempts in trying to solve the problems of climate variability instigated fluctuations in forage and cattle numbers that has always led to hunger, famine, diseases, resource conflicts and death in ASALs. It will add knowledge to the existing libraries and publications that could be collated and analyzed in future to find an ultimate solution to the problem being assessed. The suggestions made herein will be a starting point or rather a clue to those interested in carrying out more researches along this line as this work outlines the gaps and limitations that can be covered by other researchers.

1.6. Scope and Limitations

Climate variability impacts are far and wide and affect different parts of the world depending on the prevailing physical, environmental, anthropogenic and economic factors. Among the major calamities arising from this phenomenon are; intense floods, frequent and prolonged droughts, pest invasions, increased cases of vector-borne diseases into areas previously free of them, destructive tropical storms, among others. Basically, the degree to which a given society is vulnerable to any of these events culminating is dependent upon its economic standards.

Among the pastoral communities of Africa, the main environ-economic challenge arising from climate change and variability is increasing frequency in abnormal rainfall regimes resulting in to El Niño like events on one end and droughts on the other. In this study therefore, the main focus would be on bellow and above normal rainfall, with the main variable being precipitation. It would have been more fruitful to factor in other aspects such as temperatures, demographic trends, geo-politics, governance, education, conflicts and other social factors, but due to time and resource constraints, assumptions would be made on some of these factors while others will be held constant. In terms of livestock data, it is difficult to gather reliable data on pastoral livestock populations, partly because of reluctance of herd owners to divulge such information, partly owing to the high degree of fluctuation in such herd and flock sizes, and the exorbitant cost of conducting time to time surveys. However, the government of Kenya through the ministry of Livestock and Fisheries Development has been able to conduct annual surveys mainly of cattle. This is the data that will be analyzed for the period 1979 to 2009. This too was however not detailed as it failed to separate data between different systems of cattle ranching and their corresponding production levels as management of rangelands and livestock in communal areas differ from commercial livestock ranching since livestock population in communal areas may respond differently to climate variability (Olaotswe 2006 citing Smet and Ward 2005). Spatially, not only Kajiado district faces climate variability but almost all pastoral districts in Kenya. It's however selected due to resource constraints and because it offers an almost ideal ground for investigating the study questions.

1.7. The Study Area

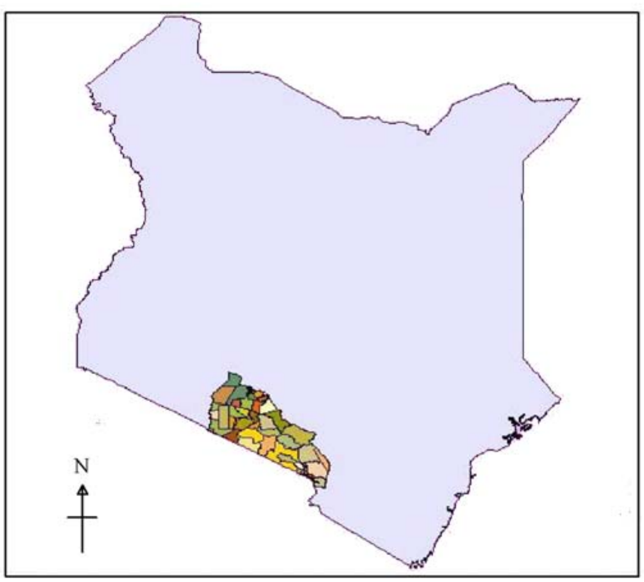
Location

The study area is located in the semi-arid southern rangelands of Kenya at an altitude ranging from 600m at the floor of Rift Valley, around Lake Magadi to 1,100m above sea level. Enclosed within longitude 36.0^0E – 37.8^0E and latitude 1.25^0S – 3.12^0S, it is bordered by the Nairobi-Mombasa railway to the north-east, Machakos County to the East, Nairobi National Park to the North, to the south is the Tanzania border, and the western wall of the Rift Valley to the West.

Administration, Population and Livelihoods

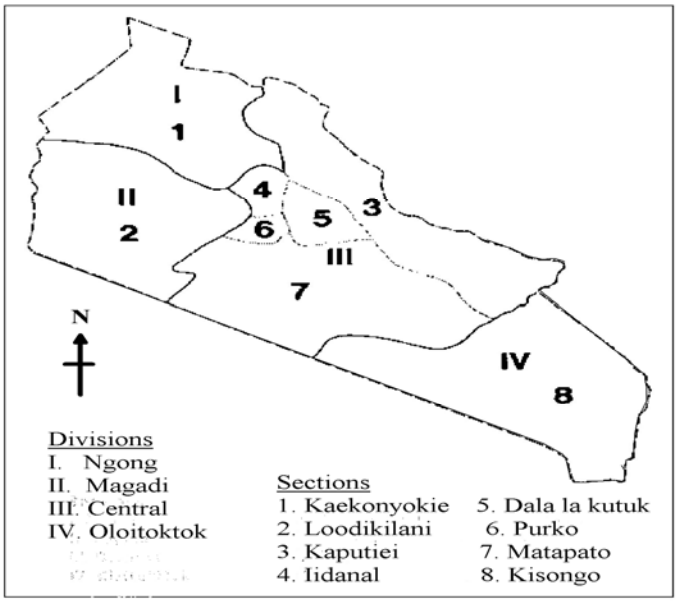
Administratively, the area is divided into four divisions namely: Ngong, Magadi, Kajiado Central and Oloitoktok, 120 sub-locations and three constituencies (GOK, 1999 population census report). These are the locations to be considered in this project as there are time to time changes in boundaries and creation of new districts within the existing ones.

Fig.1.0: *Map showing the administrative boundary of Kajiado County relative to the rest of Kenya. Kajiado ranches are shown in different colors.*



Source: *adapted from Bekure et al., 1991*

Fig. 1.1. Map of Kajiado County showing administrative Divisions and Maasai Sections.



Source: Adopted from Bekure et al., 1991

Kajiado county has an estimated population of 405,685 and an area of 21,902.9 km^2, translating to an average density of 19 persons per km^2 (GOK, Kajiado District: District Strategic Plan 2005 – 2010). The Maasai form the bulk of population by ethnicity but in many cases, they have deserted their former nomadic way of life and settled near water supplies where they are dependent on their cattle for livelihood (GOK, Kajiado District: District Strategic Plan 2005 – 2010), where they are now mostly organized into group ranches, owning 90% of the cattle in Narok and Kajiado Districts (Bukure *et al*, 1991). The District Strategic Plan indicates that from the censuses, the average population density has increased over the years from 4 to 7 to 12 to 19 per km^2 in the years 1969, 1979, 1989 and 1999 respectively. By 1999, the highest population density was in Ngong division (4.5 persons per km^2) and was expected to grow to 66 persons per km^2 in 2008, while the lowest density was 8 persons per km^2 in Magadi division and was expected to increase to 11 persons per km^2 in 2008 (GOK, Kajiado District: District Strategic Plan 2005 – 2010). The general population growth rate for the district is 4.5% per annum, and life expectancy at birth is 45 years (GOK, Kajiado District: District Strategic Plan 2005 – 2010).

Physiography

Kajiado County is divided into three main physiographical divisions namely; ground occupied by the basement system, the volcanic plains and the plateaux and the Rift Valley (Matheson 1966). These also form the ecozones of the Rift Valley, the upland Athi Kapiti Plains, the Central Hills, and the Amboseli Plains (GoK, 1982, Bekure *et al*. 1991).

The Rift Valley runs from north to south and is generally 5060 km long (Matheson 1966). The geology is predominantly quaternary volcanic. The floor of the Valley is step-faulted, and comprises a series of horsts running north and south with flat bottomlands between them. The numerous rocky scarps and slopes have shallow, reddish-brown, stony clay-loams. The bottom lands have deeper and more varied soils, including alluvial deposits. The broken and rocky terrain restricts access to much of this ecozone. Upland Athi-Kapiti Plains are mainly open rolling land that drains towards the Athi River basin in the east (Matheson 1966). Geologically, they derive from volcanics but there is a band of tertiary sediments running south-west to north-east across the centre of the plains. The soils are mostly deep black Vertisols (Matheson, 1966). Around Lake Magadi, almost all the rainfall is concentrated in two rainy seasons, March to April and in December, and often occurs as a result of isolated storms accompanied by strong winds from the east and north-east (Baker, 1958). The climate is hot and dry with moderate to low humidity, varying from 27 to 50 per cent of saturation (Baker, 1958).

Central Hills at the south-eastern edge of the Athi-Kapiti Plains is where the land falls away more steeply to the east. Numerous gneiss and limestone hills protrude from the slope, the largest, on the southern boundary, rising to 2800m (Matheson, 1966). Soils are red, sandy and often shallow. In the eastern part of the zone, the land is much dissected and divided by water courses that drain into the north-easterly flowing Kiboko River, a tributary of the Athi River (Matheson, 1966).

Amboseli Plains are divided into two distinct parts. The western half is geologically an extension of the basement system in the Central Hills (Matheson, 1966). It is an area of gently undulating plains with deep, reddish-brown clay loams and a variety of poorly drained Vertisols. In the eastern part of the plains the geology changes abruptly to quaternary volcanics with deep, well-drained soils, many of which are very rocky. In the western lee of the Chyulu Ranges much of the land is covered by lava flows. Most of the western part of the plains drains into the Kiboko River. The eastern plains drain south-eastwards into the headwaters of the Tsavo River.

Climate

Most of Kajiado County lies in the semi-arid and arid zones (Bekure *et al.* 1991). It is characterized by warm and hot climate with temperatures ranging between 20º C and 28º C with a mean of 25ºC (GOK, 2008). Only eight percent of its land is classified as having some potential for rain-fed cropping, mostly in the Athi-Kapiti Plains, close to Nairobi and in the south of the District, along the Kilimanjaro foothills (Bekure *et al.* 1991). Mean annual rainfall ranges from 300 to 800mm, while the average annual potential evapotranspiration ranges from 1600mm to 12200mm (GOK, 2008), which means there is moisture deficit for the greater part of the year. Rainfall is bimodal with short rains from October to December and long rains from March to May. The distribution of rainfall between the two seasons changes gradually from east to west across Kajiado District (Bekure *et al.* 1991). In eastern Kajiado more rain falls during the short rains than during the long rains while in western Kajiado the majority of rain falls during the long rains (Bekure *et al.* 1991). The rainfall pattern is also strongly influenced by altitude with the high areas around Loitokitok receiving high averages of 1,250mm while the low areas around Lake Magadi and Amboseli receive an average of about 500mm per annum (GOK, 2005). The temperatures also vary with altitude where the low laying areas record high temperatures of about 30 degrees (GOK, 2005). The rainfall of the region is partly related to the Inter-tropical Convergence Zone (ITCZ), with local variations in topography playing a major role in the distribution patterns (Brown and Cochem, 1973). Temperatures too vary from mean maximum of 34^0C around Lake Magadi to a mean minimum of 10^0C on the foothills of Mount Kilimanjaro and Ngong Hills (GOK, 2008).

Table 1.1**:** *Moisture availability zones in the Kenya rangelands***.**

Zone	**Classification**	**Moisture index (%)**	**Annual rainfall (mm)**	**Percentage of Kenya's land area**
IV	Semi-humid to semi-arid	40-50	600-1100	5
V	Semi-arid	25-50	450-900	15
VI	Arid	15-25	300-550	22
VII	Very arid	<15	150-350	46

Source: Adopted from Bukure et al 1991

Vast areas of the country's rangelands are very arid, accounting for 46%. In total, semi-humid to semi-arid, arid, semi-arid and very arid accounts for 88% of Kenya's rangelands, leaving only 12% of humid.

Table 1.2: *Distribution of agroclimatic zones in Kajiado County*

Agro-Climatic Zones	Average Area (Ha)
II to III	168,840
IV	717,570
V	1,160,775
VI	63,315

Source: GOK Kajiado District Annual Progress Report, July 2008-June 2009.

As shown in the table above, the bulk of the district is in Agro Climatic Zone V (55%) and VI (37%), which are semi-arid and arid respectively. The rest of the district falls in Agro Climatic Zone II, III and IV, accounting for a sum of only 8% of the county.

Table 1.3: *Distribution of agroclimatic zones in the four ecozones of Kajiado County*

	Percentage of ecozone land area in zone:			
Ecozone	**IV**	**V**	**VI**	**Total area (km^2)**
Rift Valley	7	71	23	6850
Athi-Kapiti	31	69		2040
Central Hills	14	69	27	4400
Amboseli	15	26	69	6270
Kajiado District	8	56	36	19560

Source: Adopted from Bekure et al., 1991

The table shows that the county is colonized by a total of 92% of ASAL ecosystems with only Athi-Kapiti ecozone free of arid patches. Rift Valley Ecozones lead in percentage of semi-arid lands (71%) while vast areas of Amboseli Ecozones are arid (69%).

Vegetation and Water Resources

According to Bekure *et al*.,1991, many woody species have been identified in the area but the predominant species in most parts of zones V and VI are *Acacia mellifera, Acacia tortilis, Acacia nubica, Acacia ancistroclada*, *Acacia nilotica, Commiphora riparia, Commiphora africana* and *Balanites aegyptiaca.* Less drought-tolerant species (e.g. *Combretum, Grewia* and *Premna)* are confined to zone IV. Open grasslands predominate in the Athi-Kapiti Plains and many parts of the Amboseli ecozones. Athi-kapiti plain receives low rainfall of 760mm and is dominated by the *Acacia-Themeda* associations (Kareri 2010). Bush and woodland are found mostly in the Central Hills and in the western part of the Amboseli ecozone. Forest is rare and mostly confined to isolated remnants on hill crests and on the lava flows in the Chyulu ranges. In areas around Lake Magadi, the vegetation is limited to stunted thorn bushes and small patches of grass, but watercourses are marked by lines of isolated trees (Baker, 1958). In the larger basins like the Koora plain, the plain east of Ol Doinyo Nyiro, and the Kwenia Swamp, which are the centers of small internal drainage systems, and in the low-lying ground adjacent to the Uaso Nyiro river, the soil tends to be dark and supports a more luxuriant vegetation (Baker, 1958). These dark soils are related to black cotton soil and exhibit large deep cracks when they dry up in the hotter months (Baker, 1958).

The main sources of surface water are the Uaso Nyiro River in the Rift Valley, two streams in the northern part of the Athi-Kapiti Plains, the Kiboko River, which drains much of the Central Hills and the northern part of the Amboseli ecozone, and several springs in the southern part of the Amboseli zone. Across Mashuru Division, vegetation varies from grasslands to dense wooded shrublands with a few patches of forest on the major hills (Macharia and Ekaya, 2005, citing Macharia *et al.*, 2001).

Climatic, geological and physiographic characteristics of this county are the core fundamentals that inform the kind of economic activities predominant in this area. The afore-described administrative boundaries have also been changing from time to time in line with legislations, for example, the previously known constituencies are currently transformed into districts. However, most of the information captured is mainly descriptive of Kajiado County, previously the greater Kajiado District.

Table 1.4**:** *Percentage of land area under vegetation of different types in the four ecozones of Kajiado County.*

Woody cover	**Percent of area**					
Percentage	**Vegetation type**	**Rift Valley**	**Athi-Kapiti Plains**	**Central Hills**	**Amboseli Plains**	**Total**
0 - 2	Open grassland	9	71	14	37	26
2 - 20	Wooded and bushed grassland	74		10		26
20 - 40	Bush and woodland	16	29	75	59	44
> 40	Forest and other types	1		1	4	2

Source: Adopted from Bekure et al., 1991

The table shows that most of the county is colonized by bush and woodlands while forest and other types of vegetation not described compose only 2%. Open grasslands, wooded and bushed grasslands, together forms the largest percentage (52%) combined and this, together with socio-cultural and climatic factors could be responsible for the pastoral activities predominant in the county.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Introduction

Researchers strongly believe that the current gradual rise in global surface temperatures is responsible for climate change variability catastrophes that have increasingly hit various parts of the world. As reported in the Highlights of National Academies Reports, 2008 edition, temperature readings from around the globe show a relatively rapid increase in surface temperature during the past century. In arid lands, a possible increase of 1–3°C is projected over the next 50 years due to a doubling of the carbon dioxide (CO_2) content of the lower atmosphere to 700 parts per million (p.p.m), as assumed by most scenarios stemming from General Circulation Models -GCM (Le Hou´erou, 1995). The predicted increase in temperature would most probably have the effect of increasing potential evapotranspiration rates in the drylands, and in the absence of any large increases in precipitation, many drylands are accordingly predicted to become more arid, a dynamic that will most probably lead to expansion of degraded lands. The global increase in potential evapotranspiration (PET) is projected to be some 75–225mm per year. The ratio of mean annual precipitation to PET would then decrease by about four to five percent, assuming that no substantial changes in rainfall took place in arid and semiarid lands (Le Hou´erou, 1995).

Sub-Saharan Africa for example is predicted to be particularly hard hit by global warming because it already experiences high temperatures and low (and highly variable) precipitation, the economies are highly dependent on agriculture, and adoption of modern technology is low (Kurukulasuriya and Mandelsohn, 2006). East Africa on its part appears to have a relatively stable rainfall regime, although there is some evidence of long-term wetting as a result of the high likelihood of increase in annual mean precipitation in the region (Christensen *et al*., 2007). This is not however uniform in all parts of the region, and even within countries there will be a great variability. Many of the impacts of climate change and variability will materialize through changes in extreme events such as droughts and floods with their resultant compounding effects materializing in socio-economic sectors such as health, agriculture, livestock raring and even trade.

