IMPACTS OF CLIMATE CHANGE ON SPATIAL AND TEMPORAL DISTRIBUTION OF RANGELAND VEGETATION IN KENYA

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DECLARATION AND CERTIFICATION

DECLARATION

This thesis is my original work prepared with no other than the indicated sources and support and has not been presented elsewhere for a degree or any other award.

Sign: ……………………………… Date: ……………………………….

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology a thesis entitled "**Impacts of climate change on spatial and temporal distribution of rangeland vegetation in Kenya".**

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DEDICATION

I dedicate this work to my wife, Jackline and daughters Audrey and Ashlyn, my mum and my uncle Wilson.

ACKNOWLEDGEMENT

Foremost, I wish to recognise the invaluable guidance from my supervisors Dr. F. N. Muyekho, Dr. E. N. Masibayi and Dr. S. M. Makindi. My gratitude also goes to NACOSTI/NRF for their partial field work funding, Z. Odira and other staff of MMUST for their support in this research.

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ACRONYMS AND ABBREVIATION

AEZ	Agroecological Zones
AOI	Area of Interest
ASALs	Arid and Semi-arid Lands
ASDS	Agricultural Sector Development Strategy
CC	Carrying Capacity
CEM	Climate Envelop Modelling
CHIRPS	Climate Hazards Group InfraRed Precipitation with Stations
CIAT	International Center for Tropical Agriculture
CSA	Climate Smart Agriculture
DM	Dry Matter
EACCCMP	East African Community Climate Change Master Plan
EMCA	Environmental Management and Coordination Act
ENM	Ecological Niche Models
ERS	Economic Recovery Strategy
FAO	Food and Agriculture Organization of the United Nations
FESWNET	Famine Early Warning Systems Network
GCM	General Circulation Models
GDP	Gross Domestic Product
GHA	Greater Horn of Africa
GIS	Geographical Information System
ICRC	International Committee of the Red Cross
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
KALRO	Kenya Agriculture and Livestock Research Organization

KCCAP	Kenya Climate Change Adaptation Programme
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KIs	Key Informants
KWS	Kenya Wildlife Service
LULC	Land Use Land Cover
Maxent	Maximum Entropy
MCK	Map Comparison Kit
MODIS	Moderate Resolution Imaging Spectroradiometer
NAP	National Adaptation Plan
NCCRS	National Climate Change Response Strategy
NDMA	National Disaster Management Authority
NDVI	Normalized Difference Vegetation Index
NEMA	National Environmental Management Authority
NPP	Net Primary Productivity
PBO	Parliamentary Budget Office
PDNA	Post-Disaster Needs Assessment
RCP	Representative Concentration Pathways
SRES	Special Report on Emission Scenarios
TLU	Tropical Livestock Unit
UNEP	United Nations Environment Program
USGS	United States Geological Service
WMO	World Meteorological Organization
WRI	World Resources Institute

ABSTRACT

Rangeland vegetation are important resources for livestock, wildlife and human beings and are largely influenced by climatic conditions. The effects of climate change are varied and among them is uncertainty in dynamics of rangelands vegetation. The rangeland vegetation in Kenya supports the key economic activities of livestock and tourism. This significant contribution to GDP underscores the need to model the impacts of climate change on the rangeland vegetation for the country to promote sustainable development. This study analysed the spatio-temporal trend of rainfall and vegetation from 2001 to 2015 and also modelled the impacts of climate variations on the spatial and temporal distribution of rangeland vegetation in Kenya in the base-year and the future climatic periods of the years 2050 and 2070. The study further conducted Key Informant interviews to analyse Kenya's mitigation and adaptation measures in relation to the projected climate impacts on the rangelands vegetation. The research was accomplished by trend analysis of Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data of fifteen years (2001 to 2015), modelling the influence of climate on the rangeland vegetation in the base-year (1960 to 2000), 2050 and 2070 climatic periods, establishing the ASALs livestock carrying capacity and a critical analysis of Kenya's climate change and related policies and legislations. The spatial data was sourced from USGS, ILRI, and Africover Project processed and analysed in ArcGIS, DIVA-GIS, Maxent, Map Comparison Kit and Geoda softwares. The monthly rainfall trend ranged from -15 to 20 mm while the annual trend showed a reduction of -6 to 0 mm in the entire country which shifted spatially in some years; the monthly MODIS NDVI trend was between -0.065 to 0.060; the dependence of MODIS NDVI on rainfall was significant with annual coefficients of determination of 0.541 in 2002 and 0.763 in 2006 and the fifteen years mean at 0.617. Results of modelling show that the 2050 climate will decrease grass niche suitability by 44.99%, the unsuitable will increase by 87.01%, the grass niche suitability location will shift by 76.7% and the category areas change by 46.4%; the 2070 climatic period grass niche suitability will shrink by 55.21%, the unsuitable category increase by 106.80%, the location will shift by 77.8% and the category areas will change by 66.0%; the Kenyan ASALs livestock carrying capacity patterns were the same as the grass niche suitability; and the reviewed climate change policies and legislations demonstrated that Kenya has responded adequately to climate change. The research concluded that the rangeland vegetation (grass) will decline and shift location in the both future climatic periods. The study made the following recommendations; further research using more refined spatial datasets; inclusion of other variables in Maxent model; modelling future seasonal grass niche suitability and livestock carrying capacity changes; model grass niche suitability using other representative community pathway climate data; and policy reorientation to focus on impacts in a specific area.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Rangeland vegetation are important resources depended upon directly by livestock and wildlife and indirectly by human beings. The rangelands according to World Resources Institute (1986) are defined as wild forage-producing areas under native grass and other forage plants used, among other things, for livestock, wildlife, and watershed maintenance that can be too rocky, steep, poorly drained or cold to farm. The rangeland vegetation support livestock grown for meat, hides, skins and wildlife which is critical for economic development for Kenya (Kenya Institute for Public Policy Research and Analysis (KIPPRA), 2014). Most of these resources are located in the ASAL regions which constitute 40.5% of the terrestrial area excluding Greenland and Antarctica (FAO, 2005) and are largely influenced by climatic conditions (Allen *et al.*, 2010; Crimmins *et al.*, 2011). Anomalies in climate have been documented by many researchers who have come up with models to develop climate scenarios with regard to the changing atmospheric conditions (IPCC, 2007; Settele *et al.*, 2014).

The average weather parameters taken over long periods of more than thirty years define the climate of a particular area (Goosse *et al.*, 2010). Climate change denotes an abnormality in the state of the climate that can be identified by the variability of its properties and that persists for a decade or more years (Settele *et al.*, 2014). Wilby and Dawson (2007) in their studies concluded that climate alteration may be due to naturally occurring processes or anthropogenic activities and science has unearthed evidence of climate change in the past as a result of natural phenomena. The current climate change is believed to have been largely influenced by human activities through release of greenhouse gases to the atmosphere. These gases have altered the composition of the atmosphere, upsetting the earth's heating system (Hegerl *et al.*, 2007).

The development of human society has generated more greenhouse gasses that are responsible for the earth's warming effect (IPCC, 2007). The influx of these greenhouse gases have led to entrapment of more heat setting up other adjustments in the earth systems. Scientific research has shown that the earth has warmed up by an average of about 0.6 ^{o}C since the late 19th century (Settele *et al.*, 2014). It is also projected by (Settele *et al.*, 2014) that the temperature will increase by 1.4 ^{o}C to 5.8 ^{o}C by the year 2100 at a global scale. Temperature anomalies in Kenya are reported to be 0.4 to 1.6 ^{o}C with climate change related deaths of 70 to 120 per million population (Patz and Olson, 2006). This warming up has triggered other events on the earth's surface like melting of the arctic ice, rise in sea level, change in rainfall patterns, its quantity and frequency among others.

The changes in temperature and rainfall patterns will have a direct impact on the land use land cover (LULC) (Stephenson, 1990) and other organisms. In reference to vegetation, climate change can cause significant effects on its spatial and temporal distribution. Variations in vegetation which is an important ecosystem and a natural resource will disrupt both ecological and economic activities that are directly or indirectly depending on it. Ecologically, particular biomes have distinct characteristics including the animals supported by natural vegetation (Campbell, 1996). Ecosystems such as tropical rangelands support directly and indirectly a huge number of livestock, herbivores and carnivores respectively which support key economic activities in Kenya (KIPPRA, 2013). These economic activities are ranching, livestock keeping, tourism and agriculture and directly depend on weather.

Hegerl *et al.* (2007) findings indicate that developing countries such as Kenya will be hit by climate change because Kenya's economy is largely dependent on agriculture and wildlife which are sensitive to climatic changes. A large part of the country (about 80%) is classified as arid and semi-arid lands (ASALs) and is prone to drought and floods. Many livestock keeping communities, ranches, and game reserves are located in these regions in Kenya. In addition, the country's population is growing and people are migrating to these fragile ecosystems increasing pressure on the limited vegetation resources (GoK, 2012e). Climate change is therefore a concern for Kenya as it plans to advance sustainable utilization of its natural resources and promotion of Vision 2030, Sustainable Development Goals and Africa's 2063 Agenda. To achieve these goals, it is necessary to model the effects of climate change on the spatial and temporal rangeland vegetation distribution in order provide useful information to the policy and decision makers at the local, regional and national level. Such important information includes the nature of investment by the government and the locals with regard to rangeland vegetation availability and future management. If the model predicts an increase in rangeland vegetation distribution, then the investments should be geared towards development of livestock, wildlife and tourism related economic activities. In case of decrease in rangeland vegetation resources, the only option available is to invest in other areas of economy that are not threatened by climate change impacts.

Incidentally, geographical information system (GIS) is being applied in environmental analysis and ecological modelling studies. Trends in vegetation is monitored by use of Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) while temperature and rainfall data is used in climate monitoring. Researchers including Ward (2007) and Zonneveld *et al.* (2009) have used GIS in their studies and have recommended its application in similar studies as they are easy to use, integrate a lot of information and perform complex analysis. Geographical information system provides a very effective means for graphically conveying multifaceted information and display data that make present and future pattern observation clear of interested features, facilitating communication of ideas, policy formulation and resources management.

Kenya covers a land area of 582,646 km^2 with approximately 80% of this area being arid and semi-arid lands (ASALs) and is divided into seven agro-climatic zones using a moisture index (Sombroek *et al.,* 1982). The index used is annual rainfall expressed as a percentage of potential evaporation. The areas with an index > 50% have a high cropping potential and are grouped into zones I, II, and III. These account for 12% of Kenya's land area. Semi-humid to arid regions receive less than 1000 mm of rain and have moisture indices < 50%. These are classified into zones IV, V, VI, and VII and are generally referred to as savannah grasslands (De Leeuw *et al.,* 1991). These are the regions where livestock and tourism form the bulk of economic activities (KIPRA, 2014). The Kenya Wildlife Service (KWS) lists 54 National Parks and Reserves under its jurisdiction (KWS, 1996) with 34 (63%) located in the savannah rangelands.