2.2. Climate Change and Variability Scenarios

Since IPCC's first report in 1990, model projections have suggested global average temperature increases between about 0.15°C and 0.3°C per decade from 1990 to 2005. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) indicates that climate model projections for the period between 2001 and 2100 show an increase in global average surface temperature of between 1.1 and 5.4 °C, with varying model estimates depending on future trends in fossil-fuel emissions for the same period (Thornton *et al*., 2006). Observed values of about 0.2°C per decade, strengthen confidence in near-term projections (IPCC, 2007). Climate model simulations under a range of possible emissions scenarios suggest that for Africa, and in all seasons, the median temperature increase lies between 3°C and 4°C, roughly 1.5 times the global mean response(Christensen *et al*., 2007). Half of the models project warming within about 0.5°C of these median values (Christensen *et al*., 2007). Studies by Hulme *et al*., (2001) point out that climate change over much of the greater horn of Africa has implications for present and future vulnerability.

Rainfall changes in Africa as projected by most Atmosphere-Ocean General Circulation Models (GCMs) are relatively modest, especially when compared with current rainfall variability (Vincent, 2007). It may as well become more intense, but whether there will be more tropical cyclones or alteration to the frequency of El Nino events remains speculative (Sivakumar *et al*., 2005). In the horn of Africa wet extremes of high rainfall events occurring once every 10 years are projected to increase during both the short and long-rains, respectively (Thornton *et al.*, 2006). Also on record is that there has been a gradual increase in extremely wet seasons of about 20%. This means that close to one in five seasons will be extremely wet, as compared to one in twenty in the preceding period (Christensen *et al.*, 2007). Dry extremes are projected to be relatively less severe during September to December.

Around Kenya in general, the spatial and temporal pattern of climate over Kenya is quite variable, partly due to the existing complex landforms and several large inland water bodies, including the Lake Victoria basin. The mean annual rainfall in the country shows a wide spatial variation, ranging from 200 mm in the driest areas to 1,200 – 2,500mm in wetter areas bordering the Lake Victoria and central highlands east of the Rift Valley (Ojwang *et al.*, 2010). According to Ojwang *et al.* (2010), variability of rainfall is expected to increase and warmer temperatures are likely to increase the intensity and frequency of extreme weather events in the region, meaning that many areas in East Africa will be faced with an increased risk of longer dry spells and heavier storms. The net effect is that many parts of the greater Horn of Africa may well present higher probability of season failure to crops where clearly these annual cycles of rainfall are increasingly unpredictable (Thornton *et al.,* 2006).

2.3. Rainfall Characteristics

Rainfall is important as it is the principle determinant of the main variability events of floods and droughts which are the key parameters affecting herbage growth. In Africa, Sahel has been in the forefront in experiencing these phenomena. During the second half of the 20th century, the Sahel witnessed a dramatic reduction in mean annual rainfall throughout the region (Hulme *et al*., 2001). According to IPCC, a rainfall decrease of 29–49 percent has been observed in the 1968–1997 period compared to the 1931–1960 baseline period within the Sahel region (IPCC, 2001). Inter-annual rainfall variability is large over most parts of Africa, with a substantial multi-decadal variability also substantial in some areas (IPCC AR4 WG2, 2007). In regions such as West Africa, a decline in annual rainfall since 1960 has been noted. Some specific regions have recorded a decline of about 10% in Southern Africa, 4% in the Tropical Rainforest of West Africa, 3% in Northern Congo forest and 2% in Southern Congo forest. The IPCC Working Group II Fourth Assessment Report (AR4 WG2), 2007 report also states that East Africa is experiencing an intensifying dipole rainfall patterns on the decadal time scale characterized by increasing rainfall in the northern sector and declining amounts over the southern sector.

In the greater horn of Africa, large water bodies and varied topography give rise to a range of climatic conditions, from a humid tropical climate along the coastal areas, arid low lying inland elevated plateau regions across Tanzania, Kenya, Somalia, Ethiopia and Djibouti. The presence of the Indian Ocean to the east, and Lake Victoria and Lake Tanganyika, as well as high mountains such as Mount Kilimanjaro and Mount Kenya induce localized climatic patterns in the horn of Africa region (KNMI, 2007). In general, over two-thirds of the horn region receives less than 500mm of rainfall per year (Osbahr and Viner, 2006). In its classification, FAO (1960) put this region (Horn of Africa and Kenya) in a group comprising Djibouti, Ethiopia, Kenya and Somali as characterized by low rainfall and high variability and as some of the driest places in the world. In this region, inter-annual variability of rainfall is remarkably coherent within a region defined by a micro-climate. The Short Rains, in particular, are characterized by greater spatial coherence and are linked more to large scale than regional factors. According to Ogallo (1993), the Long Rains (March to May) contribute more than 70% to the annual rainfall and the Short Rains less than 20%, implying that much of the inter-annual variability comes from Short Rains (coefficient of variability = 74% compared with 35% for the Long Rains), an assertion confirmed too by Herrero *et. al*., 2010. As a result, the Short Rains are more predictable at seasonal time scales than the Long Rains (Ogallo, 1993).

In Kenya, Orindi *et al*, (2007) indicate that over two thirds of those areas around the northern and Southern parts of Rift Valley as well as parts of Coast province receive less than 500mm of rainfall per year and are classified as arid. The government of Kenya however classifies that most Semi-arid lands are concentrated around the lower parts of Eastern province and Southern end of the Kenyan Rift Valley (Arid and Semi-Arid Lands, ASAL, National Vision and Strategy, 2005); this is where Kajiado County is situated. The climate projection for the ASAL of Kenya may include longer and more frequent dry periods interspersed with intense but shorter and unpredictable periods of rainfall (Ojwang *et al*., 2010). Such weather patterns are likely to deplete water and pasture resources, leading to natural resource scarcity.

Over the past decades, rainfall delays have led to drought conditions in the country. As noted by Ogallo (1993) climate model experiments using AR4 climate scenarios indicate that droughts are likely to continue (notwithstanding the generally wetter conditions), particularly in northern Kenya in the forthcoming decades. In many model simulations, the drought events every seven years become more extreme than present. In 2009, a three week late and below normal long rainfalls, coupled with poor temporal and spatial distributions were reported in Kajiado (Kenya Food Security Steering Group, 2009). Most notable were Mashuru and Namanga divisions which recorded a 10-20 percent normal (Kenya Food Security Steering Group, 2009). As a result pasture and browse conditions ranged from fair to poor throughout the pastoral livelihoods resulting in an earlier than normal migration of livestock to other parts of the cluster including Tsavo and subsequently to coast province and Tanzania (Kenya Food Security Steering Group, 2009). The cost impacts of floods compared to droughts in Kenya in the past years revealed that losses from floods of 1997/98 summed up to a cost of between $ 850 and $ 1213 million, while droughts of 1998-2000 cost the economy an estimated $ 2.8 billion (Mogaka *et al*. 2006, cited in the Stockholm Environmental Institute, project report of 2009).

The ENSO Events.

Changes in El Niño Southern Oscillation (ENSO) events may influence future climate variability (IPCC AR4 WG2, 2007). For example, whereas the drying of the Sahel region in the 1970s is linked to a positive trend in Equatorial Indian Ocean Sea Surface Temperature by IPCC AR4 WG2 (2007), at the inter-annual scale, the report cites that ENSO has a significant influence on rainfall and that severe droughts have been linked to ENSO in the recent decades. Links between El Niño events and climate variability have been suggested, and it is a common perception that high coefficients of variation in rainfall may be attributed to El Niño effects (Anyah and Semazzi, 2007). This means that even for the predicted rainfall, there is less certainty in recording near average annual events. Other climate scholars such as Thornton *et al*. (2006) however observe that currently it is not clear whether a relationship exists between both El Niño or La Niña events and prolonged drought or particularly wet periods over much of the greater Horn of Africa. On its part, Working Group II in its recommendations to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change suggests a further research on this aspect (IPCC, 2007).

Despite all the debates, impacts of the ENSO are felt across the regions. Singh (2006) observes that El Niño episodes are often associated with above normal rainfall conditions over the equatorial parts of Eastern Africa during October to December and below normal rainfall over much of the Horn of Africa during the June to September rainfall season. The El Niño rains of 1998 produced an estimated fivefold increase in rainfall in the region of Greater Horn of Africa (GHA) compared to the long term average (Galvin *et al*. 2004). On the other hand, La Niña events often give rise to a below-normal rainfall over much of the GHA during October to December and March to May; and above normal during June to September season (Singh, 2006). This system could however change as warm phases of ENSO episodes have been more frequent in recent years than episodes of cold phases (La Niña); a factor which might have led to the recent recurrences of floods and droughts in regions with strong ENSO signals such as Eastern Africa and Kenya (Singh, 2006). The predictability of these episodes can sometimes be difficult thereby compromising on early warning systems and management of vulnerable ecosystems and communities. This is because as noted by Singh (2006), ElNino episodes sometimes change to La Niña and in such cases; many locations with ENSO signals have observed severe floods that are followed by severe droughts and vice versa. This is confirmed by an example cited by Ambenje (2000), and Ojwang *et al*. (2010); that the heavy rains associated with the 1997/98 ElNino events preceded the dry conditions which were the result of 1998-1999-2000 LaNina conditions. Prior to the 1997 El Niño, much of East Africa had already experienced severe drought in early and mid 1997 (Galvin *et al*. 2004), but when the El Niño began in October 1997, it replaced the short rains with heavy storms and floods. The rains continued through March when the long rains normally begins and then continued through May. The long duration and high amounts damaged infrastructure, agriculture and caused health problems both to people and livestock; with a rise in livestock diseases such as blue tongue (Galvin *et al*. 2004). The sequence of weather episodes during this period thus points to a cyclic phenomenon in which droughts are followed by heavy rains. However, what might be unpredictable is the intensity and lengths upon which each episode would register as climate change and variability forces continue to destabilize seasonal cycles.

2.4. Droughts

Drought is a climatic anomaly characterized by deficient supply of moisture resulting either from sub-normal rainfall, erratic rainfall distribution, higher water need or a combination of all the factors. It is equally difficult to define; and this comparison by The United States National Drought Mitigation Centre summarizes this assertion; that what may be considered a drought in Bali (six days without rain) would certainly not be considered a drought in Libya (annual rainfall less than 180mm). In the most general sense, drought originates from a deficiency of precipitation over an extended period of time-usually a season or more-resulting in a water shortage for some activity, group, or environmental sector (United States National Drought Mitigation Centre, NDMC). Its impacts result from the interplay between the natural event (less precipitation than expected) and the demand people place on water supply. Human activities too can exacerbate the impacts of drought.

The major droughts which have occurred in East Africa since 1980 are; 1983/84, 1991/92, 1995/96, 1999/2001, and 2004/2005 (Ng'ang'a, 2006). Ojwang *et al*. (2010) lists the impacts specific to 2009 in Kenya as overall failure of crop harvest, the large number of wildlife and livestock that were lost due to dehydration and starvation related deaths, low water levels in power generation dams led to power rationing and high tariffs, rampant pastoralist movements with their livestock was evident in urban areas, sacks of charcoal ready for truckloads were widespread along major roads, food prices were high due to lack of commodities, and relief agents were busy distributing food aid to most vulnerable communities, among other coping mechanisms. Kajiado district is prone to climatic shocks and in particular droughts (GOK, 2005) which affects the livelihood sustainability of the people through livestock deaths and crops failure. Further droughts have the effect of exacerbating range degradation (GOK, 2005). In Mashuru Division, for example, drought phenomenon occurred during 1952-1955, 1960-1961, 1975/6, 1984, 1994 and 2000 (UNEP and GoK, 2000). It has been noted that, when weighted by gross domestic product - GDP impact, droughts pose a substantially higher risk than floods throughout the country (Ogallo, 1993). These impacts depend on the duration, severity and spatial extent of the precipitation deficit, but also and to a large extent on the environmental and socio-economic vulnerability of affected regions.

Negative impacts of climate variability on livestock production through droughts do deprive livestock drinking water and forage thereby leading to decline in milk supply. Dry seasons have also been associated with a decline in some essential forage minerals in Kenya. Justifying this in their examination of the Effect of pasture mineral levels on extensive cattle production in Kenya, Pasture Network for Eastern and Southern Africa (PANESA), 1988 reported in their findings that 'other minerals including phosphorus (P), sodium (Na), copper (Cu) and cobalt (Co) were, found to limit extensive cattle production because they were deficient particularly in the dry season'. However, during the drought period, the supply of beef and hides may go up due to increase in slaughter numbers. This could still be followed by a consequential shortage of the same as more slaughter implies decline in livestock numbers and a persistence of drought may mean a dead-end for most poor livestock owners who cannot afford commercial hay and water. This trend may look cyclic, but it is not in the present times as restocking may take a long time, while a number of pastoralists may shun livestock keeping and shift either to salaried employment or agriculture.

2.5. Forage

Precipitation, especially in dry areas is one of the major driving forces for vegetation growth and is therefore in general highly correlated with vegetation (Klein and Roehrig, 2006, PANESA, 1988). The relationship between Normalized Differential Vegetation Index (NDVI) and precipitation has been shown to reflect rain use efficiency and total vegetation production (Nicholson and Farrar, 1994). Nicholson *et al*. (1990) investigated the spatiotemporal variability of NDVI for various vegetation types and its dependency on precipitation variability. They found that the NDVI-precipitation relationship differs significantly between their Sahelian and East African sites. NDVI-precipitation ratios tend to be higher in Eastern Africa than in the Sahel. Also, the NDVI-precipitation relationship tends to be linear in the Sahel, while it tends to be log-linear in East Africa (Nicholson *et al*., 1990). The authors found that above a particular threshold value in precipitation (approximately 1000–1100mm per annum for these sites), NDVI values ‘‘saturate’’ and level off. Reasons proposed include NDVI’s declining ability to indicate photosynthetic activities with higher canopy densities, and the proposition that above a particular precipitation threshold, precipitation ceases to be the most significant limiting factor in photosynthetic activity. Klein and Roehrig (2006) however associate this lack disability to spectral distortions caused by heavy cloud cover in mountainous and high rainfall areas. Nicholson and Farrar (1994) showed that for Botswana a linear NDVI-precipitation relationship only exists below the 500mm of annual precipitation threshold while above 500mm saturation occurs. This indicates that saturation seems to occur at a lower threshold than in the Sahel and East Africa. Limits to the NDVI-precipitation relationship are also found at the lower end of the precipitation scale. Milich and Weiss (2000a) found that below 250mm the NDVI-precipitation relationship becomes unpredictable. The authors found in the northern Sahel that potential evapo-transpiration is a stronger determinant of NDVI than is precipitation.

In Kajiado district, NDVI was used in assessing the response to the 2008 - 2009 droughts in Kenya where it indicated that Satellite imagery - in detecting failures in rangeland up greening - revealed that the drought had been most severe in Kajiado and Laikipia districts (Zwaagstra, *et al.*, 2009). Land use management systems have also been identified to limit the use of NDVI. A study conducted by Klein and Roehrig (2006) in Ol pejeta conservancy in Kenya and Okpara in Benin showed that biomass for Ol Pejeta is less diminished in dry seasons because Ol Pejeta in Kenya is a well managed ranch with no human impact in contrast to Okpara in Benin

Other studies conducted around and within the Kajiado County have pointed to deteriorating forage as a result of various factors. In 2005, a study by Macharia and Ekaya reported that there had been a downward trend in range condition in recent years as a result of frequent droughts, overgrazing and an increase in utilization of the vegetation resources by man. They found out that for the past 30years the downward trend in range conditions which had affected livestock productivity in the area were; excessive use of the woody species by humans for wood-fuel, building and fencing materials, medicine and ornamentals had led to the deterioration of the rangeland due to a loss of cover, change in plant composition and biodiversity (Macharia and Ekaya, 2005). On the other hand, overgrazing and ecological succession of the grazing lands had led to further vegetation degradation in form of bush encroachment and thickening, having an overall effect of loss of grass cover and hence loss of grazing capacity by livestock, especially cattle (Macharia and Ekaya, 2005). In the neighboring county of Machakos, Tiffen *et al*. (1994), found out that there was a marked difference in vegetation structure and composition in lightly and heavily grazed portions of the rangeland, indicating that there was an increase of woody species after overgrazing, suggesting that grazing plays an important role in structuring the vegetation. The density of herbaceous cover is another important factor influencing primary productivity (PANESA 1988). A research conducted by PANESA in Tsavo, Kiboko and Amboseli to predict the rangeland production from rainfall data in ASALs of Eastern Africa reported that in Tsavo, primary productivity increased threefold when grass cover increased from 20 to 80% and that low plant cover partially explains the poor response to rainfall in the Kiboko and Amboseli areas. In the latter area, herbaceous cover is usually below 10% (PANESA, 1988).

The Government of Kenya through its Kajiado District Vision and Strategy for 2005 – 2015 (GOK, 2005) identified the following as necessary measures in curbing forage challenges: Train community on appropriate stocking rates, disposal periods, pasture conservation and soil erosion; pasture reseeding; grubbing of invasive species; train community on proper harvesting, utilization and propagation of the browse material; support alternative temporal/permanent building material for shelter and fencing – demonstration units.

2.6. Trends in Cattle Production

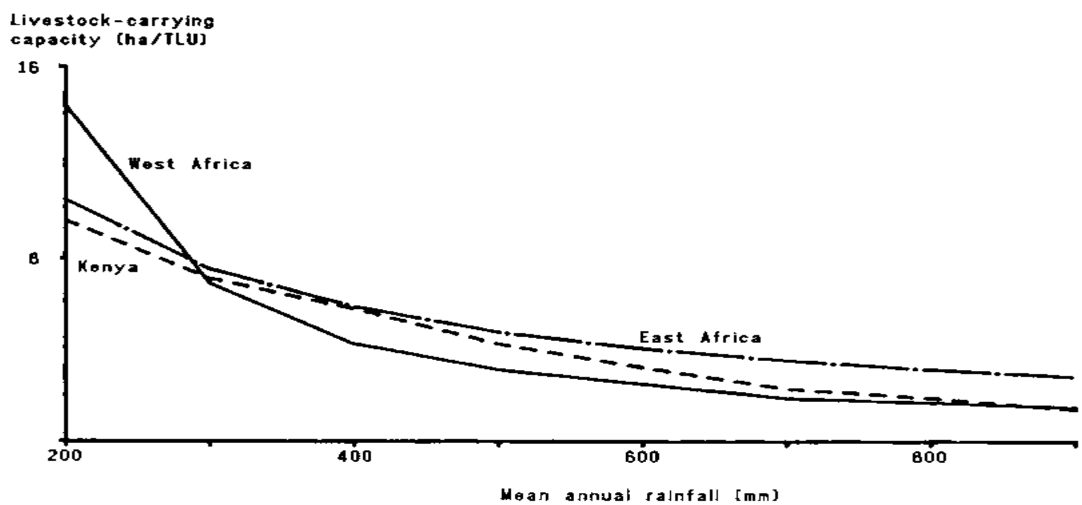
The basic determinant of livestock productivity is availability of animal food and water, then management factors such as dipping and veterinary services come-in secondary.

Lack of forage due to drought has led to loss of animals from time to time by the pastoral communities. Among the notable periods were in the 1970s and 1980s in African countries. Aerial censuses undertaken by the Ecosystems/NORAD and Ergo/ILCA in Turkana and in Central Niger documented a very large fluctuations in livestock numbers during the recent droughts (Thornton *et al*., 2006), while in Sudan, the report states that nomads east of the Nile lost almost all their animals. In their report dubbed Response to Drought in Greater Horn of Africa, Association of Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), puts the cattle mortality rates to have increased to 49% in Southern Ethiopia, 35% in Northern Kenya, and 13%, 15% and 17% in Kenya's southern agro-pastoral areas, North-West Tanzania, and South-West Uganda respectively. Similarly, small ruminants mortality rates were highest in Southern Ethiopia and Northern Kenya, recording; 52% and 43% respectively, while it was lower in Southern Kenya agro-pastoral and pure pastoral areas in central and south-western Uganda, where it recorded 11%, 21% and 22% respectively (Thornton *et al*., 2006). Contrary to this is a report by Orindi *et al*. (2007) on climate model that predicts a rise in average annual temperatures over Kenya by 5^0C, a phenomena he states could lead to decrease in cattle population by 2050 compared to sheep and goats whose population could initially increase by 2030 but reduce by 2050 (Orindi *et al.*, 2007 citing Osbahr and Viner, 2006).

Estimates of livestock-carrying capacity are usually derived directly from rainfall parameters or are linked to productivity of the vegetation (primary production). According to one proposed relationship based on annual rainfall, the average livestock carrying capacity increases from about 7ha/Tropical Livestock Unit (TLU) in the south of Kajiado District (average annual rainfall of 300mm) to about 3ha/TLU in the north (average annual rainfall of 550mm), Bekure *et al*. (1991). An ongoing survey by David Western and D. L. Manzolillo Nightingale (initiated in 1967) in Eastern Kajiado, has revealed the strongest pattern overall in the rise and fall of livestock numbers as a function of drought and rains (Figure 2.2). A comparison of this trend to human population by Western in 1994 revealed that livestock population has not risen since the late 1960s due to pasture shortage. Human numbers however increased more slowly, but steadily outran livestock increases. As a result, per capita livestock holdings have fallen steadily from 10 in the 1960s to 4 by the 1980s (Western, 1994).

In their work titled Climate variability and dry season ruminant livestock feeding strategies in Southeastern Kenya, Ndathi *et al*. (2011), reported that in the neighboring district of Kibwezi, lack of livestock feed during the dry season is the top ranked constraint to livestock production in the area and that feed shortage normally started from the month of August and ended in November. Results by Herrero *et al*. (2010) indicated that a drought once every five years in Kajiado (representative of current conditions) as has been observed in the area for a long time keeps herd sizes stable. However, when the study increased the probability of drought to once every three years, herd sizes decreased as a result of increased mortality and poorer reproductive performance (Herrero *et al*., 2010). On up-scaling the results to the ASALs regions in Kenya, they estimated that 1.8 million animals would be lost by 2030 due to increased drought frequencies (Herrero *et al*., 2010). The per capita decline could also be a result of other factors such as increase in population, urban spread, changes in land tenure system, encroachment into pastoral land by other forms of food production systems such as; agro-pastoralism and green house farming, a transformation trend Orindi *et al*. (2008), projects to occur at the rate of 1.2% - 2% per year.

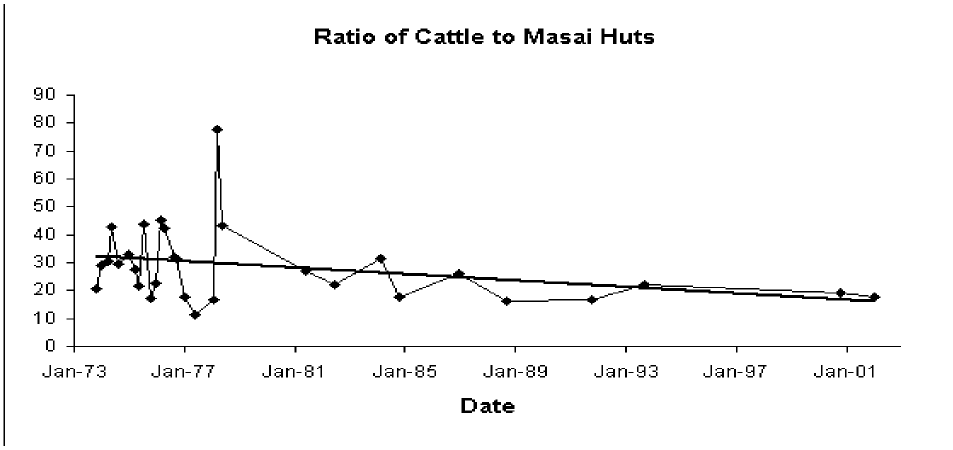
Fig. 2.1: *Livestock carrying capacity per hectare for different parts of Africa.*



Source: Bekure et al., 1991.

The graph on Figure 2.1 reveals that the livestock carrying capacity increases with decrease in mean annual rainfall.

Fig. 2.2: *The ratio of Cattle to Maasai huts (a measure of house hold livestock holdings) in the month of January from 1973 to 2001.*



Source: Adapted from Western and Manzolillo, 2003.

Table 2.1: *Projected changes in livestock and population numbers in Kenya from year 2000 to 2050).*

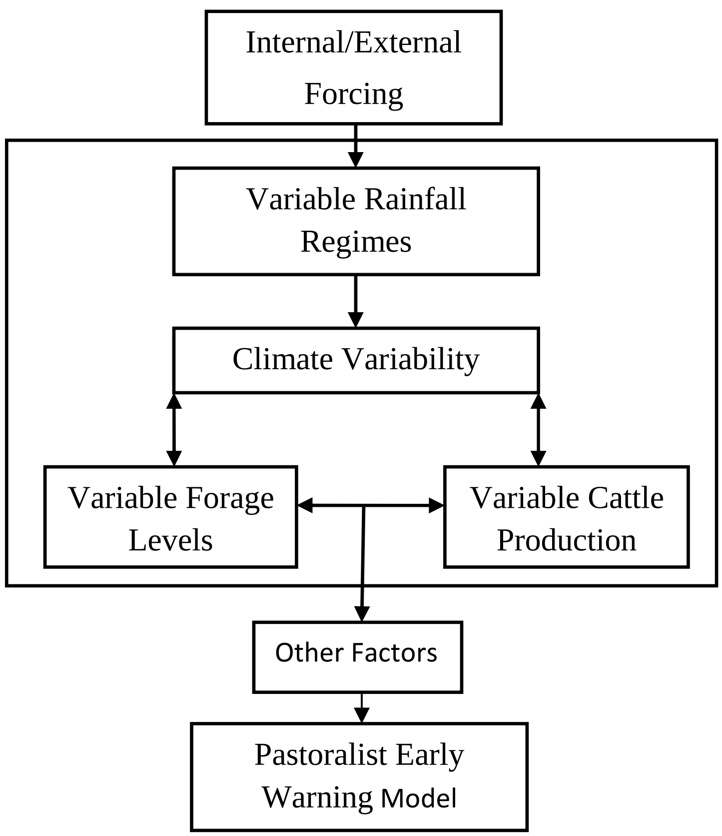
Population (000)	year		
	2000	2030	2050
Human	30,529	41,169	44,313
Cattle	13,840	12,988	12,452
Goats	9,600	11,058	10,803
Sheep	8,439	9,415	9,157

Source: *Adapted from Thornton et al., 2006.*

Flooding, another climatic extreme also has its effects on pastoralists and their herds through increased cases of livestock diseases, drowning of livestock in flood waters, and poor sales caused by inaccessibility to markets due to damaged infrastructure. For example, during the 1997/98 El Niño, pastoralists in Northern Tanzania could not access the Kenyan livestock market with ease because their normal routes were flooded, compelling them to ship their cattle by trucks via alternative expensive routes thereby reducing their profit margins (Galvin *et al.,* 2004). On the positive, during the same period, the Kenya Meteorological Services reported that the presence of more grass would reduce hunger among the pastoralist communities, while on the contrast, Somali reported large loses of livestock to flooding. Increased incidences of parasitic diseases raised the cattle mortality rates during the same period to 37% in Southern Ethiopia and to the highest of 52% in small ruminants in Northern Kenya (Thornton *et al*., 2006). According to the report, floods mortality in livestock is mainly attributed to diseases. Flooding not only narrows its effects to livestock but also human population through outbreak of water-borne epidemics such as malaria, cholera, bilharzias among other water related infections. The damage continues to physical harm, drowning and displacement of people and whatever affects the herder will definitely have a consequence on the livestock.

2.7. Conceptual Framework

Fig. 2.3: *Conceptual frame.*



Source: Researcher, 2012

Through time series analysis, evidence of climate variability was determined through variability in rainfall regimes, which is a result of both internal and external climate forcings that were not within the scope of this study. Relationships between rainfall variability and forage levels at different time scales were determined by correlation and regression to reveal inter-annual and seasonal responses. Assumption was that the major elements of climate variability that affect herbage growth are the intensity and duration of rainfall, the ratio between annual rainfall and potential evapotranspiration, and the year-to-year variation in rainfall. Consequentially, it is assumed that a decrease of annual rainfall and increase in intervals between rain events, especially when coupled with increasing temperature, will lead to less available water for vegetation germination and growth, and for microbial activity (Parsons and Athol, 1994).

Cattle production which is the other parameter under investigation was assumed to be dependent on rainfall since in pastoral areas food for livestock is mainly dependent on water/precipitation in determining availability and quality. Poor rainfall years are therefore expected to result in declined cattle performance while good rainfall years would yield a rise in cattle numbers. Mitigation or adaptation measure would require a connectivity analyses plus other factor inputs to develop a practicable pastoralist-climate early warning system.

CHAPTER THREE

3.0. METHODOLOGY

3.1. Data Sources and Description

The main sources of data for this study were secondary. The variables were:

i. Monthly Rainfall data.
ii. Annual cattle population.
iii. Dekadal forage.

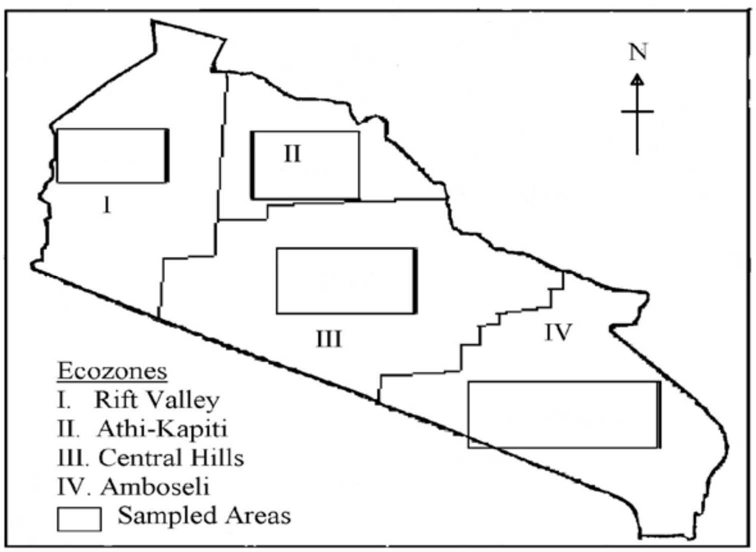
A long-term, 48 year monthly rainfall data for Mashuru Meteorological Station in the East of the study area, location; 2.10^0S, 37.10^0E, Magadi Soda Works to the West, located at 1.88^0S, 36.28^0E (here after referred to as M.S.W) and Ngong Division Office in the North; 1.31^0S, 36.65^0N (here after referred to as N.D.O) Meteorological Stations recorded from 1964 to June 2011 were obtained from the Kenya Meteorological Station in Dagorretti and Magadi Soda Works (M.S.W Meteorological Station) in Magadi. The three stations were selected for the study because they had a long-term data, their presence within different ecozones of the county and spatial spread.

Data on Cattle numbers for the study period was obtained from the Ministry of Livestock and Fisheries Development, Kajiado District Vetenary Office. It comprised a yearly census cattle numbers from 1979 to 2011. However, the data for the years 2010 and 2011 were left out of the analyses as the counts for the two years had been done only for Kajiado Central District and as such were not representative of the whole county.

Data on forage for the period between the months of January 1982 to December 2004 was acquired in the form of Normalized Difference Vegetation Index (NDVI) from http://iridl.ldeo.columbia.edu/SOURCES/.USGS/.ADDS/.NDVI. Data Library, downloadable free of charge in a user chosen format such as GeoTIFF, pdf, GIFF, or can be analyzed to extract the time series values. The values were a calculation from Advanced Very High Resolution Radiometer (AVHRR) data from National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellite. The satellite system ranged from NOAA-7, 9, 11, 9-d, 14, and 16; all mounted with 4km spatial resolution AVHRR

(Tucker *et al*, 2005). Selections were discriminately done to avoid ecozones that could lead to a large distortion of signals such as the slopes of Mount Kilimanjaro to the South East, slopes of Chiulu Hills to the East, Ngong forest, and Lake Magadi. The choice of this parameter was informed by arguments by Nicholson *et al*. 1990; and Nicholson and Farrar 1994 that the ratio of NDVI to rainfall provides a useful proxy for rain-use efficiency. Selections for each ecozones were restricted between longitudes and latitudes: 37.22^0E-37.75^0E and 2.56^0S-2.83^0S for Amboseli; 36.08^0E – 36.39^0E and 1.53^0S-1.74^0S for Rift Valley; 36.62^0E-36.92^0E and 1.533^0S-1.81^0S for Athi Kapiti; and 36.69^0E-37.07^0E and 2.01^0S-2.28^0S for Central Hills Ecozones. The total forage sampled area was $4886.36Km^2$.

Fig: 3.1: *Map of Kajiado County showing forage sampled area in every ecozone.*



Source: Researcher, 2012; base map adopted from Bekure et.al,1991.

NDVI is an indication of green leaf biomass and green leaf area derived from remotely sensed imagery. It is produced by combining sensor bands based on the principle that values vary with the absorption of red light by plant chlorophyll and the reflection of infrared radiation by water-filled leaf cells (Nicholson, 1994). It therefore assesses whether the target being observed contains live green vegetation or not. It is a remote sensing based index (ranging from 0 to 1) reflecting vegetation greenness with NDVI < 0.20 - 0.25 for bare soil and dead vegetation and NDVI of 0.6 to 0.7 for green vegetation with closed canopy (Zwaagstra *et al*, 2010). In most cases NDVI is correlated with photosynthesis, and since photosynthesis occurs in the green parts of plant material, the NDVI is normally used to indicate green vegetation cover (Nicholson, 1994). It is often directly related to other ground parameters such as percentage of ground cover, photosynthetic activity of the plant, surface water, leaf area index and the amount of biomass (Nicholson *et al*, 1998). These aspects make NDVI an instrumental tool in determining rain-use efficiency because the net annual increase of biomass, or net primary production, is a measure of the productivity of an ecosystem and this quantity bears a direct relationship to photosynthesis and NDVI is strongly correlated with both, particularly in arid lands (Nicholson *et al*, 1998).

Rainfall data for N.D.O Meteorological Station was fully available. However, data for Mashuru Meteorological Station was only available for the period 1964 to 1985 while M.S.W Meteorological Station was available for the period 1964 to 1990. The missing data for the two stations were therefore reconstructed using the formula:

$$a + bx,$$

$$a = \bar{y} - b\bar{x}$$

and:

$$b = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2}$$

x and y are the sample means AVERAGE(known x's) and AVERAGE(known y's).