It is estimated that receipts from tourism related activities in 2012 was Ksh 96.02 billion according to KIPPRA (2013). The livestock development sub-sector contributes about 42 per cent of agricultural GDP, which is about 10% directly to the overall GDP (KIPPRA, 2013) and also accounts for about 30 per cent of total agricultural production, which earns the country foreign exchange through the export of live animals, dairy products, hides and skins. Emerging challenges linked to climate in the livestock and tourism industry include emergence of new diseases and frequent drought that affect rangeland vegetation and animals. Higher temperatures are responsible for crop and livestock diseases and pests in areas their prevalence was hitherto unknown. The country has experienced a reduction in the famine cycle from 20 years (1964 to1984), to 12 years (1984 to 1996), to 2 years (2004 to 2006) and to yearly 2007/2008/2009) (Government of Kenya, 2009). At the same time, drought events have become more severe. For example, the impacts of the 2008-2011 drought is estimated at Ksh 968.6 billion (US$ 12.16 billion) and was responsible for an average 2.8% per annum decline in GDP (GoK, 2012a). During the 2008-2009 and other previous droughts in Kenya, the drought impact on livestock was devastating with loses up to 65% of some livestock (Tables 1.1 and 1.2).

Table 1.1: Livestock mortality (%) during the 2008-2009 drought in two Kenyan ASAL districts.

Area	**Cattle (%)**	**Sheep (%)**	**Goats (%)**	**Camel**	**Donkey**
Samburu Central	57	65	13	6	16
Laikipia North	64	62	34	1	-

(Source: Zwaagstra *et al.*, 2010)

Table 1.2: Livestock mortality rates (%) reported for previous droughts.

Area	**Cattle (%)**	**Shoats (%)**	**Year**	**Author**
Amboseli	32	26	2005	Zwaagstra *et al.*,(2010)
Kitengela	45	44.5	2005	Zwaagstra *et al.*, (2010)
Maasai Mara	29	21	2005	Zwaagstra *et al.*, (2010)
Simanjiro	13	17	2005	Zwaagstra *et al.*,(2010)
Kajiado	50	20	2000	UNEP and GoK (2000)

(Source: Zwaagstra *et al.*, 2010)

1.2 Statement of the Problem

The economy of Kenya and large portions of the population depend directly on natural resources including rangelands. Rangeland vegetation supports wildlife and pastoral activities which are some of the key economic activities identified as pillars of Kenya's Vision 2030 (GoK, 2006). The contribution to Kenya's GDP by the livestock and tourism industries are 13% and 10% respectively and is therefore significant (KIPPRA, 2014) and extremely dependable. These important ecosystems directly depend on climate (rainfall and temperature) that has been documented to be changing over time with devastating outcomes in some cases (GoK, 2000). Critical decisions on utilization and management of these resources in relation to livestock and tourism industries are made by individuals, interested development groups, county and national governments with limited reference to climate variability. With the implementation of devolved system of government, the stakeholders including both county and national governments development agenda cover both livestock and tourism industries with huge investments being made to spur development. These investment decisions are made with minimal reference to climate, an important factor in terms of pasture availability leading to uncertainty in development. Quite often huge losses especially in livestock are reported due lack of forage feed and to some extent human life due lack of food (Huho and Mugalavai, 2010). This research sought to address the issue by modelling the future distribution of pasture in Kenya in relation to the projected future climates allowing informed decision making. The output comprising, change in vegetation spatial and temporal distribution and quantity will be useful in making decisions on possible investment and where to invest with regard to the future climatic periods.

1.3 Research Objectives

The broad objective of the research was to analyze climate and vegetation data and model climate change impacts on spatial and temporal rangeland vegetation distribution in Kenya. The specific objectives were to:

1. Establish the spatial and temporal trends of climate and MODIS NDVI from 2001 – 2015
2. Develop scenarios of spatial and temporal rangeland vegetation distribution in the base-year, 2050 and 2070 climatic periods
3. Analyse the Kenyan rangelands grazing carrying capacity in the future climatic periods of 2050 and 2070
4. Evaluate Kenya government policies and legislations on pastoralism and wildlife in relation to climate change and suggest appropriate future mitigation and adaptation measures

1.4 Research Questions

The following research questions were formulated to guide the research:

1. What are the Spatial and temporal trends of rainfall and MODIS from 2001 – 2015?
2. In what manner will the years 2050 and 2070 climate influence the spatial and temporal distribution of rangeland vegetation in Kenya?
3. How will the Kenyan rangelands livestock carrying capacity change in the future climatic periods of 2050 and 2070?
4. What strategies has the Kenyan government put in place on climate change in the pastoralism and wildlife management policies and legislations?

1.5 Justification of the Study

Many varied studies on climate change and its impact have been done by several researchers both in developed and developing worlds. Researchers such as Zonneveld *et al.* (2009) modelled the impacts of climate change on distribution of tropical pine in south East Asia. Kigen *et al.*, (2013) studied climate change impact on the Grevy's zebra niche changes in Kenya under the future 2080 climatic period, CIAT (2011) modelled climate influence on tea growing areas in Kenya and Moore and Messina (2010) generated tsetse fly climate based prediction map for Kenya. However, no research has focused on the impacts of anticipated climate change on Kenyan rangeland vegetation which is important for livestock (KIPPRA, 2013) and is habitat of wildlife (KWS, 1996). This research focussed on modelling the base-year and future spatial and temporal rangeland vegetation distribution in Kenya. The use of modelling tools specifically ArcGIS, DIVA-GIS and Maxent software provide a cheap way of carrying out the study in terms of cost and time and also generate output that are easily understood. Unless Kenya clearly understands the impacts of climate variations on the rangeland vegetation it will be a challenging task to achieve sustainable development as enshrined in Vision 2030, Africas' 2063 Agenda and the global sustainable development goals through planning and managing these critical economic resources. In this view, it was necessary to model and have a lucid understanding of the climatic divergence in order to plan effectively from an informed perspective and guide policy makers in putting up adaptation measures at local, regional, national and international level.

CHAPTER TWO

LITERATURE REVIEW

2.1 Spatio-Temporal Climate and Vegetation Trend

2.1.1 Land Use Land Cover Changes

Land use refers to the action of human activities on their environment including mining, constructions, water damming and agriculture that change the land surface processes of hydrology, biodiversity and biogeochemistry while land cover denotes the biophysical (biological and physical) cover over the surface of land comprising vegetation, water, rocks, bare soil, and/or artificial structures (Shrestha, 2008). Several factors both natural and anthropogenic govern the type and extend of LULC of a given place either directly or indirectly. The anthropogenic factors, land-use and land-cover are linked to climate, vegetation and weather in complex ways. The increased exposure to threats on terrestrial ecosystems due to climate variability and change has resulted in adverse natural events comprising of droughts and floods (IPCC, 2007). In a particular region, the natural processes and factors responsible for LULC patterns are phenomena's like very intense precipitation, landscape characteristics, soil types and climate variability/ climate change. Vegetation clearing, massive agricultural activities and high population growth and general land surface modifications attributed to anthropogenic activities contribute to LULC changes.

Vegetation cover and crop production shows much variability across the globe and depend on the types of crop, the vegetation and the region (Fisher, 2018). The earth surface coverage of vegetation is rapidly changing with alterations observed in phenology and diversity with respect to distribution on the earth's surface. The application of geospatial technology (remote sensing and GIS) play an important role in the analyses of land use and land cover changes at global scales. The use of the two technologies has shown a change in LULC linked to climate variability (Crawford 2001). Many studies have shown that analysis and modelling of spatio-temporal features of LULC changes is significantly important for better understanding environmental management for sustainable development (Nellemann *et al.,* 2009; Shiferaw, 2011).

According to World Meteorological Organization (WMO) (2005) Sub-Saharan Africa has the highest land degradation rates of 57% in Rwanda and Burundi, 38% in Burkina Faso, 32% in Lesotho, 31% in Madagascar, and 28% in Togo and Nigeria, 27% in Niger and South Africa and 25% in Ethiopia. Land degradation risk analysis by GoK (2016a) show that 27.2% of Kenya's land in the ASALs is at very high risk of degradation. In the Sub-Saharan Africa, land degradation takes place as a result of uncontrolled vegetation clearing (deforestation, woodlands) and the expansion of crop production to ASALs; exceeding rangeland livestock carrying capacity; and unsustainable agricultural practices on croplands. The African region is projected to face the great challenges with regards to food security as a result of climate variability /climate change and other drivers of global change (Easterling *et al.,* 2007). Fischer *et al.* (2005) concluded that most climate model scenarios agree that some African countries such as Sudan, Ethiopia, Somalia, Nigeria, Senegal, Mali, Zimbabwe, Chad, Sierra Leone and Angola amongst others are most likely to experience a reduced cereal yield by 2080s.

2.1.2 The World Climate Characteristics

The classical period for performing the statistics used to define climate corresponds to at least three decades and it is designated by “climate normal period”, as defined by the World Meteorological Organization (WMO). This includes the region's general pattern of weather conditions, seasons and weather extremes like hurricanes, droughts, or rainy periods. Two of the most important factors determining an area's climate are temperature and precipitation (Goosse *et al.,* 2010). Climate is also influenced by numerous processes involving not only the atmosphere but also the ocean, the sea ice and the vegetation. Climate is thus now more and more frequently defined in a wider sense as the statistical description of the climate system (Goosse *et al.,* 2010). This includes the analyses of the behaviour of its five major components: the atmosphere; the hydrosphere; the cryosphere; the land surface and the biosphere and the interactions between them (Solomon *et al.,* 2007).

Pidwirny (2006) enumerated the factors that affect climate which are; the location on the earth; local land features like mountains; the type and amount of plants like forest or grassland; the altitude; latitude and its influence on solar radiation received; variations in the Earth's orbital characteristics; volcanic eruptions; the nearness of large bodies of water prevailing winds and human activities that increase greenhouse gasses and/or reduce the natural carbon sinks. The world climate classification has been largely based on the amount of rainfall and temperature example of which is Koeppen’s climate classification (Figure 2.1).