At Mashuru Meteorological Station, available data were forecasted against rainfall data at Wilson Meteorological Station while M.S.W data was reconstructed against Narok Meteorological Station.

Where:

Known xs=Data from Wilson Meteorological Station

Known ys=Data from Mashuru Meteorological Station

M.S.W data was reconstructed against Narok Meteorological Station.

Where:

Known xs=Data from Narok Meteorological Station

Known ys=Data from M.S.W Meteorological Station

Using Pearson's correlation (r), at a significance level 0.05, the correlations yielded 98% and 66% correlation between Mashuru-Wilson and M.S.W-Narok Meteorological Stations respectively.

3.2. Data Processing and Analysis

3.2.1. Determining the Existence and level of Climate Variability

To determine the existence and level of climate variability over the study area, an analysis of rainfall amounts between the years 1964 – 2011, was conducted. Graphical presentations were done to demonstrate seasonal and inter-annual rainfall characteristics at the three stations. Analysis of inter-annual and seasonal components for the data was done to reveal general information for a time series within a year and between different years. It was also useful for comparing the general variations among the input data series, especially for different locations for the same time period. To achieve this, excel was used to calculate the range and standard deviation for the research data.

Range =Maximum Value – Minimum Value

Standard Deviation (S)

$$= \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

Coefficient of Variation (%C.V.) was calculated to reveal the degree of seasonal and inter-annual climate variation at the three stations of study using the formula;

%C.V. = Standard Deviation / Mean

Comparative values of C.Vs among the three rainfall stations were conducted to determine the spatial differences in variability between sectors of the study area represented by the respective meteorological stations. Climate variability factors of successive poor rainfall return rate of bellow normal rainfall seasons, and heavy rainfall events were graphically identified and analyzed.

3.2.2. Determining the Relationship between Climate Variability and Forage

Data on forage was extracted in time series from http://iridl.ldeo.columbia.edu/ data library. Maximum values for the selected areas were considered then averaged over 10 days, for the period January 1982 to December 2004. Maximum values were used because it minimizes the influence of varying solar zenith angles and surface topography on the index (Nicholson, 1998). The formula applied in calculating NDVI was:

NDVI = (NIR - Red) / (NIR + Red)

Where:

NDVI: -Normalized Differential Vegetation Index

NIR: -Near Infra-red band of The Electromagnetic Spectrum

Red: -Red band of the Electromagnetic Spectrum

NDVI values were further averaged on dekadal and annual counts. Using SPSS, a regression was run for mean dekadal and annual rainfall against the dekadal and annual NDVI values for the corresponding periods; where Pearson's Correlation Coefficient (r) was used at 95% confidence interval to test the nature and strength between the variables. In this analysis, rainfall data used were from M.S.W and Mashuru Meteorological Stations since they were respectively representative of arid and semi-arid ecozones. Due to unavailability of daily rainfall data, monthly mean amounts were spread over the three dekads and applied in the analyses. Since vegetation does not immediately respond to changes in rainfall amounts, NDVI values were lagged at 0-3dekads since the maximum correlation fell within the third dekad. The maximum one month lag obtained was lower than that suggested by Nicholson et al. (1990); that in most cases NDVI is best correlated to the concurrent plus two previous months of precipitation. It however fell within the 0 to 6 lag dekads suggested by Klein and Roehrig (2006) and in agreement with the 0-28days for Sub-Saharan Africa as found by PANESA (1988). The lagged correlations were tested against un-lagged response (concurrent dekad) with rainfall records at the two Meteorological Stations. Two ecozones; Athi Kapiti, representing semi-arid climate zone (annual rainfall=450-900mm, Bekure, 1991) and Rift valley (around Lake Magadi), representing arid zones (annual rainfall=300-550mm, Bekure, 1991) were discriminately sampled. Graphical comparisons were made between individual rainfall stations data on one hand and corresponding ecozones on the other. Spectral images were generated to reveal average seasonal forage reflectance. As well, these two stations and ecozones data were averaged to reveal the general relationships over the study area.

3.2.3. Determining the Relationship between Climate Variability and Cattle Population

Rainfall data from three stations were first individually regressed against cattle numbers then averaged and regressed against the same. Based on assumption that there existed a linear association between annual rainfall amounts and annual cattle population, Pearson's Correlation Coefficient (r) was used at 95% confidence interval to measure the strength and nature of association between rainfall amounts and cattle numbers. The choice (of r) was based on the fact that data on these two parameters were ungrouped. The calculations were done using Linear Regression under 'Analyze' function in SPSS.

Rainfall effects were lagged by one year to the livestock population data so as to account for the fact that livestock population growth in a particular year was influenced by rainfall from the previous year and also that livestock data for Kajiado were taken and reported early in the year (every month of April). The nature of association between rainfall received in the area and cattle population was determined using linear regression where the total annual rainfall for N.D.O, Mashuru and M.S.W Meteorological Stations for the research period were run as independent variables while cattle population considered dependent. Rainfall data was also averaged for the three stations and graphically compared to cattle performance over the county.

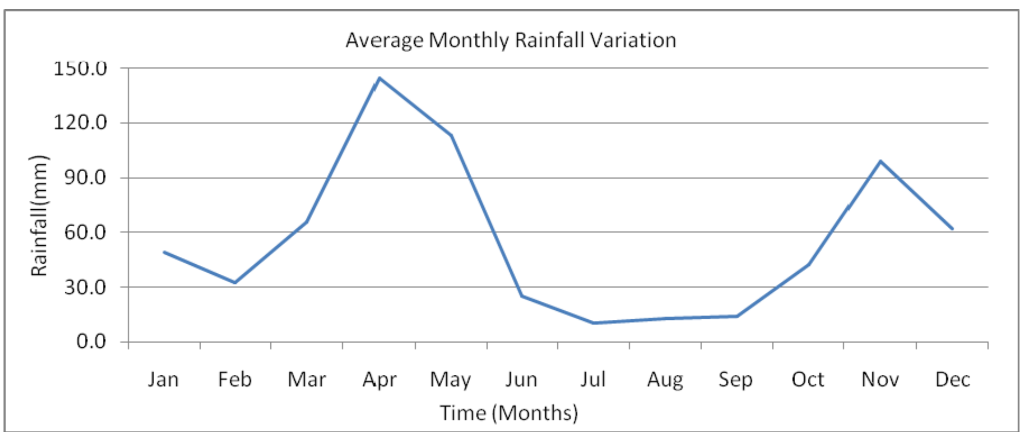
CHAPTER FOUR

4.0: RESULTS AND DISCUSSIONS

4.1. Rainfall Characteristics at Mashuru Meteorological Station

From 1964 to 2011, average rainfall at Mashuru Meteorological Station had exhibited a bimodal trend in annual rainfall characteristics (Fig 4.1.) depicting four seasons in general - short and long rain seasons and two dry seasons. On an annual calendar, the year begins with poor rains in January and February, marking the short dry season. Another dry season is experienced from the month of June to September, where a mean rainfall amounts of 25.0mm, 10.5mm, 12.5mm, and 14.2mm were recorded in June, July, August and September respectively. The three months form the driest season in the area while July marks the driest month (Mean rainfall, 10.5mm). The months of March, April and May were found to form the long rain season in the area with April registering the highest average rainfall (144.6mm). Short rains were realized from October through to December with November making the peak in high rainfall amounts, averaging 99.2mm during the 48 year research period.

Fig. 4.1: *Monthly and Seasonal Rainfall Characteristics at Mashuru Meteorological Station from 1964 to 2011.*



For the 48 year research period, Mashuru Meteorological Station recorded 26 years of below average rainfalls and 22 years of above average rainfalls (Fig. 4.2). Within this, the longest dry periods were 1964-1966, 1974-1976, 1983-1985, 1990-1996 and 2007-2009, while the wettest were 1977-1980 and 2001–2003. The highest rainfalls were experienced in 1977, 1998 and 2001 with total amounts of 1111.8mm, 1063.5mm, 1040.1mm recorded respectively. Driest years were found to be; 1969, 1975/76, 1984, 1996 and 2000 (Fig.4.2). With the exception of 1996, this finding is in agreement with reports by UNEP and GoK (2000) that in Mashuru, drought phenomenon had occurred during 1952-1955, 1960-1961, 1975/6, 1984, 1994 and 2000.

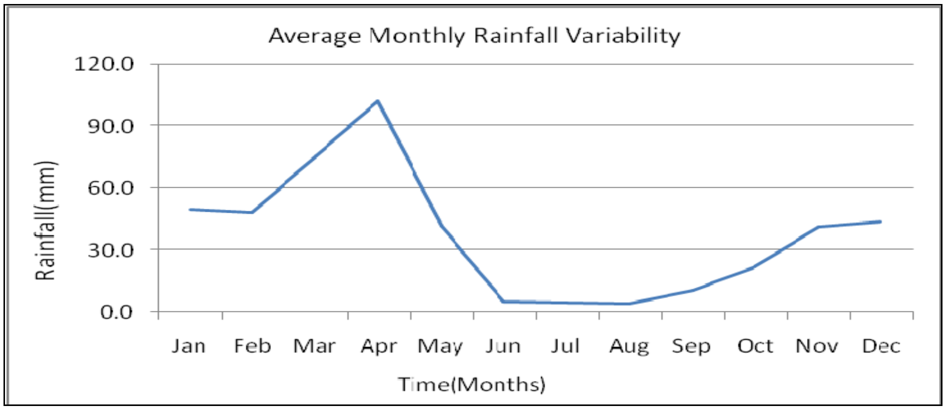
Figure 4.2: Inter-Annual Rainfall variation at Mashuru Met. Station, 1964 - 2011.

With reference to long-term mean of 671.1mm, the return rate for high rainfalls were noticed to be 10/11years-notable in 1967, 1977, 1988 and 1998, while return period for poor performing years were more frequent to a tune of 4 to 6 years. These were realized in1964, 1969, 1975/76, 1984, 1996, 2000 and 2005 (Fig.4.2); a sign that droughts could be more frequent in the area compared to return rates of above normal rains.

4.2. Rainfall Characteristics at M.S.W. Meteorological Station

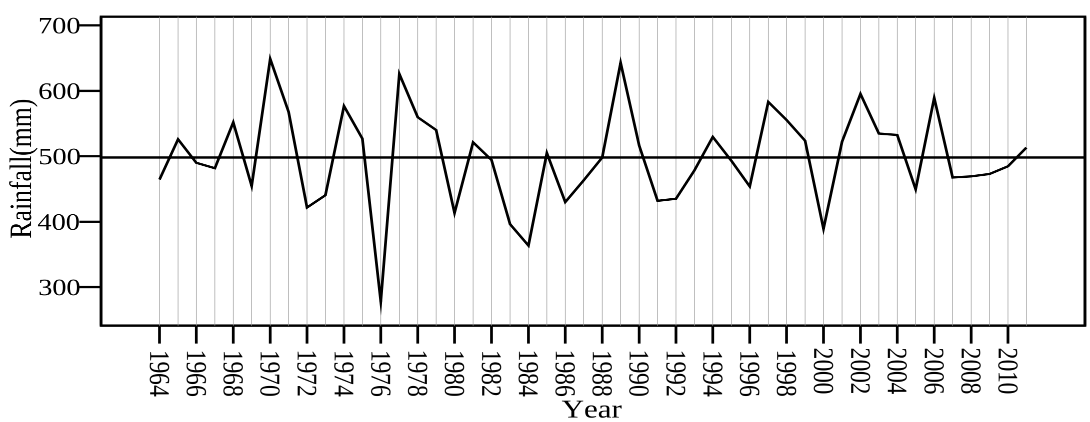
Time series of rainfall at M.S.W Meteorological Station characteristically indicate a bimodal system with long rains falling in the months of March, April and May with mean amounts of 75.5mm, 102.1mm and 42.1mm respectively, while short rains were experienced from November (41.2mm), December (43.8mm), January (49.6mm) and February (48.5mm). Figure 4.3 reveals that rainfalls begin to decline in May while dry seasons with below mean rainfalls (37.4mm) are realized from June through to October in which the lowest mean amount of 4.1mm was recorded over the past 48 years in the month of July.

Fig. 4.3: *Monthly and Seasonal Rainfall Characteristics at Magadi Soda Works (M.S.W) Meteorological Station from 1964 to 2011.*



As revealed in Figure 4.4, the station recorded 23 years of above average rainfalls and 25 years of bellow mean rainfalls with 1972-73, 1983-84, 1991-93 and 2007–2010, marking the longest seasons of poor rains, while the poorest were; 1976(230.3) and 1984(296.0). A consecutive four year time from 2001 to 2004 marked the longest period with above average annual rainfalls. Averagely, the wettest years experienced were 1970(685.2mm), 1977(640.3mm) and 1989(673.4mm).

Fig. 4.4: Inter-annual Rainfall Characteristics at MSW Meteorological Station, 1964 - 2011.

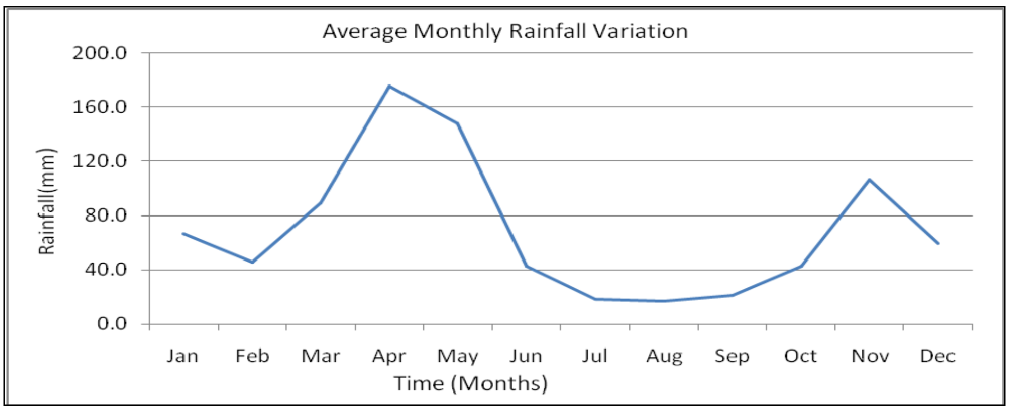


As shown in figure 4.4, extreme deviations above and below the mean annual total is not easily noticeable because most years had records fluctuating not far from the mean, except for a few such as 1970, 1976, 1977, 1984, 1989 and 2000.

4.3. Rainfall Characteristics at N.D.O. Meteorological Station

Ngong Divisional Meteorological Station witnessed a bimodal rainfall regime in which long rains fell in March, April and May, recording mean amounts of 88.8mm, 175.9mm and 147.9mm respectively (Fig.4.5). This was then followed by five drier months of June, July, August, September and October with mean records of 42.8mm, 17.5mm, 16.1mm, 20.6mm and 42.5mm respectively. Short rain season was experienced in the months of November(106.3mm), December(59.4mm) and January(66.9mm) then interjected by a dry month of February with a mean amount of 45.7mm.

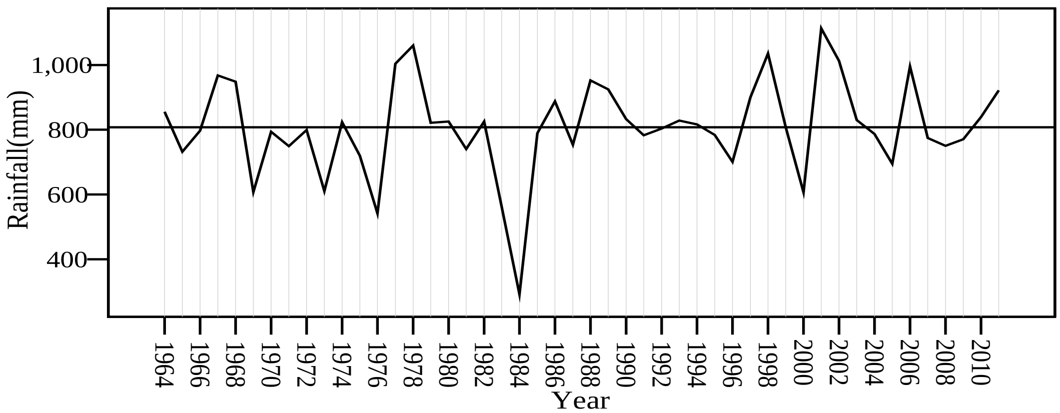
Fig. 4.5: *Monthly and Seasonal Rainfall Characteristics at N.D.O Meteorological Station from 1964 to 2011.*



As depicted in Figure 4.5, long rains typically extends for a longer period of time with a higher peak as compared to short rains.

Annualy, the station reecorded 21 years of bellow mean rainfall and 27 years of above average rainfalls, indicating that the area could be prone to more drought years. The wettest of years recorded over the period were; 1978, 1998 and 2001 which saw highs of 1251.9mm, 1200.0mm and 1374.0mm respectively. The return period for high rainfalls was a 10-year return rate (Fig.4.6), notable in 1967/68(1065/1029mm), 1977/78(1134.3/1251.9mm), 1988(1037.2mm) and 1998(1200.0mm). During the researh period, the longest wet period was experienced between 1977 to 1980 while the poor rainfall performing periods were longer; between the years1969 to 1973, 1982 to 1985, and 2007 to 2009.

Figure 4.6: Inter-Annual Rainfall variation at N.D.O Met. Station, 1964 - 2011.



As shown in Figure 4.6, the worst rainfall performing years were 1984(326.6mm) and 2000(566.8mm). However, the earlier years - notably in 1969(567.1mm), 1973(570.4mm) and 1976(505.8mm) had seen a more frequent return in severe shortage of rainfall.

4.4. Climate Variability over Kajiado County

4.4.1. Spatial and Inter-Annual Climate Variability over Kajiado County

The three stations yielded Coefficient of Varriability (C.V.) values of 24% at N.D.O. Met. Station, 26% at Mashuru Met. Station and 21% at M.S.W. Met. Station (Table 4.1), indicating an existence of higher climate variability around Mashuru to the East and Ngong in the North compared to areas around Magadi to the West of the county.

Table 4.1: Inter-Annual and spatial variability levels between the three stations

	N.D.O. Met. Station	Mashuru Met. Station	M.S.W. Met. Station
Mean(mm)	830.3	671.1	449.3
STDEV(mm)	202.3	174.9	94.0
C.V	0.24	0.26	0.21

The spatial climate variability as manifested in the rainfall characteristic over the study area varies around the three stations. Northern parts of the county (represented by N.D.O

Meteorological Station) recorded an average annual mean of 830.3mm over the period 1964 to 2011, Mashuru experienced a lower mean amount of 671.1mm while M.S.W Meteorological Station to the West registered a mean of 449.3mm over the same period. A comparison in coefficient of variation over Mashuru Meteorological Station(24%) and N.D.O Meteorological Station(26%) shows a high variability levels over areas receiving low rainfalls, an indication that climate variability increases with aridity (Ojwang *et al*., 2010). This assertion by Ojwang *et al*., 2010 is however, disputed by the existence of lower variability coefficient (21%) over more arid areas around M.S.W with mean annual rainfall of 449.3.

4.4.2. Seasonal Variability

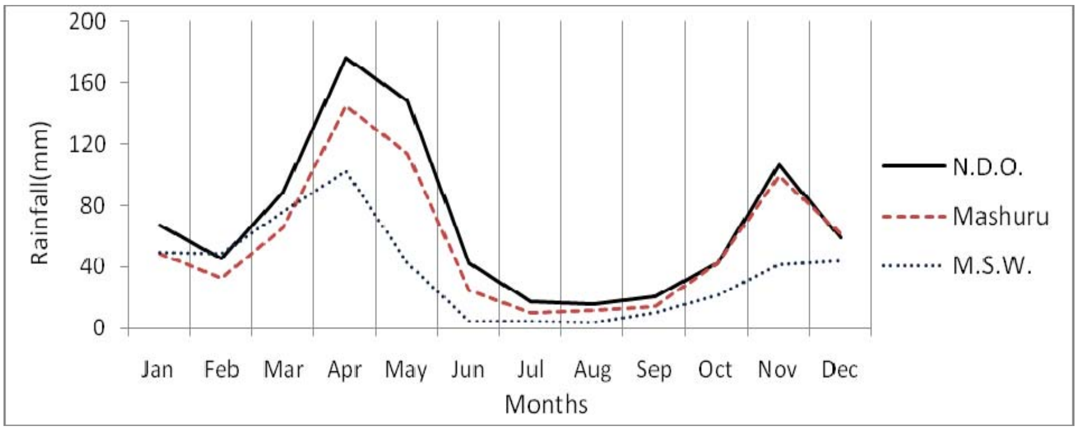
Analyses of variability yielded differences in Coefficient of Variability over seasons at the three stations (Table 4.2). During the long rains season (March - May), Ngong Divisional Office Meteorological Station had a C.V of 34%, Mashuru Meteorological Station had 40% while M.S.W. Meteorological Station experienced variability of 39%. Short rain season (October - December) had a comparatively higher C.V. of 49% at N.D.O., 50% at Mashuru and 44% at M.S.W. Generally, rainfall variability was higher in all the stations during the short rain seasons compared to long rainfall season, confirming assertions by Herrero, 2010 and Ojwang 2010 that in this region, there is higher variability during the short rain seasons compared to long rain seasons.

Table 4.2: Seasonal Variability levels between the three stations

	N.D.O. Met. Station		Mashuru Met. Station		M.S.W. Met. Station	
Season	Long Rains	Short Rains	Long Rains	Short Rains	Long Rains	Short Rains
Mean(mm)	412.53	208.18	322.51	203.31	73.25	35.63
STDEV(mm)	139.26	102.54	128.03	101.65	28.23	15.82
C.V.	0.34	0.49	0.40	0.50	0.39	0.44

The month of March appear to be the onset month for the long rains both around Ngong and Mashuru (Fig.4.7). However, there is variability in the onset amounts with Ngong in the North of the County recording a mean amount of 88.8mm, an amount higher than 65.9mm, which is the mean rainfall amount recorded for the onset month at Mashuru. April, which marks the peak of the long rain season in the area also experiences a higher rainfall mean amounts of 175.9mm around Ngong compared to 144.6mm at Masuru and 102.1mm around Magadi to the West. Throughout the long rain season, Northern Kajiado registers higher rainfalls compared to the central and Western parts of the county.

Fig. 4.7: Seasonal and Monthly Rainfall over Kajiado from 1964 to 2011



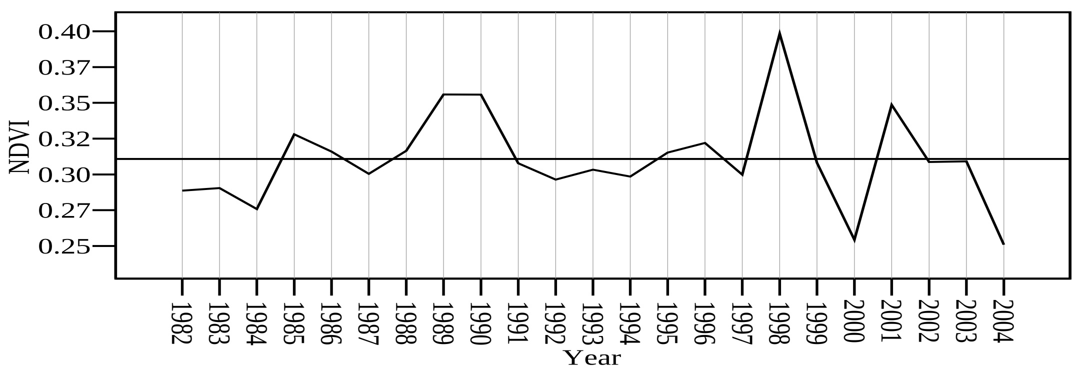
During the second rain season, the three stations appear to record onset during the month of September but with lower rainfall at M.S.W(10.8mm) and Mashuru(14.2mm) Meteorological Stations as compared to N.D.O Meteorological Station (20.6mm). However, areas around Mashuru in the East tended to receive higher intensity rainfalls (42.2mm) in the month of October, negligibly falling bellow that over Ngong areas by 0.3mm. This also repeated itself in the month of December where areas around Mashuru (62.0mm) experienced mean rainfalls higher than Ngong (59.4mm). During this season, areas to the West around Magadi tend to have its long rains from September through to February. The rains are however of low intensity, starting to plateau in November (41.2mm) through to February (48.5mm) with a higher amount recorded in January (49.6). The dry month of February exhibited an observable level of spatial variability between Eastern, Western and Northern parts of the county in that whereas N.D.O and Mashuru Meteorological Stations recorded a bellow mean rains of 45.7mm and 32.5mm respectively, areas around M.S.W Meteorological Station recorded a higher and above mean amount of 48.5mm.

4.5. Forage Response to Rainfall Variability Over Kajiado County

4.5.1. Forage Characteristics over Kajiado County

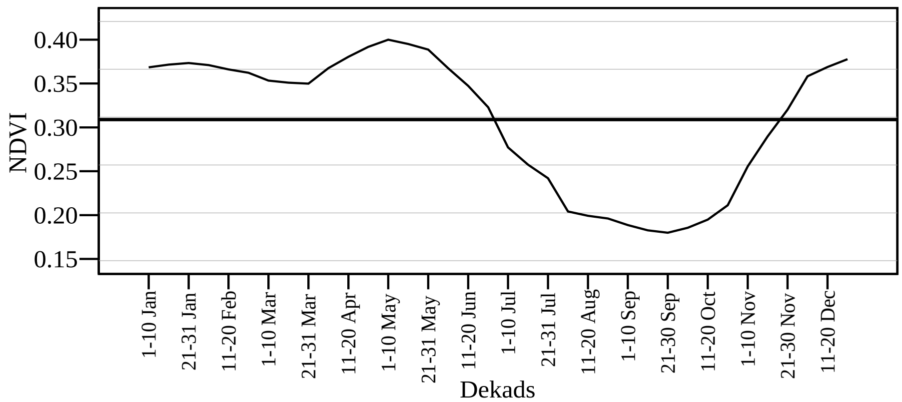
With reference to the long-term mean NDVI value of 0.309 (Fig. 4.8), the area had experienced fourteen years of below average forage cover and nine years of above average cover. The longest period during which suppressed forage were recorded were; 1982 – 1984, 1991 – 1994 and 2002-2004. A single notable year which saw vegetation sinking to its lowest was in 2000 in which an average NDVI value of 0.2524 was registered. On the other hand, the area evidently faced a long (three year) period of above average forage cover from 1988 to 1990. However, the following years only saw increased oscillation in performance where only 1996, 1998, and 2001 registered above average NDVI. Over the 23 years research period, forage had followed continuous inter-annual fluctuations registering its highest annual average of 0.3997 in 1998.

Fig. 4.8: *Integrated Inter-annual Forage Variability Over Kajiado County; 1982 - 2004*



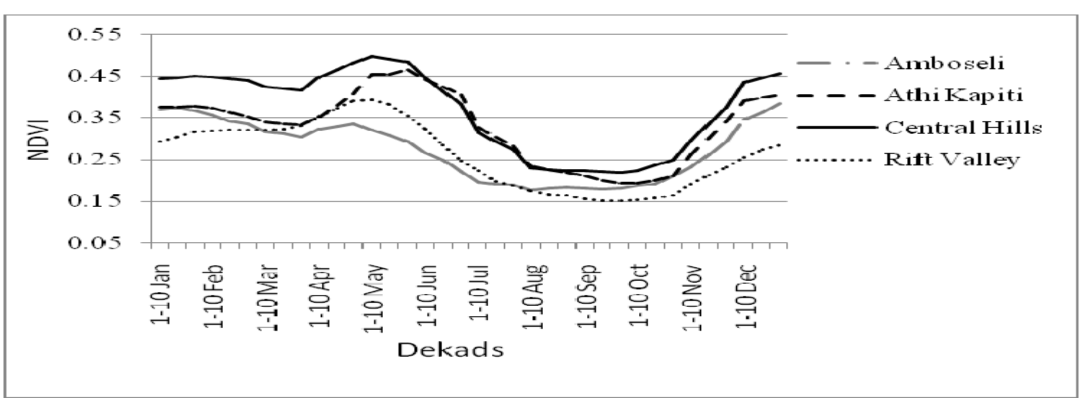
An analysis of annual variations in forage levels revealed a seasonal pattern. Figure 4.9 shows that 10-day decadal averages for the 23 year research period revealed that 7 out of the 12 months (November 21 to June 30th) had above average forage yield. Most notable good growth season was between the last dekad of April and mid dekad of May which registered a performance of above 0.4 and peaked at 0.416 in mid May (Fig. 4.9). This was then followed by a gentle decline to the second third of June and a drastic reduction in the last third of the same month. From the 1st dekad of July to the second dekad of November, the area experienced a bellow average forage cover, a period which saw times between 11th – 20th August through to 11th – 20th of October registering NDVI signatures bellow 0.2 and sinking to its average lowest of 0.1858 between 21st-30th September.

Fig. 4.9: Integrated Seasonal Forage Variability Over Kajiado County; 1982 - 2004



Spatially, forage levels varied over the three study ecozones where Rift Valley ecozones (around Magadi area) registered an all-time low forage except for the first dekad of April when it recorded values (0.352) equaling values over Athi Kapiti ecozones (Fig. 4.11) and between the last dekad of February through to mid July. Unlike the other three ecozones, forage over Amboseli tends to perform higher in the second season (November to January) as compared to the first season (April to May). In as much as forage over Central Hills were higher during most of the seasons, a sharp decline between mid June to mid August saw Athi Kapiti registering a slightly higher NDVI values compared to Central Hills (Figure 4.11).

Fig. 4.11: *Average Seasonal Forage Variability Over the four ecozones; 1982 - 2004*



Generally, healthy vegetation will absorb most of the visible light that falls on it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near infrared light. Bare soils on the other hand reflect moderately in both the red and infrared portion of the electromagnetic spectrum (Holme *et al* 1987). Analyses of both seasonal and inter-annual forage variabilities showed that between 1982 and 2004, Kajiado County never experienced either a year or season with total lack of vegetation since the lowest average NDVI signature the seasons registered was 0.233 (Fig. 4.11) while an annual lowest average was 0.276. On the other hand, neither a year nor season recorded an average NDVI signature close to unity, a sign that the area never had a total canopy cover. Despite the poor general average forage performance, there were parches of good performing seasons registering signatures above 0.5, such as April – May of 1985, 1988, 1990, and 1991, and also seasons which registered slightly above 0.6 such as early 1998 and 2011.

4.5.2. Rainfall Variability on Forage over Athi Kapiti Ecozone

As shown in Table 4.3, at a lag of 0 (within 10days of rainfall onset), association between mean monthly rainfall at Mashuru Meteorological Station and mean dekadal forage levels over Athi Kapiti Ecozone had an r-value of 0.477. This indicated that there was a low significant association between forage levels and rainfall amounts measured within 10days of onset. However, a lag of 30days for this ecozone yielded a higher r-value of 0.892 indicating a very strong relationship between forage and rainfall within one month of onset.

Table 4.3*: Correlation between Mean Monthly Rainfall and Dekadal NDVI over Athi Kapiti Ecozones within the first 10 and 30days of rainfall onset (lag0 and 30)*

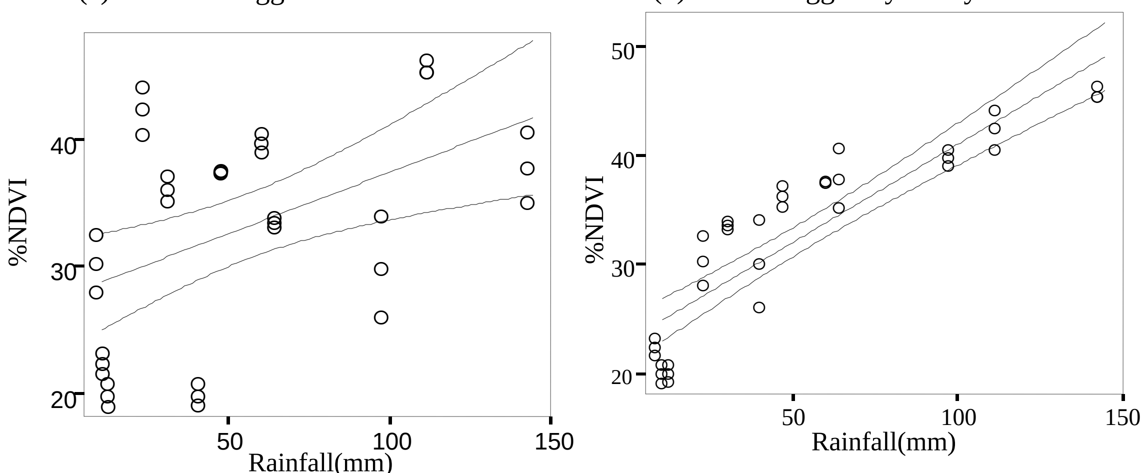
Correlations		
	NDVI(Athi Kapiti), lag0	NDVI(Athi Kapiti), lag30
Rainfall(Mashuru)	.477	.892
Sig. (2-tailed)	0.003	0

The analyses yielded test values of 0.003 and 0.0 at lags 0 and 30days respectively and were significant at 0.05 confidence level (Table4.3). Within the first 10 days (unlagged), rainfalls at this station influenced increase in forage availability over Athi Kapiti ecozones by a factor of 0.10 for every unit increase in rainfall amounts (Fig. 4.12a). A regression line generated to check the degree to which rainfall impacted upon forage had a fair curve fitting with an r^2 of 0.23 - showing that the recorded rainfalls lowly explained the fluctuations in forage availability and quality.

Fig. 4.12: Best Fit diagram showing relationship between NDVI and Mean Monthly Rainfall at Mashuru Meteorological Station at a lag 0 and 30 days.

(a) NDVI Unlagged

(b) NDVI Lagged by 30days



%NDVI = 27.72 + 0.10 * Rainfall_Mashuru
R-Square = 0.23

%NDVI = 23.05 + 0.18 * Rainfall_Mashuru
R-Square = 0.79

On the other hand, a lag of 30days over the same ecozone generated a close to unity regression line with a good curve fitting and yielded an r^2-value of 0.79 (Fig. 4.12b). This revealed that the magnitude to which rainfall influence forage levels within this period from the onset is very strong since other factors only accounted for a minimal degree of 21%. It also reflects that a unit increase in rainfall amounts led to a rise in forage level by a factor of 0.18. At the same time, the scatter plots are closely clustering around the regression line as compared to unlagged (Fig. 4.12a).