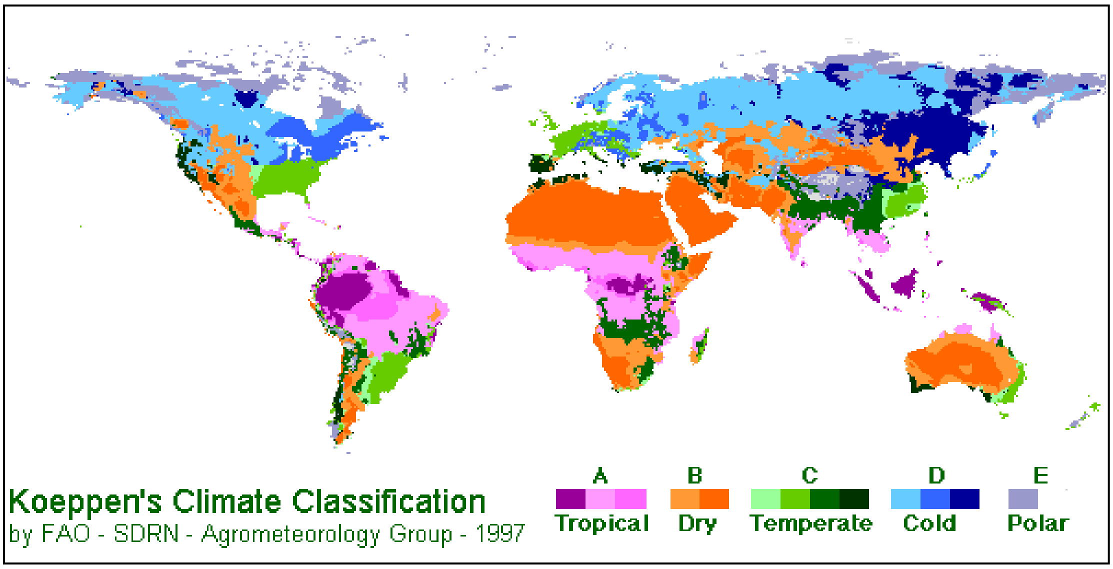

Figure 2.1: The Koeppen's climate classification.

2.1.3 World Climate and Vegetation Distribution

There exist a strong correlation between climatic and vegetation zones (Brovkin, 2002) with the moist tropics being associated with tropical forest, the dry subtropics with subtropical deserts, regions of temperate climate with temperate/boreal forests, and polar regions with tundra/polar desert. Numerous studies have documented that climate has changed with varying levels at different regions across the world in the last few decades due to human influence on nature (Solomon *et al.*, 2007; Hulme *et al.*, 1999; IPCC 2007; Settele *et al.*, 2014). These changes in climatic parameters have affected and influenced vegetation cover at varying levels hence climate and vegetation should be given equal attention. More importantly, the relationships that could exist among these interrelated components have to be identified in order to make accurate and realistic predictions on the changing conditions of the vegetation or climatic parameters.

Vegetation refers to the ground cover provided by plants, and vegetation dynamics defines changes in species composition and/or vegetation structure in all temporally and spatially. The geographical distribution and productivity of the various biomes (Figure 2.2) is controlled primarily by the climatic variables especially precipitation and temperature (Pidwirny, 2006). Approximately 75% of the earth's land surface is covered by green biomass and categorized into biomes (Fisher, 2018) whose main characteristics of each biome are as follows: The temperature in a rain forest range from 20 to 34°C; the average humidity is between 77 to 88%; rainfall is often more than 2540 mm annually. While in a deciduous forest the average annual temperature is 10°C and the average rainfall is 750 to 1500 mm a year.

The climate in grasslands is alternating wet and dry spells with warm temperature all year round. Alpine biomes are found in the mountain regions all over the world where average temperatures in summer range from 10 to 15°C and it goes below freezing in winter. The tundra which is found in the North Pole regions is the world's coldest biomes with average annual temperatures of about -56°C.

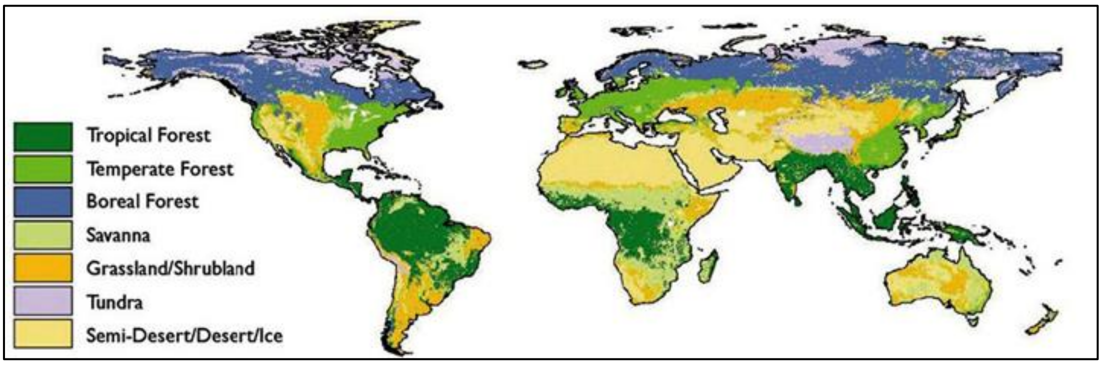

Figure 2.2: The global natural vegetation types.
Source: Benders-Hyde (2010)

2.1.4 Rangelands Ecosystem Species

The rangelands of eastern Africa are very diverse, with a variety of dominant species dependent on rainfall, soil type and management or grazing system. Eastern Africa is renowned as a centre of genetic diversity of tropical grasses and the centre of greatest diversity of cultivated grass species with more than 600 found in Kenya (Boonman, 1993). Rattray (1960) identified 12 types of grasses in eastern Africa, based on the genera of the dominant grass. These grass species include *Cenchrus, Hyparrhenia, Aristida, Chloris, Chrysopogon, Exotheca, Heteropogon, Pennisetum, Themeda, Loudetia, Panicum* and *Setaria*. The rangeland is also home to varied species of grazers, browsers and carnivores. Examples of grazers include grazers (buffaloes, wildebeests, and burchells zebra), browsers (rhinos, giraffes), carnivores (lions, cheetahs, leopards, hyenas) (Western *et al.*, 2009).

2.1.5 The Kenya Rangelands Ecosystem Climate

The savannahs are rolling grasslands scattered with shrubs and isolated trees, which can be found between a tropical rainforest and desert biome (Fisher, 2018). The east African savannahs are found in areas astride the Equator and therefore much of the region experiences two rainy seasons. A longer rainy season starts around March through to June, with the peak occurring from March to May with the shorter rainy season running from September and tapers off in November or December. Government of Kenya (2005a) indicated that over two-thirds of Kenya, particularly areas around the northern parts of the country, receive less than 500 mm of rainfall per year and are classified as arid and semi-arid lands (ASALs).

In recent years, critical drought periods in the country were experienced in 1984, 1995, 2000 and 2005/2006 (UNEP/GoK, 2000) (Table 2.1). The 2000 and 2006 droughts were the worst in at least 60 years, and between these two extreme years, several other rainy seasons failed. Climate change introduces an additional uncertainty of erratic rainfall into existing vulnerabilities in the ASALs (Osbahr and Viner, 2006).

Table 2.1: Critical droughts experienced in Kenya from 1984 – 2006.

Year	Type of disaster	Area of coverage	No. of people affected by droughts
2004–2006	Drought	Widespread	3.5 million
1999/2000	Drought	Widespread	4.4 million
1995/96	Drought	Widespread	1.4 million
1991/92	Drought	Arid/semi-arid zones	1.5 million
1983/84	Drought	Widespread	200,000

Source: Oxfam International (2006).

2.2 Climate Change Modelling

2.2.1 Projected World Climatic Changes

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Settele *et al.,* 2014) indicates that climate model projections for the period between 2001 and 2100 suggest an increase in global average surface temperature of between 1.1 °C and 5.4 °C. According to the World Meteorological Organization (WMO, 2011), climate variability represents variations in the mean state and other statistics (such as standard deviations and the occurrence of extremes among others) of the climate on all temporal and spatial scales beyond that of individual weather events. The term is often used to denote deviations of climatic statistics over a given period of time from the long-term statistics relating to the corresponding calendar period. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Hulme *et al.*, (2001) pointed out that climate change in Africa is not simply a phenomenon of the future, but one of the relatively recent past. Climate model simulations under a range of possible emissions scenarios suggest that for Africa 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). Precipitation is highly variable spatially and temporally and data are limited in some regions of the world (IPCC 2007). As reported by Sivakumar *et al.* (2005) rainfall changes in Africa projected by most Atmosphere- Ocean General Circulation Models (GCMs) are relatively modest, at least in relation to present-day rainfall variability. Great uncertainty exists, however, in relation to regional-scale rainfall changes. These rainfall results are not consistent: different climate models or different simulations with the same model, yield different patterns. The East Africa region appears to have a relatively stable rainfall regime, although there is some evidence of long-term wetting (Hulme *et al.*, 2001). There are also indications for an upward trend in rainfall in this region under global warming (Thornton *et al.*, 2007). Further in the East African region, wet extremes (defined as high rainfall events occurring once every 10 years) are projected to increase during both the September to December and the March to May rain seasons, locally referred to as the short and long rains respectively (Thornton *et al.*, 2007). The increase in the number of extremely wet seasons has risen to roughly 20% (i.e. 1 in 5 of the seasons are extremely wet, as compared to 1 in 20 in the control period in the late 20th century) (Christensen *et al.*, 2007). The dry extreme events are projected to be of low severity compared to the levels of September to December, but the GCMs do not show a good agreement in their projected changes of dry extremes of the months of March to May (KNMI, 2007; Thornton *et al.*, 2007).

Rainfall projections in Kenya are inconsistent; a range of models and scenarios suggest both increases and decreases in total precipitation (Osbahr and Viner 2006). For September to May, most models project increases in total rainfall by up to 30% with the largest increases expected in December to February (the hot, dry season). Changes in rainfall during the rest of the year are less clear and rainfall may increase or decrease by as much as 20% between June and August (Osbahr and Viner, 2006).

2.2.2 Climate Change and Vegetation

Numerous scientific studies such as IPCC (2007) and Settele *et al.* (2014) have come to the conclusion that climate has changed over the last century and will continue to change but differently under different emission scenarios. Changes have and will continue to impact developing countries such as Kenya due to various reasons IPCC (2000).

The spatial changes in vegetation composition and distribution have been documented in many different biomes worldwide. Such changes reported include migrations to new elevations to adapt to temporally and spatially altered precipitation and temperature regimes (Allen *et al.,* 2010; Crimmins *et al.,* 2011) and a shift in pine growing areas in South East Asia (Zonneveld *et al.,* 2009). Much evidence from around the world shows that dry grasslands and shrub lands are highly responsive in terms of primary production, species composition, and carbon balance to changes in water balance (precipitation and evaporative demand) within the range of projected climate changes (high confidence) (Booker *et al.,* 2013; Settele *et al.,* 2014). The geographical distribution of savannas is determined by temperature, the seasonal availability of water, fire, and soil conditions (Staver *et al.,* 2011) and is therefore inferred to be susceptible to climate change. Increasing tree cover in savannas has been attributed to among other factors, climate variability and change (Fensham *et al.*, 2009). Allen *et al.* (2010) showed that tree mortality and heat stress are negatively impacting forests across a variety of biomes and on all continents (Figure 2.3).

Climate change phenomena imply that some areas will experience increases in precipitation while others less precipitation (Settele *et al.*, 2014). Studies have shown general warming on land with some cooling over coastal locations and near large water bodies (King'uyu *et al.*, 2000; NCCRS, 2009). A reduction in cold extremes has also been observed over the ASAL, according to Settele *et al.* (2014).

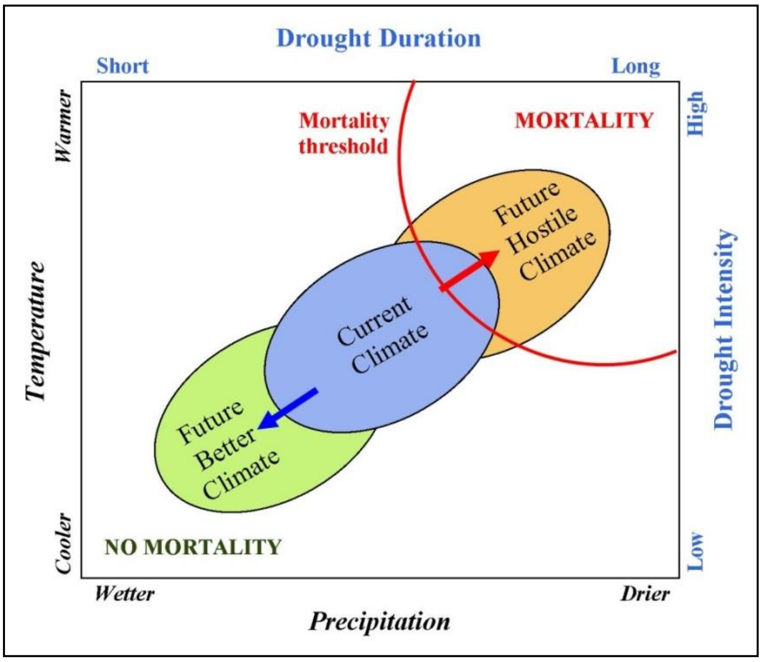

Figure 2.3: The relations between temperature, precipitation, and the duration and intensity of drought events on tree mortality.
(Source: Modified from Allen *et al.*, 2010)

The October-November-December (OND) rains show an increasing trend due to, among others, an extension into January and February over some locations in recent years (NCCRS, 2009). Bowden *et al.* (2005) discerned increasing rainfall trends over the northern portions of the Greater Horn of Africa (GHA), including northern Kenya, that is possibly related to an early onset and decreasing trends over the southern portion of the GHA, including southern Kenya that may be related to a late start in the seasonal rainfall. Projections by Shongwe *et al.* (2011) indicate the potential for an increase in the OND rainfall over Kenya by more than 10% at 95% confidence level. This means that impacts on species will vary depending on precipitation and temperature changes in each region and microclimate. Loraine *et al.* (2009) rank deserts and shrub lands third among fourteen biomes in terms of the velocity of temperature change during the most recent period of climate change.

2.2.3 Spatial Climate Change Impact Modelling

A number of studies have been done on spatial species distribution modelling, either using one method, or a comparison of different methods. Williams *et al.* (2009); Phillips *et al.* (2006); and Ward (2007) in their studies recommended the use of Climate Envelope Modelling (CEM) in species distribution studies. The climate envelope model refers to a subset of species distribution models that use climatic variables to make spatial predictions of environmental suitability for a particular species. These models use mathematical functions to describe the relation between species presence points and the climatic conditions. On the basis of these rules, it is possible to extrapolate and index environmental suitability for the modelled species from a layer of environmental data. This extrapolation involves using the mathematical functions describing the species-environment associations and applying the same to environmental data from other times or place. The Ecological Niche Models (ENM) such as Maxent can be used to show suitable habitat and probability of species locations based on “presence-only” occurrence of species and environmental layers (Phillips *et al.,* 2006).

Presence-only models use data points where species were found and not locations where species were absent (Phillips *et al.*, 2006) and uses geo-referenced species location points and other variables of interest such as climate, slope and elevation. Species locations are produced as point locations using latitude and longitude coordinates, while the environmental and climate layers are given in raster format (Phillips *et al.,* 2006). Maxent recognizes where species are likely absent based on the fact they are not recorded as present in certain locations (Elith *et al.,* 2011) and is sufficient (Phillips and Dudik 2008). Resulting maps from Maxent show species likely distributions across a given study area (Phillips *et al.,* 2006). The model has been shown to be effective using presence-only species occurrence data (Elith *et al.,* 2006, Williams *et al.,* 2009). Additionally, the model performed better than other existing models (Elith *et al.,* 2006; Phillips *et al.,* 2006). Table 2.2 is a list of various studies conducted using Maxent in species distributions models.

Table 2.2: Selected studies that used Maxent model.

Purpose	**Extend**	**Organism**	**Source**
Growing areas in the current and future climates	Kenya	Sorghum bicolour	Kigen *et al.* (2014)
Niche extent in the current and future climates	Kenya	Grevy’s zebra	Kigen *et al.* (2013)
Growing areas in the current and future climates	Kenya	Many crops	International Center for Tropical Agriculture, 2011
Growing areas in the current and future climates	South East Asia	Pine	Zonneveld *et al.* (2009)
potential geographic distribution	New Zealand	Ants	Ward (2007)
Test model performance against other methods	Regional	Many Species	Elith *et al.* (2006)

The term “niche” in ecology could refer to realized or fundamental niche. Wiens *et al.* (2009) said that a fundamental niche is the range of environmental conditions where a species could theoretically occur. The realized niche also takes into account biological interactions (competition, disease, etc.) which may preclude a species from occurring in a given location which the environmental conditions would otherwise say is possible (Wiens *et al.,* 2009). One of Maxent’s final outputs is a map of gridded data with a probability of occurrence from zero (0) to one (1) for each grid cell (Phillips *et al.,* 2006). This map, resulting from the given species’ locations and the probability curves from each environmental and climate variable, is an estimate of the realized niche for a given species (Phillips *et al.,* 2006). Model outputs are a representation of a species’ niche or habitat and may be interpreted in different ways (Soberón and Peterson, 2005). A realized niche map output is dependent on how the model is used. For example, if actual species locations are being used to model observed distributions, a representation of the realized niche is being modelled. If past presence-only data is being used to model future changes, model outputs are a combination of fundamental and realized niche. Future model projections predict the suitable habitat for a species based on where a species was previously found, assuming the species did not adapt to changing climatic conditions (Wiens *et al.,* 2009). A projection map based on old suitable conditions would be a combination representative of the future fundamental and realized niche, while a map that showed other aspects, where a species had completely shifted to, would represent only the realized niche. Christensen *et al.* (2004) and Zonneveld *et al.* (2009) support this point by showing Maxent to be a successful method of predicting ground locations and the realized niche of a species. Maxent is an accurate model that can be used to determine a species’ suitable habitat and outputs can be used effectively for planning and conservation (Christensen *et al.*, 2004; Zonneveld *et al.*, 2009).

Several climate change impacts research on organism's niche have been conducted in different regions using Maxent under different climate change scenarios (Yesson and Culham 2006; Kigen *et al.,* 2013; Kigen *et al.,* 2014; Yates *et al.,* 2010; Elith *et al.,* 2011). Rebelo and Jones (2010) ground-truthed Maxent projections, concluding that the model outputs accurately represent species' realized habitat. The future climatic change impacts on plants and animals' research is becoming popular though limitations in relation to future projections are at hand. While it is possible to assess the base-year modelled grass niche accuracy, Phillips *et al.* (2006) pointed that a major weakness of Maxent is lack of actual data for validation to assess model accuracy of the projected future periods. Thus, the Maxent future projections have some level of uncertainty.

2.3 Rangelands Carrying Capacity

Plants use radiation energy from the sun through the process of photosynthesis to convert atmospheric CO_2 and water to organic sugars. This ecosystem productivity is influenced by weather and seasons with water and temperature being the primary factors. The climate of a place is therefore critical in the ecosystems production and controls the number of organisms the ecosystem can support. A close relationship exists between pasture and climate as a consequent of plant evolvement and adaptations over long periods of time (FAO, 1995). Because of this interaction, dominant natural pasture groups have become associated with a particular climate. Accordingly, the different agroclimatic zones have different vegetation type and characteristics, thus different livestock carrying capacities. Carrying capacity (CC) is defined as the maximum possible stocking of herbivores that a unit of rangeland can support on a sustainable basis (FAO, 1988).

The estimates of livestock carrying capacity are usually derived directly from rainfall parameters (FAO, 1995) or are linked to productivity of the vegetation (primary production) (Bekure *et al.*, 1991). Within the different climatic regions of the world, researchers have developed exchange ratios (e.g. Tropical Livestock Units, Livestock Units, e.t.c) for standardization of different ruminant breeds that can be supported by a unit of land. Estimates of CC are commonly based on the assumption that livestock require a daily dry matter (DM) intake equivalent to 2.5% to 3.0% of their bodyweight. Thus, for a tropical livestock unit (TLU) of 250 kg of weight, 2.3 to 2.7 tons of dry feed per annum is needed. Many researchers have proposed varied relationships between primary production and carrying capacity based on one or a combination of the following; annual rainfall, the rainfall use efficiency, the type and characteristic of vegetation cover, the degree of canopy cover and the type of soil. De Leeuw and Tothill (1990) presented an estimation of dry matter (DM) production from annual to seasonal rainfall for West Africa, Zimbabwe and Kenya from several sources (Table 2.3).

Table 2.3: Estimation of total DM production from annual to seasonal (t DM ha^{-1}).

Rainfall	**200**	**400**	**600**	**800**
West Africa	0.6	1.1	1.7	2.2
Zimbabwe	0.5	1.7	2.2	2.5
Zimbabwe	0.7	2.6	3.2	3.7
Kenya	1.1	2.3	3.6	-

Source: De Leeuw and Tothill (1990)

Bekure *et al.* (1991) in their studies showed that the average livestock carrying capacity increased from about 7 ha/tropical livestock unit (TLU) (A TLU is equivalent to 250 kg live weight) in the south of Kajiado County with an average annual rainfall of 300 mm to 3 ha/TLU. In the north region of Kenya with annual rainfall of 550 mm, the relationship between median rainfall (MR, mm) and net primary productivity (NPP, kg $DMha^{-1}$) is given by NPP = 1000 + 7.5MR. Other researchers came up with different regression equations for seasonal rainfall on standing biomass in East African region (Table 2.4).