4.5.3. Rainfall Variability on Forage over Rift Valley Ecozone

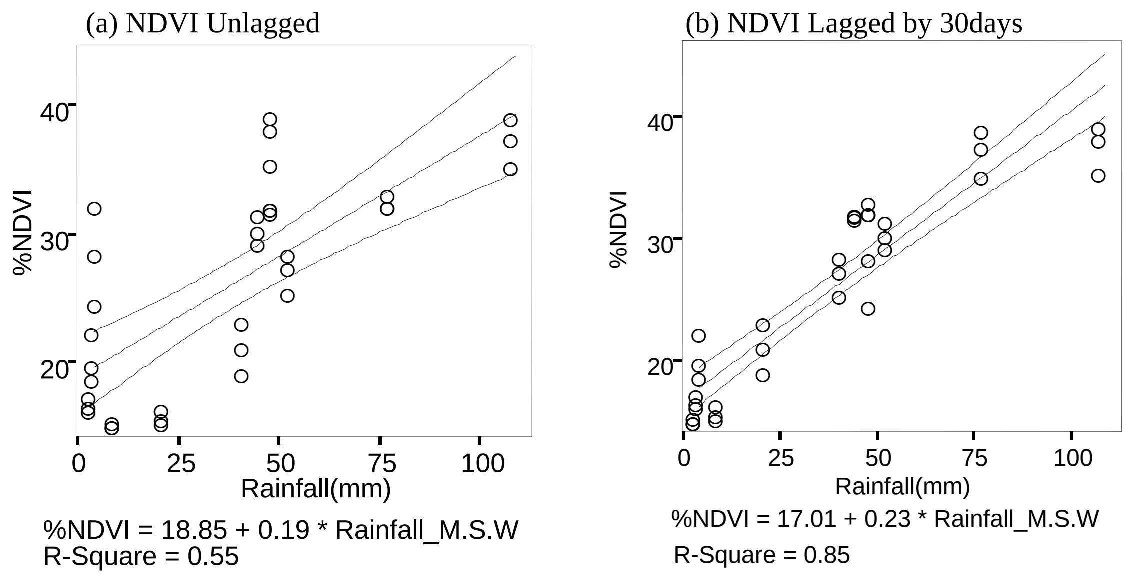
Within Ten days of rainfall onset, correlation between monthly rainfalls at M.S.W Meteorological Station against forage at the Rift Valley Ecozone yielded a strong correlation value of 0.739 significant at 0.05 confidence level (Table 4.4). This indicated an existence of a very strong significant association between rainfall and forage within this ecozones as rainfalls accounts for upto 74% of forage.

Table 4.4*: Correlation between Mean Monthly Rainfall and Dekadal NDVI over Rift Valey Ecozones within the first 10 and 30days of rainfall onset (lag0 and 30)*

Correlations

	NDVI(Rift Valley), lag0	NDVI(Rift Valley), lag30
Rainfall(M.S.W)	.739	.923
Sig. (2-tailed)	0	0

Fig 4.13: Best Fit diagrams showing relationship between NDVI and Dekadal Mean Rainfall at M.S.W Meteorological Station at a lag of 0 and 30 days



As indicated in Table 4.4 and Figure 4.13b, when forage over Rift Valley Ecozone was lagged by 30 days and correlated with decadal rains at M.S.W Meteorological Station, it yielded a correlation coefficient of 0.923, significant at 0.05 confidence levels, an indication of a very strong significant association between rainfall and forage levels over this ecozone. 30 days after onset, rainfalls at this station explained upto 92% of forage available over this ecozone and accounted for changes in forage performance to a magnitude of 85%, with a further increase in unit rainfall raising percentage forage level by a factor of 0.23 (Fig.4.13b). A generated regression line displayed a close to unity curve fitting showing that forage dynamics over the Rift Valley Ecozones were highly impacted upon by rainfall since other factors only accounted for 15% of forage available and 7.7% of changes in forage level. This is also evidenced by the scatter plots closely clustering around the regression line.

4.5.4. Seasonal Forage Response to Rainfall Variability

As depicted in Figure 4.14, at the onset of long rains over Central Kajiado in the last dekad of February, a 30 day lapse period in forage response occurs pushing forage onset by the same amount of time to the last dekad of the following month(March 21st – 31st). Similarly, as the rainfall peaks in the month of April, a corresponding peak in forage around Athi Kapiti Ecozone is realized later in the last dekad of May. A drop in mean rainfall amounts from 144.6mm in April to 113.3mm in May correspondingly led to an equal temporal (30days) forage decline from the last dekad of May to the last dekad of June. A further sharp drop in rainfalls from 113.3mm in May to its lowest mean of 10.5mm in July evidently impacted on forage levels from the last dekad of June through to the end of September.

Fig. 4.14: *Forage Response to Variations in Rainfall amounts*

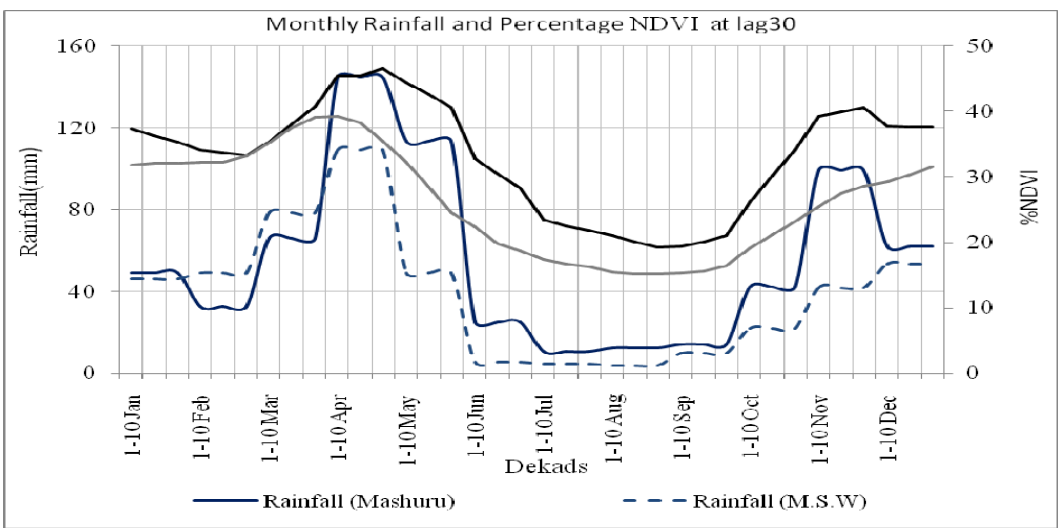
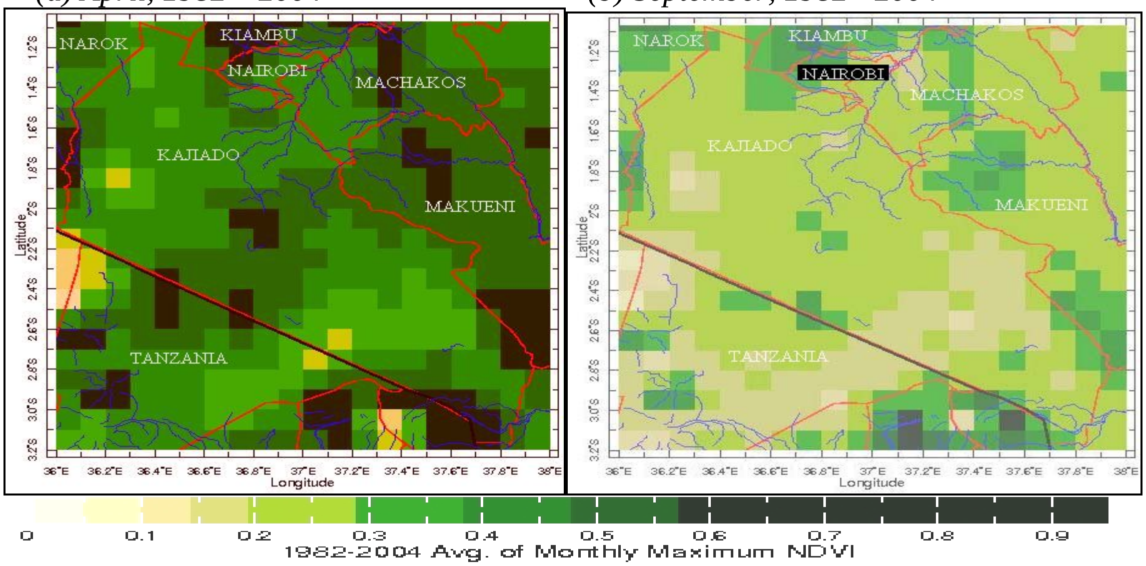


Fig. 4.15: (a) and (b) Compares average seasonal forage reflectance levels between the peak month of April and the most depressed month of September for the period 1982 - 2004

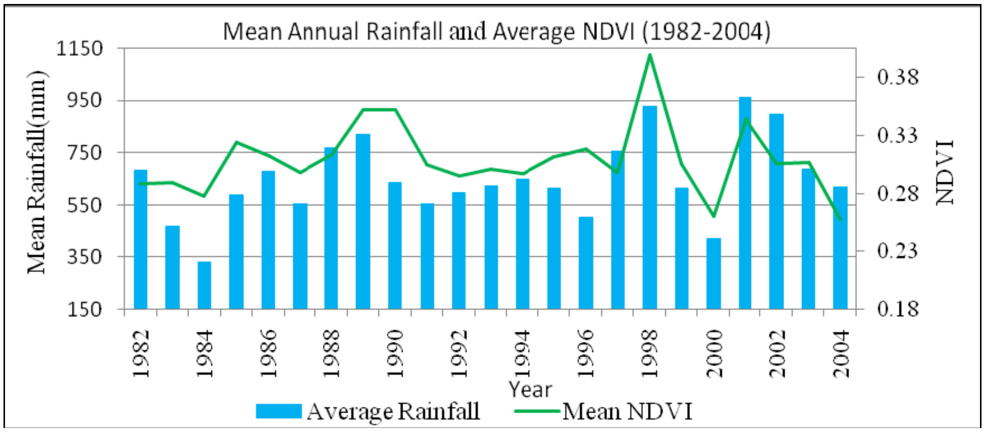
(a) April, 1982 – 2004 *(b) September, 1982 - 2004*



4.5.5. Inter-annual Forage Response to Rainfall Variability

As depicted in Figure 4.16, there was a responsive tendency by forage to fluctuations in rainfall over the 23 years study period. The low rainfall amounts recorded in the years 1983, 1984 and 2000 were accountable for the bellow mean NDVI values of 0.29, 0.28 and 0.26 respectively registered over that period. A push to forage peaks in 1985, 1989, 1998, and 2001, were as a result of high rainfalls received in those years, a confirmation of findings by Jahnke 1982, that in low rainfall areas, fodder production is a function of annual rainfall.

Fig. 4.16: Average annual fluctuations in forage in response to rainfall over Kajiado County.



In as much as rainfall accounted for forage performance in the area, it did not account for a constant climb in forage against annual decline in rainfall from an average total of 614.2mm and 502.6mm in 1995 and 1996 respectively (Fig. 4.16). The good performance by forage over this period could be associated to management practices Klein and Roehrig (2006) or assertion by the same authors that in Kenya, rainy season can fail completely but even in the driest years some vegetation growth occurs.

4.6. Relationship between climate variability and cattle population

This analysis had a specific aim of finding out how climate variability through variability in annual rainfall amounts impacted on cattle numbers with time. The three meteorological stations were first independently correlated against cattle population and then averaged. Correlation analyses in Table 4.5 yielded correlation coefficients of; 0.023, 0.064, and 0.083 over N.D.O, Mashuru and M.S.W Meteorological Stations respectively, while an average of all the rainfall stations had a correlation coefficient of 0.053. As well, none of the correlations was significant at 0.05 confidence level.

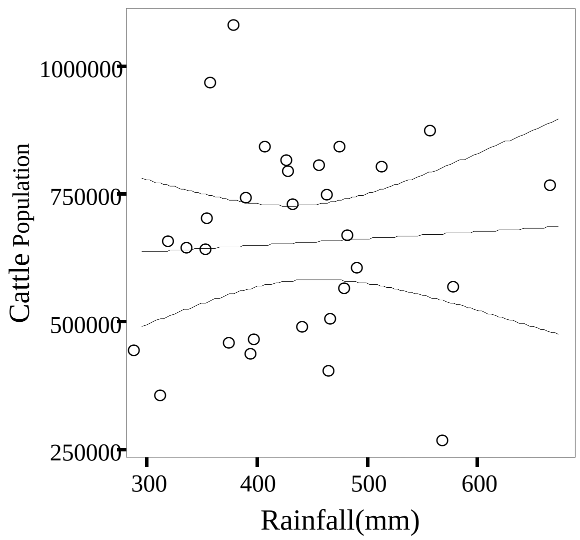
Table 4.5: *Correlation between Annual Cattle Population, The three rainfall stations and their annual average.*

		N.D.O	Mashuru	M.S.W	Average Rainfall
Cattle Population	Pearson Correlation	0.023	0.064	0.083	0.053
	Sig. (2-tailed)	0.901	0.734	0.656	0.777

4.6.1. Annual Cattle Population and Rainfall at M.S.W. Meteorological Station

Analysis at M.S.W yielded an R-value of 0.083 (Table 4.5), an indication of a weak but positive association between annual rainfall amounts and cattle population. The analyses indicated that only 8% of cattle population could be explained by rainfall amounts received at this station. For every unit change in annual rainfall, the model revealed a corresponding change in cattle population by 132.84 (Fig. 4.17).

Fig. 4.17: Best Fit diagram showing relationship between Annual Cattle Population and Rainfall Amount at M.S.W. Met.Station.



Cattle Population = 596387.48 + 132.84 * M.S.W

R-Square = 0.00

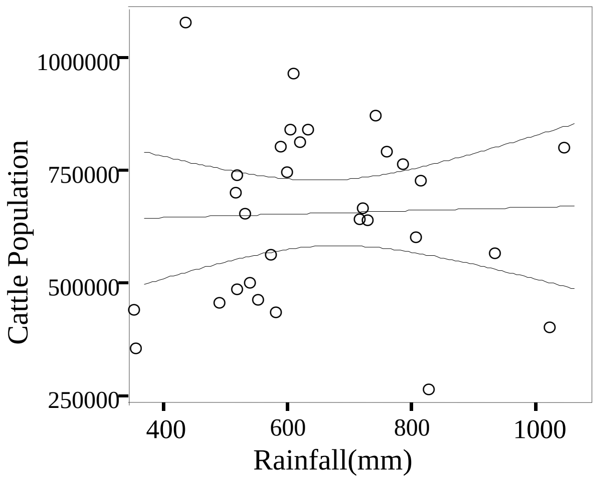
To determine the degree to which annual rainfall at this station explained cattle numbers, a regression line was generated with curve fitting (Fig. 4.17). It showed that a few rainfall observations explained cattle production. By being far from unity of annual rainfall observation, r^2 indicated the non-existence of a good curve fitting. It is also notable that r^2 of 0.00 expressed no magnitude of correlation between cattle numbers and annual rainfall amounts.

4.6.2. Annual Cattle Population and Rainfall at Mashuru Meteorological Station

The association between annual rainfall at Mashuru and annual cattle population in Kajiado had a correlation coefficient value of 0.064, with failed significance value of

0.734 tested at 0.05 confidence level (Table 4.5, pg 50). This was an indication of a low association between annual rainfall amount and cattle population, an implication that a larger percentage of about 94% fluctuation is a result of other factors.

Fig. 4.18: Best Fit diagram showing relationship between Annual Cattle Population and Rainfall Amount at Mashuru Met. Station



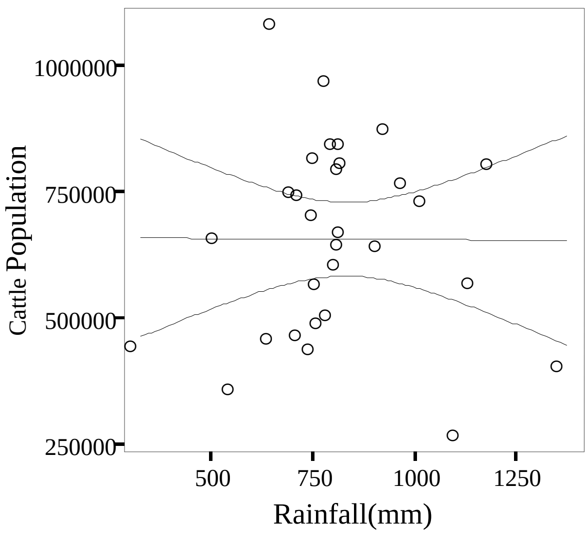
Cattle Population = 629641.80 + 38.16 * Mashuru
R-Square = 0.00

To check on how annual rainfall over this station explained cattle numbers, a regression line was generated with curve fitting (Fig 4.18). Far and widespread scatter plots showed that a few rainfall observations explained cattle population where an increase in unit rainfall resulted in rise in cattle population only by 38.16. By being far from unity of annual rainfall observation, r^2 of 0.00 indicated that the model could not explain the magnitude of relationship.

4.6.3. Annual Cattle Population and Rainfall at N.D.O. Meteorological Station

Table 4.5 (pg 50) shows that the association between annual rainfall at N.D.O and annual cattle population in Kajiado had a correlation coefficient value of 0.023. This was an indication of a very low and negative association between annual rainfall amount and cattle population, an implication that a larger percentage of about 98% fluctuation is a result of other factors. A test of significance of 0.05 confidence level yielded 0.9, a value showing lack of a significance correlation.