Table 2.4: Regression equations for seasonal rainfall on standing biomass in East Africa.

Area	Equation		Reference
Amboseli	Y = -367+3.8X	(N = 6; R^2 = 0.99)	Western and Grimsdell (1979)
Kiboko	Y = + 262 + 4.41X	(N = 38; R^2 = 0.78)	Too (1985)
Serengeti	Y = 262 + 4.8X	(N = 7; R^2 = 0.93)	Braun (1973)
Tsavo	Y = 380 + 8.0X	(N = 89; R^2 = 0.65)	van Wijngaarden (1985)
Serengeti	Y= -1644 + 10.7X	(N = 12; R^2 = 0.62)	Braun (1973)
Serengeti	Y = -185 + 6.6X	(N = 24; R^2 = 0.90)	Sinclair (1979)
Athi	Y = -251 + 1.2X + 0.01X2	(N = 24; R^2 = 0.95)	Potter (1985)
Serengeti	Y = -1052+8.6X	(N = 10; R^2 = 0.56)	Braun (1973)

Y = Biomass (kg DM ha^{-1}); X = rainfall (mm) (Source: Bekure *et al.* (1991))

FAO (1995) has provided an estimation of grass biomass yield in relation to the rainfall (Table 2.5). It shows production of feed, in dry matter (DM) in terms of weight per unit area (kg ha^{-1}), under different annual rainfall regimes (mm/year) and the relative animal carrying capacity in relation to unit area per grazing factor (ha/Tropical Livestock Unit).

Table 2.5: Estimated DM production and carrying capacity.

Rainfall (mm)	Total above ground DM (kg ha^{-1})	Carrying capacity (ha/TLU)
100	N/A	Over 20
200	450	17
300	675	10
400	900	7
500	1125	6
600	1130	4

Source: FAO (1995)

Similarly, van Wijngaarden (1985) in Eastern Kenya predicted a seasonal rainfall of 200 mm, a yield of 1.1 ton DM on deep sandy clay soils and 0.6 tons on shallow gravelly soils and further concluded that for each 10% increase in woody cover perennial herbaceous cover declined by 7% reaching zero cover when the woody canopy reached 90%. Sombroek *et al.* (1982), showed that high biomass of the *Themeda* grasslands in the Serengeti and Athi plains is attributed to the relatively high fertility of the deep Vertisols over basalt and standing biomass of 3 to 4 t DM ha^{-1} were recorded on similar soils in Kajiado (Page *et al.*, 1975; Karue, 1975, cited in De Leeuw and Nyambaka, 1988). In Tsavo, the same rainfall and plant density standing biomass on deep well drained sandy clays was 30 to 55% higher than on shallow gravelly soils (Table 2.6).

Table 2.6: The effect of seasonal rainfall, plant cover and soil type on end of season standing biomass in Tsavo National Park, Kenya.

	Rainfall (mm)					
	100			300		
	Percent cover					
Perennial grass	10	20	40	10	20	40
Annual grass	10	30	40	10	30	40
	Standing biomass (kg DM ha^{-1})					
Deep soil[a/]	200	450	760	600	1350	2270
Shallow soil[b/]	150	290	590	450	860	1760

[a]/ Ferral- and Luvisols. [b]/ Cambisols. (Source: De Leeuw and Nyambaka (1988))

2.4 Kenya's Climate Change and Related Policies and Legislations

The world over, there are concerns of climate change which have led countries to develop policies that mitigate the adverse impacts while maximizing the positive aspects of climate change. The policies have been developed both at national, regional and international scale with cooperation from organizations such as the United Nations Environment Program, Food and Agriculture Organization of the United Nations,, the World Bank amongst others. Kenya as a country has not been left out and has number of policies geared towards climate management (GOK, 2013b).

2.4.1 Kenya Vision 2030

The Kenya Vision 2030 is a vehicle for facilitating accelerated transformation of the country into a rapidly industrializing middle-income nation by the year 2030 (GoK, 2006). Kenya is affected by climate change related disasters. Over 70% of natural disasters that affect the country are weather related, and the economy is heavily dependent on climate sensitive sectors. It has been noted that in the recent past the frequency, magnitude and severity of disasters has been increasing with resulting negative impacts including loss of life and property and destruction of infrastructure. The approaches to disaster management are mostly reactive though disaster risk reduction is increasingly picking up. The institutional capacity to collect data on land use for environmental analysis and policy making is weak, and hence assessment and monitoring of strategic environmental resources remain a challenge. Therefore there is need to build data bases and analytical capacity for sustainable resource use and management.

2.4.2 The National Policy for the Sustainable Development of Northern Kenya and other Arid Lands

This policy focuses on climate resilience requiring Government to find solutions to address climate challenges and to come up with mitigation measures to manage drought and strengthen livelihoods (GoK, 2012c). The policy also focuses on an enabling environment for accelerated investments in "foundations" to reduce poverty and build resilience and growth. The establishment of the National Drought Management Authority (NDMA), the National Disaster Contingency Fund and the Council for Pastoralists education are provided for in the policy.

2.4.3 The Draft National Disaster Management Policy, 2012

This policy institutionalizes disaster management and mainstreams disaster risk reduction in the country's development initiatives (GoK, 2012f). The policy aims to increase and sustain resilience of vulnerable communities to hazards. However, it has shortcomings at implementation level.

2.4.4 Environmental Management and Coordination Act (EMCA 2015)

The Environmental Management and Coordination Act (EMCA) (1999) amended (2015) is the principle instrument of government for environmental management (GoK, 2015b). The Act provides for the relevant institutional framework for the coordination of environment management including the establishment of the National Environment Management Authority (NEMA) which is the designated national implementing entity for the Climate Adaptation Fund.

2.4.5 The Agricultural Sector Development Strategy 2010-2020

This is the Kenya's overall national policy document guiding the agricultural sector. It is geared towards promotion of sustainable food production and agroforestry (GoK, 2010a). There are also broad-based propositions for the forestry detailed in one of the sub-sectors of the agriculture component.

2.4.6 The National Environment Action Plan (NEAP, 2009-2013)

This action plan provides for a framework for the coordination of environment related activities by the private sector and government of Kenya to guide the paradigm of economic development activities, with a view to integrating and balancing environment issues and development for better management of resources (GoK, 2009b).

2.4.7 Threshold 21 (T21) Kenya

The Threshold 21 is a vigorous modelling tool intended to support wide-ranging, combined long-term development planning (LEDS, 2018) for a given country. The T21-Kenya model was developed to assimilate the exploration of the threats, risks and impacts of climate change on the key sectors of the society, environment and economy, so as to evaluate rational national development policies that encourage sustainable development, poverty eradication, and increased well-being of vulnerable groups, within the context of Kenya's Vision 2030.

2.4.8 Tourism Act Revised Edition 2012 (2011)

The Revised Tourism Act (GoK, 2012b) paves way for the development, management, marketing and regulation of sustainable tourism and tourism-related activities and services, and for connected purposes in Kenya. It further provides for institutional framework for the tourism management including the establishment of the Tourism Management Authority and Tourism Research Institute and Monitoring Mechanism.

2.4.9 National Tourism Strategy 2013-2018

The Kenya National Tourism Strategy 2013-2018 aimed at providing strategic interferences under the key strategic themes (GoK, 2013d) which include:

- Operational product development and deployment process
- Enhancing marketing of Kenya's tourism diverse products
- Insufficient financing and improvement of the investment environment

- Promotion of research and information management and
- Develop and enhance human capital, legal, policy and institutional framework

2.4.10 The National Climate Change Response Strategy (2010)

The National Climate Change Response Strategy (NCCRS) (2010) was the first policy document to recognise the certainty of climate change in Kenya (GoK, 2009a). The NCCRS has been useful in directing national and county policy since the year 2010. This disposition brought forward confirmation of climate impacts on the country's diverse economic sectors and provided a plan of adaptation and mitigation approaches to be undertaken.

2.4.11 National Climate Change Action Plan (2013 – 2017)

The National Climate Change Action Plan (NCCAP) (2013 – 2017) is a comprehensive and elaborate document setting out the effort to achieve low carbon and climate resilient development in Kenya (GoK, 2013e). This action plan document provided ranked activities for climate change adaptation and mitigation measures and a road map for supporting conditions at policy, legislation and institutional frameworks. It touches on many issues on climate comprising the following:

- Climate Change Action Planning in Kenya
- Preparation of Kenya's Climate Change Action Plan
- Low Carbon Climate Resilient Development
- Adaptation
- Mitigation
- Financing Implementation of the Action Plan
- Enabling Policy, Legislative and Institutional Framework

- Knowledge Management and Capacity Development
- Technology
- National Performance and Benefit Measurement Framework

2.4.12 The Wildlife Conservation and Management Act 2013

The Wildlife Conservation and Management Act, 2013 (GoK, 2013a) is the principle instrument of the Government of Kenya for the conservation and management of Wildlife and utilization. It also provides for the relevant institutional framework for the wildlife conservation and management including the establishment of the Kenya Wildlife Service (KWS) which is the designated national body for the conservation and management of wildlife.

2.5 Conceptual Framework

This study proposes that the vegetation availability and the degree of growth are largely influenced by the climate in a particular place (Figure 2.4). Thus, there is a strong correlation between climate elements (rainfall, temperature and other climate derivatives) and vegetation distribution. The maximum vegetation distribution and biomass production are governed by the prevailing climate specifically precipitation and temperature.

In the ASALs, the limiting factor of vegetation development and distribution is a combination of both rainfall amounts and temporal distribution. Therefore a change in weather parameters directly influences both vegetation growth and distribution especially the grass. The currently experienced climate variability phenomenon is thus expected to have caused and will cause changes of grass distribution in the current and future time periods respectively. These changes in rangeland vegetation distribution are in both time and space following the optimum weather parameters of rainfall and temperature. In this case, the weather parameters are the independent variables while the spatio-temporal distribution, rangeland carrying capacity and climate change mitigation measures are the dependent variables.

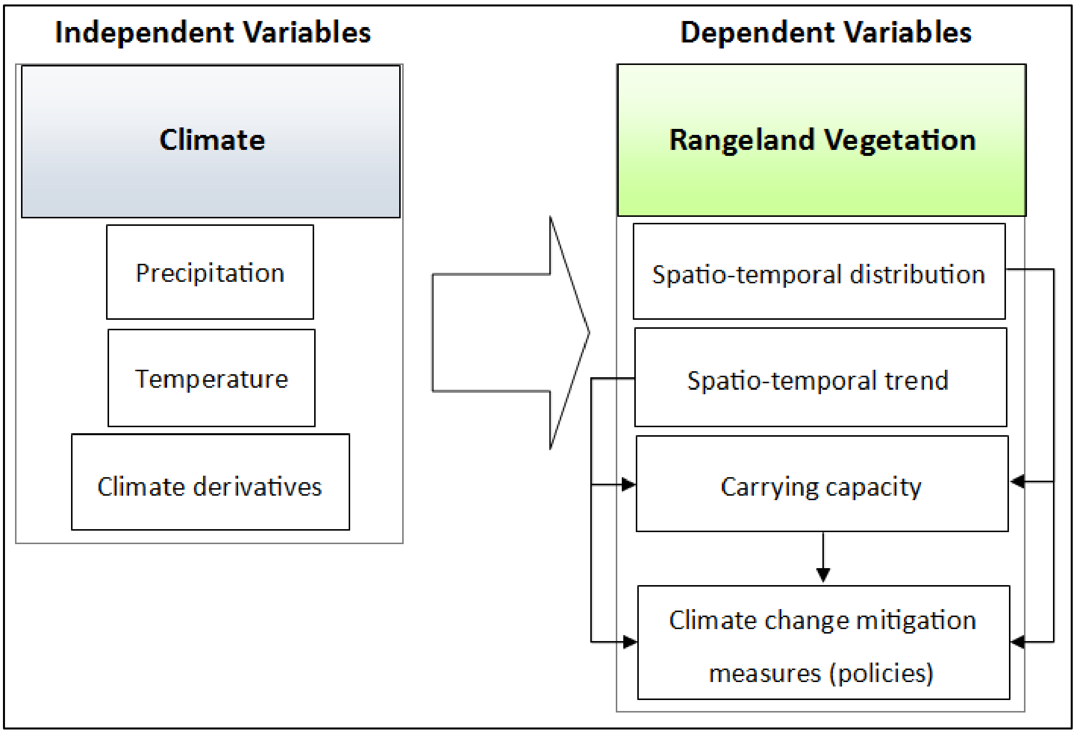

Figure 2.4: Conceptual framework.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

Kenya is located in the east African region covering a total of 582,646 km^2 with about 80% of it classified as arid and semi-arid lands (ASALs) (Figure 3.1). It is divided into seven agroecological zones (AEZs) with AEZs I – III classified as high potential areas and the others low potential areas. The AEZs classification is based on rainfall, soil moisture pattern, soil types and vegetation types. Sombroek *et al.* (1982) and PANESA (1988) summarized characteristics of the AEZs in relation to precipitation and major grass species (Table 3.1).

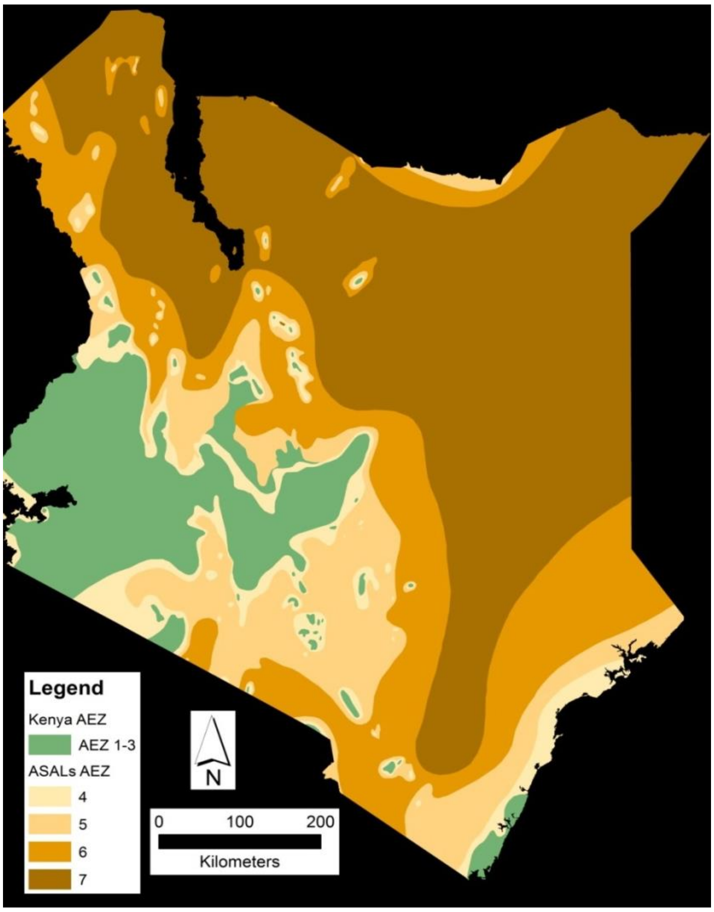

Figure 3.1: Map of study area based on administrative boundaries of Arid and Semi-Arid lands.

Table 3.1: A summary of AEZs IV - VII characteristics.

AEZ	Classification	Moisture Index (%)	Precipitation (mm)	Major Grass Species
IV	Semi-humid to semi-arid	40-50	600-1100	*Themeda triandra, Pennisetum mezianum, P. straminium, P. massaiense, Eragrotis spp., Hyperenia spp., Seteria spp., Digitaria spp.* and *Centhrus ciliaris*
V	Semi-arid	25-50	450-900	*Eragrotis superb, Centhrus ciliaris, Cymbopogon spp., Bothriochloa spp.,* and *Heteropogon contortus*
VI	Arid	15-25	300-550	*Aristida adoensis, Stipagrostis hirtigluma, Aristida mutabilis, Cymbopogon aucheri, Tetrapogon spp., Enneapogon cenchroides* and *Chloris roxburghiana*
VII	Very arid	<15	150-350	*Cynodon dactylon, P. coloratum, Sporobolus spp., A. adoensis, Rhynchetrum* spp., *Enteropogon macrostachys, Eragrostis superb,* C. *roxburghiana, E. macrostachyus, Eragrostis caespitosa, Aristida papposa, P. maximum, E. superba* and *Chrysopogon Spp.,*

Kenya's current population is estimated to be 46,748,000 (PopulationPyramid.net, 2015) living in both urban and rural areas in the 47 counties. Kenya's gross domestic product was Ksh 1.7 trillion for the 2014/2015 financial year (PBO, 2014) with the bulk of it from agriculture based activities. Other notable economic activities that depend on weather patterns are wildlife-based tourism which is threatened due to climatic variations. Data sources, processing and analysis and analysis varied depending on the data types and objectives. Figure 3.2 is a summarised methodology used in the research indicating the processes and analysis subjected to the data.

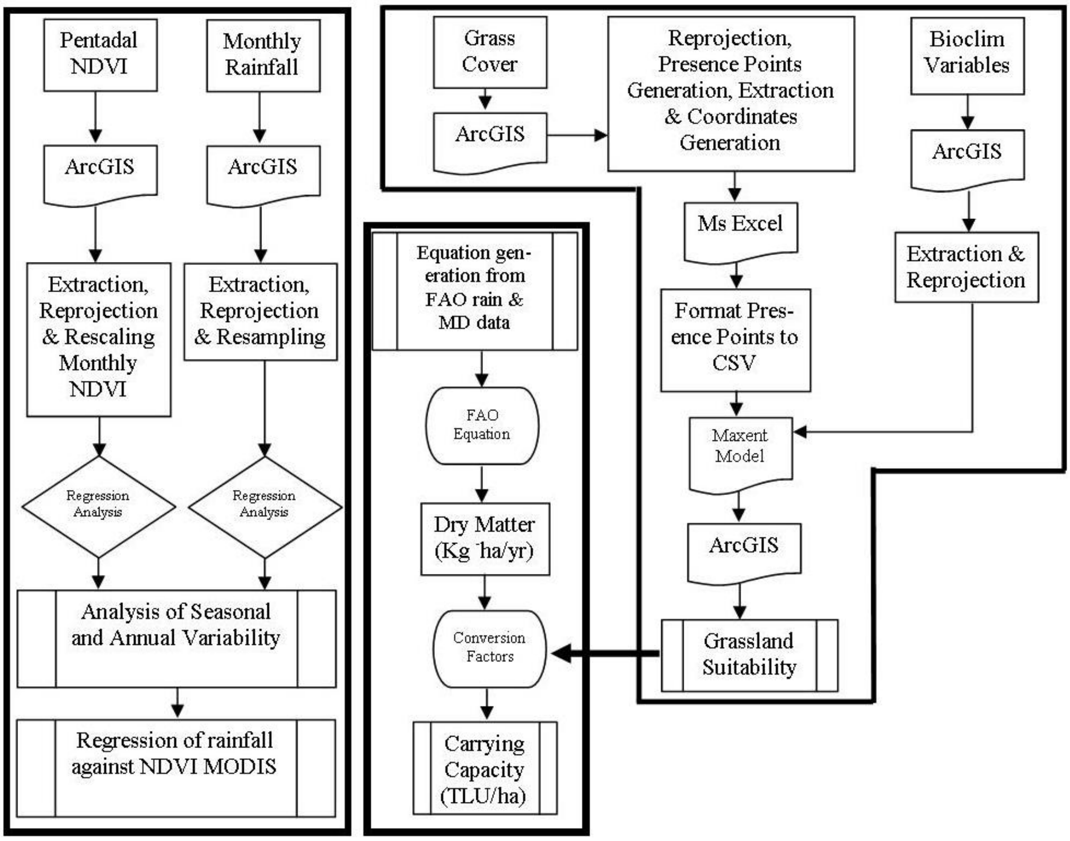

Figure 3.2: Summarised methodology of the research study.

3.2 Data Collection and Processing

3.2.1 MODIS NDVI and Rainfall Data

3.2.1.1 MODIS NDVI Datasets

The vegetation data referred to as MODIS NDVI (Moderate Resolution Imaging Spectroradiometer Normalized Difference Vegetation Index) provided the vegetation phenology and was sourced from the United States Geological Service (USGS) website www.earlywarning.usgs.gov (FEWSNET, 2015). They are multi-temporal images acquired by NASA Terra (AM-1) satellite's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor. The data is derived from monitoring the world's vegetation with a spatial resolution of 250m (0.002413DD) with varied temporal resolution.

Kenya is grouped under the Eastern Africa countries and a total of 1080 raster images were downloaded for the period covering 2001 to 2015 (15 years). The downloaded monthly data contained six dekadal datasets in 180 zipped folders. A spatial model (Appendix 1) developed in ArcMap was used to process the data to generate mean monthly spatial data covering Kenya. Additionally, the resultant MODIS NDVI data were converted from stretch of scale of 1 to 255 to the ratio scale of -1 to 1. Further extraction of the MODIS NDVI data to the specific area of interest (AOI) was carried out in ArcMAP (Figure 3.3). The AOI was selected from Africover Kenya aggregate spatial data downloaded from United Nations website www.un-spider.org (United Nations, 2015). The AOI identification was guided by the Africover Project "Usable definition" document which constituted "Natural and Semi-natural Terrestrial Vegetation" and "Bare Areas" (Appendix 2).