Fig. 4.19: Best Fit diagram showing relationship between Annual Cattle Population and Rainfall Amount at N.D.O Meteorological Station



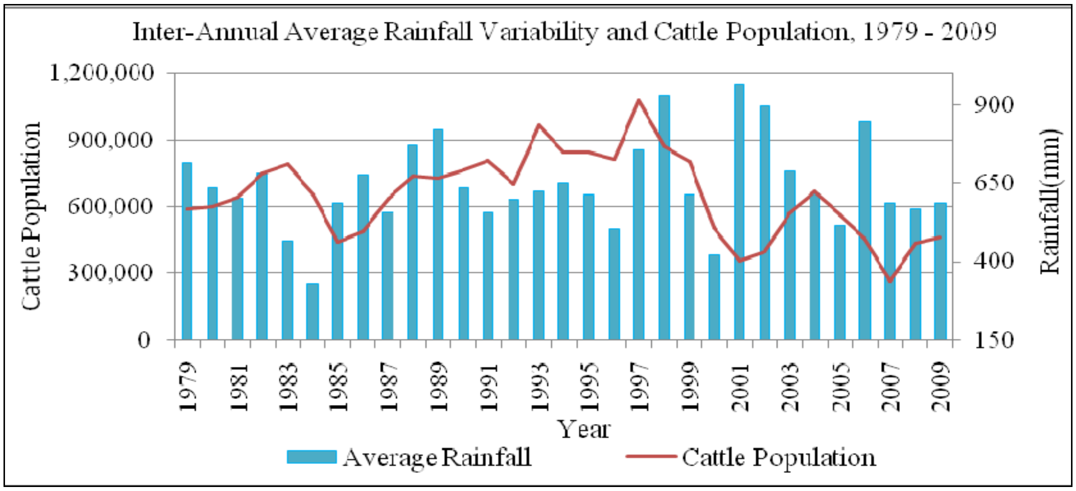
Cattle Population = 658861.02 + -4.46 * N.D.O
R-Square = 0.00

The degree to which annual rainfall amounts at this station affected cattle performance was established to be nil (Fig. 4.19), a result justified by the numerous scatter points far spread from the regression line. A rise in unit cattle population was a result of a decline in annual rainfalls by a factor of 4.46 at this station.

4.6.4 Cattle Populations and its Association with Annual Rainfall over Kajiado County

The total livestock population in Kajiado followed “up and down” pattern whereby population increased for a couple of years and then crashed. Even though there was weak correlation between rainfall amounts and cattle population, trends reveal that cattle respond positively to increase in rainfall and declines with poor rainfall performance (Fig. 4.2). The increase in population could be explained by abundance of forage and water during rainy years which in turn results in increased livestock birth rates and reduced mortality rates. Conversely, the population crashes are due to shortage of water and forage which cause increased mortality and reduced birth rates.

Fig. 4.21: Inter- Annual Average rainfall variability and annual cattle response in Kajiado between 1979 and 2009.



The results suggested that livestock populations were likely to be influenced by multiple poor rainfall years than single drought years as reported in other studies (Oba, 2001). It follows that recovery in cattle population appears to be affected by the length of dry season/year preceding a wet one and the length of the wet season/year itself. After the high rainfalls characterizing the ENSO of 1997/98 which saw a boom in cattle numbers to a 31 years maximum of 1,080,073, a drop in rainfall for two consecutive years in 1999 and 2000, to a low of 612.3mm and 419.2mm respectively, corresponded to a fall in livestock numbers to 802,930 and 502,802 in the same years. Despite a rise to above mean rainfalls in 2001 (962.1mm) and 2002(896.6mm), cattle population continued to fall deeper to a low of 354,386 and 400,406 in the same years. An attempt to recover to an equilibrium number thus is from time to time interrupted by intervening poor rainfall years. Such had also been previously experienced in 1985/86. However, constant rise in rainfalls from 1987 to 1989 had led to a rise and less fluctuations in cattle numbers until 1991 before it got slightly interrupted by poor rains of 1991(Fig. 4.2). The livestock population in Kajiado County therefore continued to fluctuate continuously without stabilizing. The results thus support arguments by Boone *et al.*, (2002) that if rainfall variability is high, the livestock populations are modulated by frequent droughts and subsequently never reaching equilibrium (Boone 2002 *et al.*, citing Ellis and Galvin, 1994).

CHAPTER FIVE

5.0. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. SUMMARY

Rainfall over Kajiado had overtime revealed high variability both spatially, seasonally and inter-annually, implying that climate variability is experienced in the area. Spatially, rainfall variations revealed that Mashuru to the East exhibited higher climate variability (C.V. = 26%) compared to areas around Ngong in the North (C.V. = 24%) and areas around Lake Magadi in the West (C.V=21%). Annual mean rainfall over the three study stations respectively showed a large variation in amounts of 830.3mm, 671.1mm and 449.3mm at N.D.O, Mashuru and M.S.W. Meteorological Stations. Similarly, there was higher variability during the short-rain seasons as compared to long-rain seasons over the three stations. Short-rain seasons at N.D.O. respectively registered a mean, standard deviation and variability coefficient of; 208.18mm, 102.54 and 49%. Mashuru Meteorological Station had a mean of 203.31mm, standard deviation of 28.23mm and a C.V of 50%, while M.S.W. Meteorological Station yielded a mean 35.63mm 15.82mm and 44% mean, standard deviation and C.V. respectively. Long-rain seasons over the county registered a C.V. of 34%, 40% and 39% at N.D.O, Mashuru and M.S.W. Meteorological Stations respectively.

Forage over Kajiado County had a long-term mean performance of 0.309 NDVI-value for the 23 year. Within this period, fourteen years registered below mean NDVI with only nine years recording above mean performance. Seasonally, Middle of May had the highest forage growth of 0.416 NDVI, while the poorest performing month was in September with values of bellow 0.2. On an annual calendar, the area had recorded bellow mean NDVI-values between the months of July to the middle of November while the rest of the months had an above mean NDVI. Results indicated that forage indices over the Rift Valley ecozones were strongly correlated to rainfall, accounting for 74% of forage present at onset and 92% at peak. Over Ath-Kapiti ecozones, rainfall accounted for 48% at onset and 89% at its peak. Graphical analyses revealed that forage availability was highest over the Central Hills followed by Athi-Kapiti ecozones. It however fluctuated with seasons between Rift Valley and Amboseli Ecozones with Rift Valley registering higher performance during the long-rain season but gets overtaken by Amboseli in the short-rain season. Generally, forage over the county maximally and uniformly (over all the ecozones) responded to rainfall in the third dekad of onset.

A correlation analyses of the nature of relationship between cattle and rainfall yielded a positive but low correlation coefficient values of 0.023, 0.064 and 0.083 for N.D.O, Mashuru and M.S.W Meteorological Stations respectively and 0.053 for their average. This was an indication of a weak association between annual cattle numbers in Kajiado and the annual rainfall recorded at the three stations, an implication that rainfall variability is not the sole parameter impacting upon cattle production in the area and that other factors largely contribute in the trends. At a significance of 0.05, the correlations yielded values of 0.901, 0.734, 0.656 and 0.777, values far much lower than 95% thus negating the hypothesis that climate variability impacts positively on cattle population in Kajiado County.

5.2. CONCLUSION

Findings of this study showed that both inter-annual and seasonal climate variability is high in Kajiado County and as such the rainfalls were unreliable and unpredictable. Comparisons of C.Vs showed that there existed spatial climate variability to a tune of 5% while on a seasonal account the variability range was wider to a tune of between 5 to 15 percent. Rainfall had a direct and significantly high influence on forage performance. The high correlation coefficients over the two ecozones of Rift Valley (arround Lake Magadi) and Athi-Kapiti indicates that in arid and semiarid regions, NDVI correlates well with percentage vegetation cover, biomass, and biological productivity (Nicholson 1994). Solely considered, annual rainfall amount was found not to be a good predictor of annual cattle population and that other factor such as; cattle population itself, water availability, competing land-use activities and socio-cultural and economic transformations contribute more to fluctuations in cattle numbers.

It is however important to note that climate variability may not only be of negative impact as frequently reported; it also presents vast opportunities for pastoralists, so long as appropriate managerial practices are put in place. In as much as increasing and stable/less variable precipitation would be more beneficial to pastoralists, it is important to note that although pasture and ecosystems are more productive with more precipitation, lower precipitation may help reducing animal diseases that are quite significant for livestock.

5.3. RECOMMENDATIONS

Responses to climate variability and change involve two main strategies of: adaptation to reduce sensitivity to climatic changes and mitigation to reduce the magnitude of climate change impact in the long run. These are however best founded on strong policy. Pastoralist policy makers should therefore come up with strong policies that would be based on pastoral systems management.

Most appropriate to effect both in policy is availability of climate data and weather information for decision makers and researchers on ASALs. This would only be made successful by installing effective weather stations in each and every ecozones to enhance precision and data reliability. Livestock counts should also be conducted within time periods less than a year; such as monthly or quarterly counts. More effort also needs to be put in educating pastoralists on climate variability and how it impacts on primary resources of pasture/browse as well to increase knowledge on effects of climate variability on livestock population dynamics as it will ensure that appropriate management practices are adopted to cope with recurring problems associated with the phenomena.

This research was limited only to three climate variability impact attributes of rainfall, forage and cattle. Researches should advance by imputing other physical variables such as; temperatures, humidity, soil factors as well and human factors such as insecurity and demographics. In addition, the focus of this research was on two linearly interrelated dependent variables and one independent variable. Analyzes were also independently done on the relationship between the dependent and independent attributes thereby leaving a gap on how and what is the connectivity and linear relationship that could exist between the three. The study thus recommends that further researches design an interlink and come up with an integrative model for building a pastoralist early warning system.

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APPENDICES

Appendix 1: Monthly Rainfall at N.D.O. Meteorological Station, 1964 – 2011

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1964	39.4	98.8	71.2	319.0	85.5	1.3	77.0	44.4	58.9	20.8	36.6	22.4	875.3
1965	99.6	5.3	34.3	225.8	79.7	21.4	4.3	8.2	10.2	61.2	86.6	68.8	705.4
1966	90.5	25.1	102.9	220.7	136.3	13.0	2.6	34.9	11.7	37.4	108.5	6.9	790.5
1967	0.0	6.9	211.3	211.3	342.1	24.9	19.5	44.4	19.7	49.3	95.4	40.9	1065.7
1968	0.0	119.6	97.4	183.6	227.0	66.8	0.0	0.0	0.0	34.3	232.1	69.1	1029.9
1969	56.6	43.7	98.3	2.8	172.2	22.9	0.0	31.7	8.4	52.4	78.1	0.0	567.1
1970	130.4	54.9	63.6	259.8	171.8	20.6	0.0	0.0	2.0	27.1	32.5	23.2	785.9
1971	29.8	19.1	3.8	150.3	268.1	17.7	19.8	39.9	16.5	11.4	26.5	124.1	727.0
1972	0.0	96.6	72.6	5.1	191.5	147.4	4.9	0.0	36.0	118.1	113.5	7.6	793.3
1973	145.6	62.6	1.3	105.9	53.0	42.5	0.0	6.0	64.0	7.0	69.0	13.5	570.4
1974	15.0	6.5	99.0	315.0	65.0	69.0	104.5	1.5	19.7	16.2	61.5	55.0	827.9
1975	0.0	1.0	35.2	204.1	149.2	20.9	47.7	5.9	70.8	48.2	41.1	66.4	690.5
1976	3.2	14.8	23.1	68.9	79.9	75.0	19.8	12.5	42.5	9.8	55.4	100.9	505.8
1977	38.2	90.5	6.0	382.0	213.1	75.0	16.0	37.0	10.0	25.5	174.6	66.4	1134.3
1978	163.4	32.5	407.0	289.0	55.0	11.0	0.0	20.1	45.0	70.2	39.6	119.1	1251.9
1979	42.0	152.3	144.6	57.8	168.5	100.5	8.0	0.0	28.7	35.7	75.8	11.0	824.9
1980	50.5	27.0	20.2	115.0	292.3	32.0	4.8	27.1	7.5	7.8	196.7	49.4	830.3
1981	2.0	1.5	82.4	280.9	205.3	16.5	19.1	14.2	31.1	39.8	11.0	12.0	715.9
1982	0.0	20.2	16.5	156.6	122.1	38.3	14.6	7.5	28.6	153.3	187.9	84.8	830.4
1983	0.0	105.6	0.0	169.8	31.7	49.7	10.4	8.0	0.0	0.0	0.0	148.4	523.6
1984	6.9	0.0	0.0	59.7	0.0	0.0	15.5	17.5	23.8	86.5	79.7	37.0	326.6
1985	0.0	178.1	143.0	207.0	58.4	30.4	5.9	0.0	4.4	19.2	101.5	31.7	779.6
1986	16.9	21.6	66.7	255.6	231.8	21.2	9.5	11.0	9.1	31.7	132.5	118.9	926.4
1987	41.9	28.4	27.5	250.9	132.8	68.9	16.2	12.9	16.3	24.6	100.3	11.8	732.6
1988	71.3	35.8	176.7	287.1	154.7	91.8	12.5	14.3	23.9	27.0	41.4	100.7	1037.2
1989	100.7	32.1	66.6	249.8	163.6	20.6	35.5	16.1	14.2	39.5	78.4	171.5	988.5
1990	48.1	36.0	261.9	162.8	115.8	19.8	10.8	13.7	11.7	35.8	73.2	51.6	841.2
1991	29.7	22.8	148.9	140.0	151.1	40.2	10.4	10.8	10.6	33.7	124.7	47.6	770.6
1992	0.5	29.2	30.8	362.9	105.8	30.3	48.3	13.0	11.1	36.7	54.8	75.8	799.3
1993	287.2	73.8	13.6	31.0	140.0	53.5	9.3	14.2	8.6	40.8	103.1	59.5	834.5
1994	11.5	47.8	56.5	164.1	133.3	70.6	13.8	22.0	9.8	47.5	206.5	34.1	817.6
1995	40.7	51.4	134.3	88.8	139.7	78.7	17.3	15.6	19.9	64.1	97.3	24.5	772.4
1996	6.1	41.4	133.4	101.1	107.5	73.0	15.1	17.4	10.5	25.8	136.7	0.0	668.0
1997	0.0	21.5	19.8	288.7	144.1	23.5	12.6	18.6	8.6	58.6	271.3	79.4	946.6
1998	461.5	77.9	76.0	92.3	314.8	63.4	37.1	14.9	14.2	0.1	31.2	16.7	1200.0
1999	2.0	21.5	124.9	151.0	81.9	19.6	11.2	19.7	17.6	35.2	218.0	102.8	805.4
2000	9.2	21.5	30.7	93.5	103.7	51.0	10.6	11.7	20.5	38.9	115.3	60.1	566.8
2001	492.8	24.6	274.1	114.4	121.4	65.3	24.8	16.3	16.7	46.4	111.0	66.3	1374.0
2002	147.6	42.6	81.6	174.8	186.9	32.4	15.7	16.1	16.0	59.3	235.0	145.0	1153.0
2003	89.3	44.2	56.1	178.5	263.9	33.6	14.8	23.8	17.3	37.2	56.0	22.5	837.3
2004	25.9	47.4	96.7	231.7	140.9	31.9	10.2	10.5	24.5	28.7	62.4	65.6	776.5

2005	22.9	36.6	96.8	139.3	172.2	32.8	17.2	15.2	17.1	33.6	56.2	21.2	661.0
2006	71.4	40.3	107.3	216.4	128.7	31.8	17.3	17.6	19.8	23.0	326.5	118.0	1118.2
2007	91.6	67.7	66.2	144.7	153.6	41.5	15.8	16.4	29.7	28.5	64.6	39.6	759.8
2008	5.1	47.8	145.0	143.4	93.5	31.7	15.6	17.6	22.7	66.3	125.5	13.8	728.0
2009	41.3	28.1	45.7	150.6	160.2	45.7	14.3	14.1	19.1	48.2	90.1	97.1	754.4
2010	126.5	53.3	84.7	132.1	164.2	36.2	12.4	18.3	27.8	60.4	100.5	34.1	850.5
2011	55.5	36.4	104.5	105.8	125.4	46.6	18.6	19.5	33.9	136.0	187.4	113.2	982.8
Mean	**66.9**	**45.7**	**88.8**	**175.9**	**147.9**	**42.8**	**17.5**	**16.1**	**20.6**	**42.5**	**106.3**	**59.4**	**830.3**