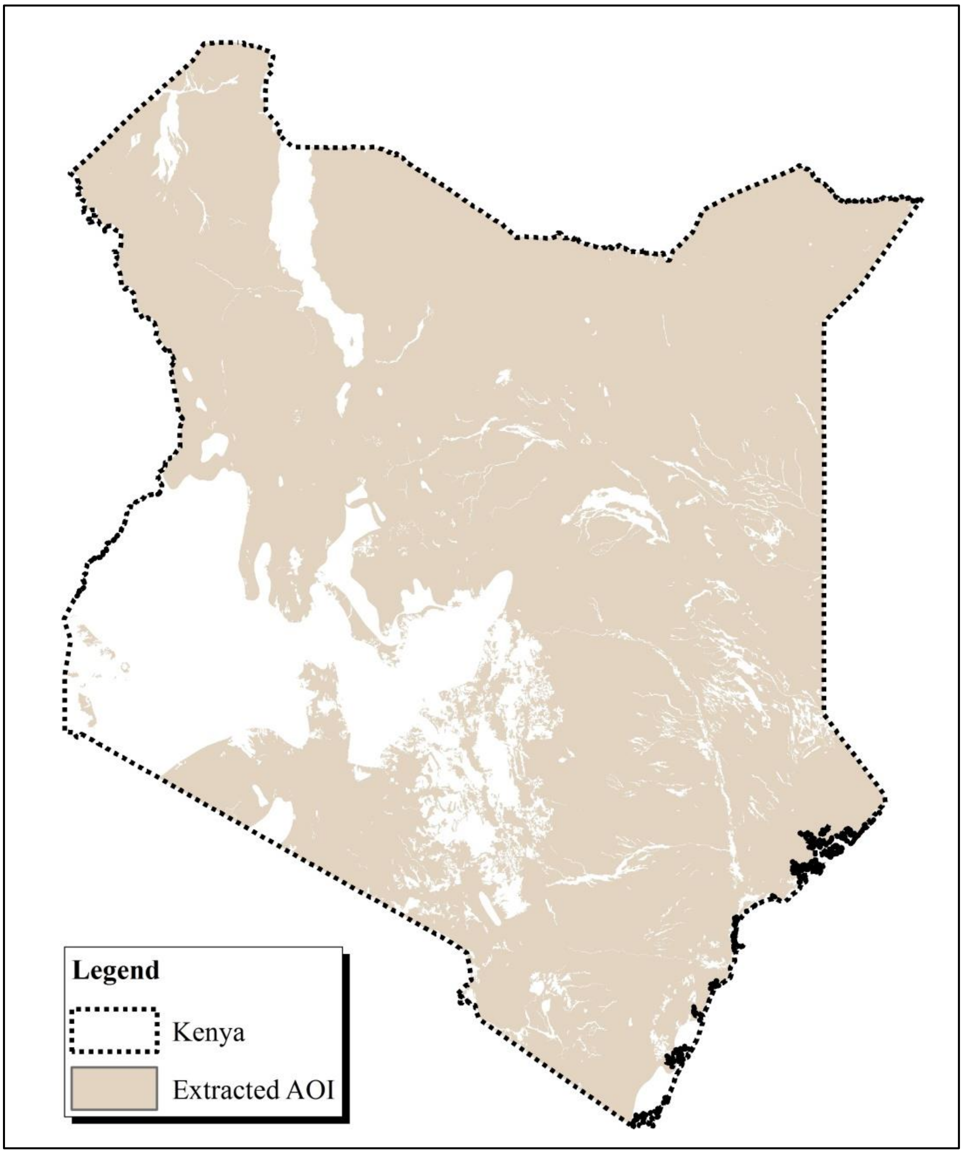

Figure 3.3: The identified area of interest from Africover data.
(Source: United Nations, 2015)

3.2.1.2 Rainfall Datasets

The rainfall dataset covering the study period was downloaded from the USGS website www.earlywarning.usgs.gov, (FEWSNET, 2015) and processed in the same manner as MODIS NDVI. The rainfall data is called Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) and comprises monthly rainfall data. It has a resolution of 5,500m (0.050000001Decimal degrees) covering the whole world. Processing and analysis of this rainfall data was done in same way as the

MODIS NDVI with an additional step of resampling to match MODIS NDVI data resolution.

3.2.1.3 Bioclim Datasets

The Bioclim climate dataset comprising precipitation, minimum and maximum temperature was used. This data comprise the base-year period and future (2050 and 2070) climatic periods (Appendix 3). These climate data was sourced from global climate data website www.worldclim.org, (WorldClim, 2015) with a resolution of 1 km under special report on emission scenarios (SRES). The variables, (Table 3.2) are coded as BIO1 representing annual mean temperature and the last being BIO19 denoting precipitation of coldest quarter.

Table 3.2: The 19 Bioclim variables.

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly) (max temp - min temp)
BIO3 = Isothermality (BIO2 / BIO7) (* 100)
BIO4 = Temperature Seasonality (standard deviation *100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

The Bioclim data generation models show much greenhouse gas will be emitted and at what year emissions will peak. The Coupled Model Intercomparison Project provides four different scenarios among them is Representative Concentration Pathways (RCP) 4.5 which this study used. The RCP 4.5 data were used as it is one of the two medium stabilisation levels indicating that CO_2 levels in the atmosphere will be 650 ppm causing a radiative forcing of 4.5W/m^2 (Watts per square meter) in the year 2100 (Moss *et al.,* 2010). The climate data files were then extracted by mask using Kenya shapefile and re-projected to WGS 1984.

3.2.2 Data Analysis and Spatial Modelling

3.2.2.1 Rainfall and MODIS NDVI Spatial Data Analysis

The rainfall and MODIS NDVI spatial data processing and analysis was done using several softwares. Spatial processing used ArcMAP version 10.2.1, DIVA-GIS version 7.5 analysed the spatial trends by regression of stacked images and Map Comparison Kit version 3.2 generated the Kappa statistics following Power *et al.* (2001) procedures. The Kappa spatial similarity analysis was done on monthly and annual basis using Kappa Location (K_{Loc}) and Kappa Histogram (K_{Histo}) for location and size of area variability evaluation respectively. The individual monthly/annual spatial data were compared against their means for the period under study. Kappa statistic evaluation for this study was based on the 0.50 threshold which generated binary data of “Not Similar” (0.00 to 0.49) and “Similar” (0.50 to 1.00). The influence of rainfall on MODIS NDVI was determined by spatial regression analysis using GeoDa software version 1.12. Both rainfall and MODIS NDVI raster data were aggregated by a factor of 20 to generate new raster using mean statistics. This aggregation enabled data reduction from 377,440 pixels to 18,872 pixels within the area of interest for ease of processing in GoeDa. A fishnet with labels was created for extraction of 18,872 data points in both rainfall and MODIS NDVI datasets in ArcMAP.

3.2.2.2 Rangeland Vegetation Cover, Agroecological Zones and Grass Presence Points

The spatial rangeland vegetation was generated by Africover Project and was sourced from the United Nations website www.un-spider.org, (United Nations, 2015). The Africover Projected prepared and presented this data in shapefiles with varying grassland coverage of polygons ranging from 30 to 100%. For spatial modelling analysis, grassland data coverage of 60 to 100% was extracted and merged into one polygon and then extracted for each AEZ (Figure 3.4). The AEZ spatial data was downloaded from International Livestock Research Institute (ILRI) website (http://192.156.137.110/gis/) and processing done in ArcMAP.

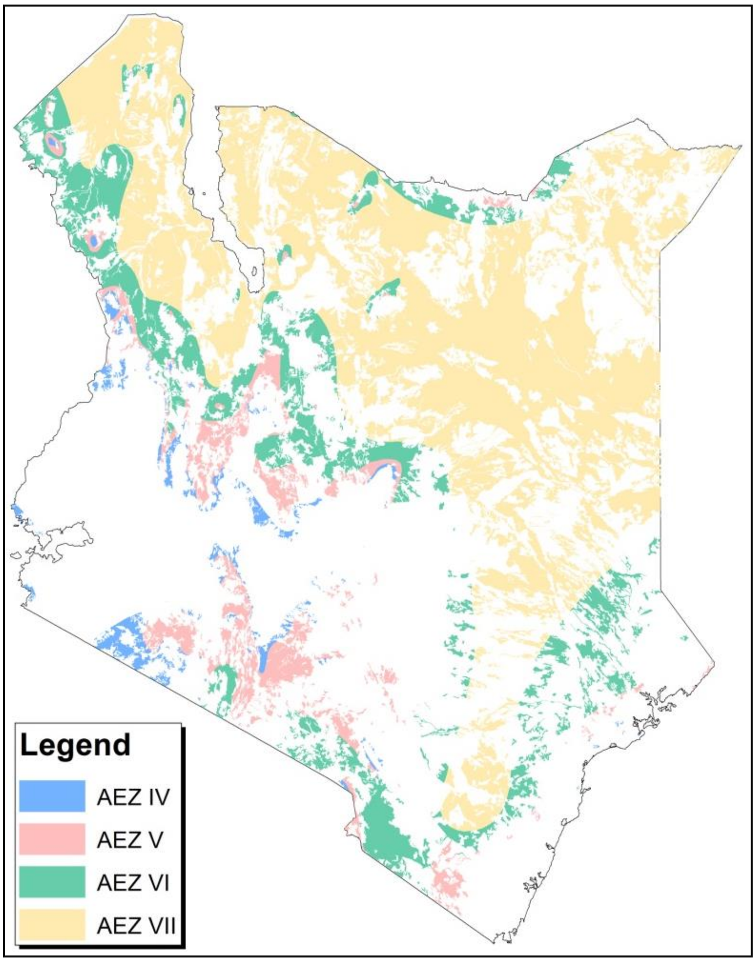

Figure 3.4: The spatial coverage of Africover grassland by AEZs.

Within the grassland polygon, a total of 7,863 grass presence points (Table 3.3) at least 1000m apart were generated for the seven agroecological zones (AEZ) in Kenya (Figure 3.5). The AEZs determination is dependent on the potential evaporation rates.

Table 3.3: Grass presence points by AEZs.