Source: Kenya Meteorological Department, 2012

Appendix 2: Monthly Rainfall at Mashuru Meteorological Station, 1964 – 2011

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1964	40.0	40.0	0.0	204.0	71.0	7.0	4.0	4.0	3.0	25.0	11.0	12.0	488.0
1965	70.4	0.0	24.5	225.9	45.6	55.7	4.2	0.0	0.0	40.3	81.2	58.1	605.9
1966	38.5	41.2	111.6	119.3	66.9	25.5	1.0	95.0	5.0	15.0	111.6	3.0	633.7
1967	0.0	40.2	14.4	217.8	453.6	16.7	5.0	16.8	8.5	69.7	88.0	6.5	937.2
1968	0.0	81.2	113.9	251.3	91.1	13.1	0.5	1.0	1.4	22.0	194.0	37.5	807.0
1969	67.7	40.1	51.0	11.0	125.5	0.0	0.0	0.0	0.1	26.8	75.3	67.2	464.7
1970	80.7	8.2	142.9	168.1	126.3	15.3	1.1	0.2	0.0	34.2	49.3	21.0	647.2
1971	44.6	0.4	5.3	221.5	258.6	8.0	2.9	11.0	13.0	8.5	33.2	88.9	695.8
1972	2.5	50.4	26.0	8.4	109.8	112.6	14.6	2.2	59.4	156.2	89.4	99.7	731.2
1973	140.0	63.5	41.3	188.7	66.2	11.1	3.2	0.0	64.6	9.4	51.4	12.6	652.0
1974	8.7	5.6	109.8	191.5	40.6	67.0	38.3	4.8	14.1	14.1	76.4	25.8	596.7
1975	0.0	0.0	18.3	101.3	71.7	3.7	6.4	0.1	74.8	46.8	72.5	28.1	423.8
1976	0.2	11.1	18.1	84.9	54.6	27.4	8.0	6.4	38.3	11.2	85.7	73.3	419.1
1977	14.2	36.0	26.9	347.0	237.4	51.5	22.0	66.3	11.1	17.6	186.8	95.1	1111.8
1978	105.9	25.1	166.6	169.7	21.4	2.2	3.3	18.4	3.1	49.2	70.2	108.3	743.3
1979	24.8	266.1	93.5	84.9	98.9	24.3	18.8	5.3	29.9	18.1	65.3	94.7	824.7
1980	67.4	3.8	37.3	79.0	350.2	11.9	0.3	2.2	1.5	11.2	150.4	18.5	733.7
1981	0.4	0.0	79.7	248.5	109.8	21.0	4.6	20.7	31.4	29.5	28.3	43.7	617.6
1982	0.8	8.0	21.3	147.1	124.9	3.6	7.2	0.6	9.5	142.0	168.1	144.0	777.2
1983	1.2	96.6	30.8	103.7	26.7	21.2	14.6	20.3	0.9	46.6	14.5	172.6	549.7
1984	3.0	0.0	3.3	65.0	0.4	2.2	7.1	14.6	8.0	109.8	93.5	63.7	370.6
1985	0.0	67.9	65.5	143.9	43.6	22.4	36.2	1.0	14.7	13.2	49.6	78.8	536.7
1986	10.5	0.0	47.9	218.2	230.3	1.1	0.0	0.0	0.0	9.9	119.4	108.6	745.9
1987	28.8	7.8	15.8	213.7	81.9	52.5	9.4	3.8	9.0	0.5	94.6	17.3	535.1
1988	58.2	19.3	138.0	247.8	114.6	77.7	2.9	7.3	20.5	4.2	49.0	92.8	832.5
1989	71.6	16.7	47.8	212.7	127.9	0.3	43.2	12.4	5.9	32.8	77.6	153.7	802.6
1990	33.1	19.6	207.7	130.7	56.3	0.2	1.4	5.9	2.1	24.2	73.7	51.2	606.2
1991	19.7	0.1	115.3	85.9	109.2	21.0	0.1	0.0	1.1	19.5	113.4	47.9	533.3
1992	0.3	9.0	18.5	318.7	41.4	10.2	65.7	4.0	1.1	26.4	59.4	72.0	626.7

1993	208.6	78.0	4.4	4.8	92.7	35.7	0.0	7.2	0.0	35.9	96.7	58.0	622.1
1994	6.6	38.0	39.6	131.0	82.6	54.4	5.2	28.4	0.4	51.2	176.5	36.4	650.4
1995	28.1	43.6	103.3	59.6	92.2	63.4	11.4	11.1	14.6	89.1	92.2	28.2	636.7
1996	2.7	28.1	102.5	71.3	44.0	57.1	7.6	16.0	0.3	1.5	122.7	0.0	453.6
1997	0.0	0.0	9.6	249.1	98.8	2.7	3.1	19.0	0.0	76.6	226.5	75.0	760.4
1998	336.3	84.4	55.6	62.9	354.2	46.6	46.2	9.2	5.9	0.0	41.3	21.0	1063.5
1999	0.3	0.0	95.1	118.6	5.6	0.2	0.7	22.1	11.2	23.2	185.3	94.9	557.3
2000	5.0	0.0	18.6	64.1	38.3	33.0	0.3	0.7	15.6	31.5	106.1	58.3	371.5
2001	359.0	2.3	217.7	83.9	64.8	48.7	24.6	13.0	9.8	49.9	102.8	63.6	1040.1
2002	106.4	30.1	60.2	141.1	162.9	12.5	8.7	12.5	8.7	78.9	198.4	131.2	951.6
2003	63.7	32.5	39.3	144.7	278.2	13.9	7.0	33.3	10.8	29.3	60.5	26.0	739.1
2004	17.3	37.4	72.5	195.0	94.0	12.1	0.9	0.0	23.9	10.3	65.4	63.0	591.8
2005	15.0	20.7	72.6	107.5	140.9	13.0	11.3	10.1	10.4	21.2	60.6	24.9	508.2
2006	50.6	26.4	81.2	180.4	75.8	11.9	11.5	16.4	14.6	0.0	268.8	108.0	845.7
2007	65.4	68.7	47.6	112.6	113.0	22.6	8.8	13.2	29.7	9.8	67.1	40.7	599.1
2008	2.0	38.1	112.1	111.4	23.0	11.9	8.5	16.4	19.0	94.6	114.0	18.5	569.6
2009	28.7	7.6	30.9	118.3	122.9	26.9	6.2	7.0	13.4	54.1	86.8	90.0	592.7
2010	90.9	46.5	62.7	100.7	129.0	16.8	3.0	18.5	26.8	81.4	94.8	36.0	706.9
2011	38.9	20.4	78.9	75.8	70.8	28.2	13.8	21.6	36.1	251.4	161.7	103.8	901.6
Mean	**49.1**	**32.5**	**65.9**	**144.6**	**113.3**	**25.0**	**10.5**	**12.5**	**14.2**	**42.2**	**99.2**	**62.0**	**671.1**

Source: Kenya Meteorological Department, 2012

Appendix 3: Monthly Rainfall at M.S.W. Meteorological Station, 1964 – 2011

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1964	24.5	48.3	55.7	149.6	27.4	1.7	24.9	21.4	2.3	9.1	23.7	9.8	398.4
1965	19.5	57.1	72.7	157.0	20.7	0.5	0.0	0.0	14.3	69.1	10.8	55.6	477.3
1966	6.7	69.0	140.7	139.9	23.7	1.7	0.0	3.2	4.9	5.8	17.9	15.9	429.4
1967	0.0	18.4	5.9	159.1	90.1	0.2	1.5	6.3	7.7	18.0	30.5	81.5	419.2
1968	0.0	69.5	145.6	175.0	9.3	11.0	0.2	0.0	5.7	11.7	71.2	16.0	515.2
1969	99.9	59.9	32.2	13.0	96.3	1.0	0.0	1.7	1.1	19.4	56.1	6.4	387.0
1970	134.8	48.8	190.7	197.8	69.2	0.0	0.4	0.0	3.2	5.0	19.0	16.3	685.2
1971	63.0	13.0	35.0	130.7	76.3	0.0	15.0	18.3	0.0	15.2	26.9	146.6	540.0
1972	84.3	57.2	20.3	25.2	41.2	44.2	0.0	0.0	10.4	20.2	38.5	9.8	351.3
1973	111.6	50.5	0.0	100.9	12.5	9.8	0.0	1.3	20.5	7.5	31.1	25.7	371.4
1974	1.2	16.1	74.1	351.5	29.6	13.5	23.3	5.8	4.2	1.2	24.6	9.4	554.5
1975	21.8	15.3	58.4	111.9	86.5	0.0	27.7	0.0	17.0	23.9	11.6	104.6	478.7
1976	15.7	30.8	14.2	46.5	39.6	2.1	0.3	2.3	13.6	0.0	44.3	20.9	230.3
1977	60.8	52.7	16.5	236.7	101.8	1.9	17.6	2.4	0.2	18.6	78.6	52.5	640.3
1978	52.1	180.4	121.4	13.8	0.0	0.0	0.0	11.7	10.1	25.5	44.0	68.2	527.2
1979	88.2	64.4	81.6	126.5	13.1	4.5	8.7	0.0	8.4	33.2	18.6	50.6	497.8
1980	5.4	47.7	58.3	172.4	1.4	0.0	1.8	10.2	2.7	14.9	23.1	5.0	342.9

1981	42.8	146.9	154.8	62.0	0.0	0.0	0.0	4.9	19.2	19.8	15.8	4.6	470.8
1982	37.4	35.7	97.8	37.9	1.5	0.8	0.0	3.6	15.1	111.6	87.3	6.6	435.3
1983	92.0	7.3	12.9	20.4	5.2	1.4	0.5	3.1	41.4	25.1	41.8	74.8	325.9
1984	2.5	0.0	166.0	13.2	0.0	1.3	0.0	0.0	11.2	45.5	55.5	0.8	296.0
1985	88.9	72.5	131.3	21.7	2.3	0.0	0.0	0.0	24.9	24.9	21.8	60.3	448.6
1986	61.0	21.6	30.5	91.3	72.0	1.2	0.0	0.0	8.1	12.0	32.9	29.4	360.0
1987	77.9	27.7	47.3	66.7	55.5	25.4	6.2	0.0	6.2	0.9	75.4	7.6	396.8
1988	59.2	22.9	108.8	102.4	11.2	16.0	0.0	14.6	3.0	12.5	22.3	67.0	439.9
1989	48.0	31.4	73.1	199.0	95.9	2.4	2.7	2.7	37.0	16.6	2.9	161.7	673.4
1990	34.2	107.5	81.7	111.3	23.3	0.2	3.4	2.8	9.3	18.0	31.0	41.5	464.3
1991	21.9	25.7	67.1	97.9	21.2	8.9	3.4	3.3	9.3	17.2	46.9	39.3	361.9
1992	27.0	49.1	53.4	95.6	16.6	2.5	9.3	3.5	9.3	18.3	25.4	55.6	365.3
1993	66.0	52.2	47.9	29.0	80.5	20.2	0.0	3.6	9.2	19.9	40.2	46.1	414.8
1994	38.9	59.6	81.1	103.8	53.9	2.1	3.9	4.3	9.3	22.5	72.0	31.4	482.8
1995	43.9	40.3	96.9	59.4	75.9	6.1	4.5	3.7	9.6	29.0	38.4	25.9	433.5
1996	37.9	61.5	95.8	71.2	6.8	26.0	4.1	3.9	9.3	14.1	50.5	5.0	386.2
1997	36.7	24.7	55.7	178.2	76.2	0.0	3.7	4.0	9.2	26.8	91.9	57.6	564.7
1998	115.8	72.6	36.7	98.3	111.4	12.9	7.6	3.6	9.4	13.4	18.1	21.0	520.8
1999	37.2	24.3	164.4	58.5	8.1	0.0	3.5	4.0	9.5	17.8	75.5	71.1	474.1
2000	38.5	28.3	58.0	62.4	6.5	0.0	3.3	3.3	9.6	19.2	44.0	46.3	319.4
2001	121.1	49.3	51.0	103.1	10.6	3.5	5.6	3.7	9.5	22.3	42.6	49.8	472.3
2002	62.1	45.9	73.9	104.0	78.3	0.0	4.1	3.7	9.5	27.2	80.8	95.6	585.2
2003	52.1	47.3	55.5	107.7	141.9	0.1	4.0	4.4	8.1	18.8	25.7	24.4	490.0
2004	41.3	49.1	86.3	161.2	39.9	0.0	3.2	3.2	9.8	15.6	27.7	49.5	486.7
2005	30.8	39.3	96.7	68.7	66.5	0.0	4.4	3.6	4.2	17.4	25.8	23.6	381.1
2006	39.1	43.8	91.6	146.4	28.9	0.0	4.4	3.9	24.7	13.4	98.9	79.9	575.0
2007	52.5	67.8	57.6	73.6	50.1	4.2	4.1	3.7	10.1	15.5	28.4	34.3	402.1
2008	37.7	50.4	122.9	72.5	0.4	0.0	4.1	3.9	15.9	29.9	47.1	19.3	404.1
2009	44.0	33.1	40.6	82.0	55.9	6.9	3.9	3.5	11.7	23.0	36.2	67.7	408.6
2010	58.5	53.2	73.2	61.3	59.4	1.1	3.6	3.9	10.2	27.7	39.4	31.1	422.6
2011	46.4	36.2	89.8	34.8	26.5	7.1	4.6	4.0	10.5	56.6	66.1	77.1	459.7
MEAN	**49.6**	**48.5**	**75.5**	**102.1**	**42.1**	**5.0**	**4.7**	**4.1**	**10.8**	**21.9**	**41.2**	**43.8**	**449.3**

Source: Magadi Soda Works Meteorological Department, 2012

Appendix 4: Dekadal NDIV, 1982 – 2004.

	Ecozones			
Dekads	**Amboseli**	**Central Hills**	**Athi-Kapiti**	**R.V(Magadi)**
1-10 Jan	0.3707	0.4439	0.3757	0.2931
11-20 Jan	0.3735	0.4470	0.3763	0.3031
21-31 Jan	0.3671	0.4505	0.3774	0.3158
1-10 Feb	0.3573	0.4486	0.3735	0.3180
11-20 Feb	0.3426	0.4442	0.3633	0.3205
21-28 Feb	0.3351	0.4404	0.3534	0.3212
1-10 Mar	0.3160	0.4248	0.3406	0.3221
11-20 Mar	0.3119	0.4202	0.3366	0.3222
21-31 Mar	0.3044	0.4163	0.3334	0.3313
1-10 Apr	0.3234	0.4495	0.3529	0.3525
11-20 Apr	0.3301	0.4657	0.3797	0.3751
21-30 Apr	0.3357	0.4823	0.4075	0.3904
1-10 May	0.3205	0.4975	0.4545	0.3924
11-20 May	0.3080	0.4908	0.4548	0.3823
21-31 May	0.2940	0.4847	0.4648	0.3548
1-10 Jun	0.2662	0.4455	0.4431	0.3226
11-20 Jun	0.2481	0.4142	0.4255	0.2847
21-30 Jun	0.2217	0.3825	0.4056	0.2456
1-10 Jul	0.1967	0.3144	0.3270	0.2240
11-20 Jul	0.1909	0.2940	0.3042	0.1985
21-31 Jul	0.1887	0.2741	0.2826	0.1875
1-10 Aug	0.1759	0.2289	0.2339	0.1736
11-20 Aug	0.1802	0.2251	0.2254	0.1668
21-31 Aug	0.1833	0.2235	0.2181	0.1634
1-10 Sep	0.1801	0.2235	0.2097	0.1544
11-20 Sep	0.1780	0.2204	0.2007	0.1515
21-30 Sep	0.1805	0.2182	0.1925	0.1518
1-10 Oct	0.1877	0.2242	0.1933	0.1534
11-20 Oct	0.1915	0.2365	0.2006	0.1566
21-31 Oct	0.2101	0.2494	0.2097	0.1642
1-10 Nov	0.2317	0.2954	0.2620	0.1914
11-20 Nov	0.2620	0.3356	0.3013	0.2120
21-30 Nov	0.2933	0.3765	0.3415	0.2318
1-10 Dec	0.3470	0.4353	0.3918	0.2548
11-20 Dec	0.3642	0.4465	0.3995	0.2748
21-31 Dec	0.3852	0.4576	0.4065	0.2851

Appendix 5: Annual Rainfall and Cattle Population

YEAR	N.D.O	Mashuru	M.S.W	Average Rainfall	Cattle Population
1979	824.9	824.7	497.8	715.8	591,341
1980	830.3	733.7	342.9	635.6	602,800
1981	715.9	617.6	470.8	601.4	644,000
1982	830.4	777.2	435.3	681.0	748,000
1983	523.6	549.7	325.9	466.4	792,000
1984	326.6	370.6	296.0	331.0	655,000
1985	779.6	536.7	448.6	588.3	442,540
1986	926.4	745.9	360.0	677.5	486,600
1987	732.6	535.1	396.8	554.8	639,152
1988	1037.2	832.5	439.9	769.9	741,220
1989	988.5	802.6	673.4	821.5	727,730
1990	841.2	606.2	464.3	637.2	765,010
1991	770.6	533.3	361.9	555.3	806,130
1992	799.3	626.7	365.3	597.1	700,000
1993	834.5	622.1	414.8	623.8	966,390
1994	817.6	650.4	482.8	650.3	842,700
1995	772.4	636.7	433.5	614.2	842,700
1996	668.0	453.6	386.2	502.6	814,992
1997	946.6	760.4	564.7	757.3	1,080,073
1998	1200.0	1063.5	520.8	928.1	873,813
1999	805.4	557.3	474.1	612.3	802,930
2000	566.8	371.5	319.4	419.2	502,802
2001	1374.0	1040.1	472.3	962.1	354,386
2002	1153.0	951.6	585.2	896.6	400,406
2003	837.3	739.1	490.0	688.8	567,200
2004	776.5	591.8	486.7	618.3	667,700
2005	661.0	508.2	381.1	516.8	564,964
2006	1118.2	845.7	575.0	846.3	457,982
2007	759.8	599.1	402.1	587.0	264,863
2008	728.0	569.6	404.1	567.2	436,271
2009	754.4	592.7	408.6	585.3	464,230

Source (Cattle Population): Kajiado District Livestock Development Office, 2011