AEZ	Presence points
Zone IV	89
Zone V	495
Zone VI	1341
Zone VII	5938

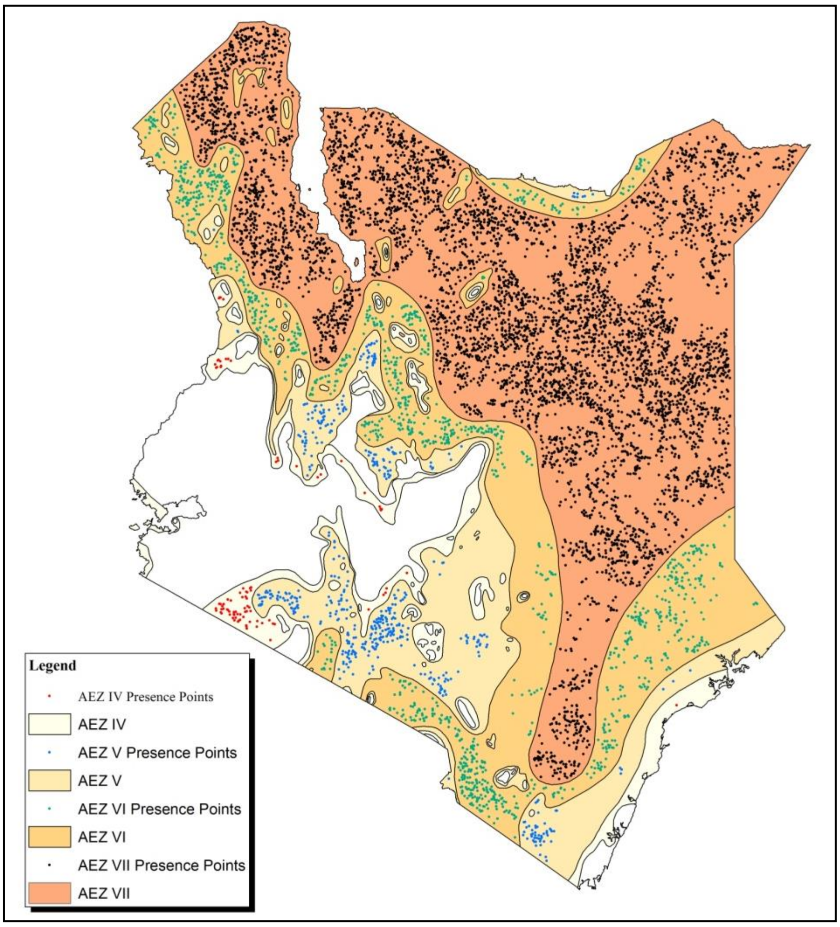

Figure 3.5: The randomly generated grass presence points by AEZs.

The AEZs IV – VII with potential evaporation rate of < 50% are the regions where livestock keeping and tourism-based wildlife are the major economic activities. The

AEZ zones IV – VII was extracted as new dataset using the selection method in ArcMAP. A buffer of -5000m was established and used to extract the random presence points for each AEZ (Table 3.4). The presence points coordinates were then generated and exported to Ms Excel for processing and conversion to comma separated value (CSV) format providing the presence-only locations needed for Maxent ecological niche modelling (Philips *et al.,* 2006).

3.2.2.3 Maxent Modelling and GIS Analysis

The data used for spatial and temporal modelling were climate elements and presence-only vegetation points. Using Maxent and ArcMAP, the base-year and years 2050 and 2070 potential spatial distribution of rangeland vegetation were modelled and spatial processing and analysis done. The Maxent modelling software requires that all the data be in American Standard Code for Information Interchange (ASCII) (.asc) format and identical in terms of spatial reference and pixel resolution (Philips *et al.*, 2006). A total of six different Maxent models were run using the presence-only points, the base-year and projected 2050 and 2070 future climatic periods (Figure 3.6). All Maxent model runs used Maxent 3.3.3 downloaded from www.cs.princeton.edu/~schapire/maxent/.

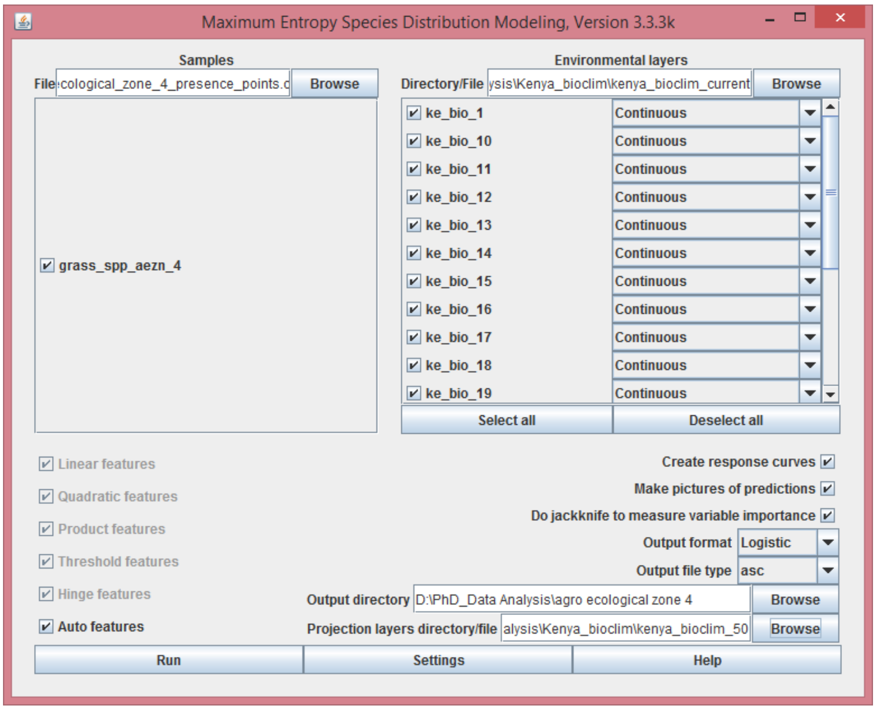

Figure 3.6: Screenshot of AEZ IV Maxent model setup.

The Maxent model generated probability curves for each variable from presence-only points and the bioclim data (Philips *et al.*, 2006) resulting in probability map (Figure 3.7).The output shows the influence (percent contribution) of each variable on the vegetation location, the response of vegetation to each variable and a final probability map of the vegetation likely occurrence based on the statistical model run on a scale from 0 to 1.

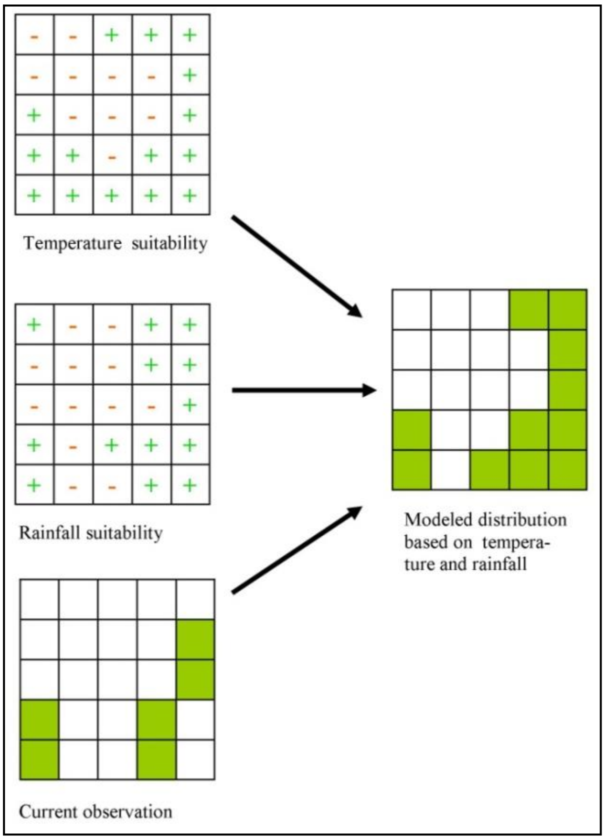

Figure 3.7: Maxent input and output species distribution probability map.

The output spatial data were exported and processed in ArcMAP for spatial analysis in each AEZ and for the entire country (Kenya). An ArcMAP model (Appendix 4) was built to process the spatial data to generate both binary and scaled raster datasets. The model was constructed using three ArcMAP tools that generated the binary raster for the AEZs. For the binary data reclassification, the "10 percentile training presence logistic threshold" was used to generate the "unsuitable" and the "suitable" categories. The "unsuitable" category ranged from 0 – threshold value while the "suitable" category had several levels. The suitable grass niche areas were scaled from threshold value to 0.5 representing low suitability, 0.5 to 0.6 denoting medium suitability, 0.6 to 0.7 indicating high suitability and 0.7 to 1.0 signifying excellent suitability. These processes were run for each AEZ and new raster datasets for the whole country generated using "Mosaic to New Raster" tool by use of maximum values option for the three climatic periods. Using the base-year potential grass niche spatial distribution as the basis of comparison, the future rangeland vegetation distribution were quantified and mapped. The Kenya's population in each suitability category was analysed for the base-year and future climatic periods. The population data used in the analysis was sourced from (PopulationPyramid.net, 2015) and its distribution pattern was based on the year 1999 Kenya census.

3.2.2.4 Analysis of temporal and spatial change in grass niche

Both spatial shift and quantitative changes of the grass niche were run using Kappa Location (K_{Loc}) and Kappa Histogram (K_{Histo}) in MCK. The Kappa Location analyses location change while Kappa Histogram examines sizes of areas similarity for the used dataset categories. Kappa statistics evaluation was based on scales with an example developed by Altman (1991). This scale has five categories of "Poor" (0 to 0.2), "Fair" (0.21 to 0.40) "Moderate" (0.41 to 0.60), "Good" (0.61 to 0.80) and "Very Good" (0.81 to 1.00). However, for this study a threshold of 0.5 was used and generated binary data of "Not similar" (0.00 to 0.49) and "Similar" (0.50 to 1.00). The grass niche suitability changes by climatic periods were obtained by subtraction of base-year raster from the projected future climate raster.

3.2.2.5 Model performance and accuracy assessment

Model evaluation provided information regarding whether a model can predict distributions that are different than random. The Maxent model performance analysis was based on the Area Under Curve (AUC) scores returned from the ran model which discriminates between presences and background points. The AUC scores range from 0 to 1 and the significant value scaled as ≥ 0.5 is better than random and denotes higher predictive power and ≤ 0.49 is worse than random.

3.2.2.6 Maxent model limitations and assumptions including

The Maxent model limitations were:

i. the possibility of over-fitting, limiting the capacity of the model to generalize well to independent data;
ii. biases in the occurrence localities where the climatic factors are favourable but other factors not included in the model limit the species occurrence

The assumptions made in the models were:

i. the grass species climatic requirements are the same the base-year and future climates
ii. the grass community require the same environmental parameters thus sharing the same niche
iii. the rangeland vegetation is influenced by climate parameters (rainfall and temperature) only

3.2.2.7 Analysis of Temporal and Spatial Change in Climate Parameters

The climatic parameters of interest were rainfall, for the fifteen year period under study. The analysis was both at monthly and annually where comparisons were based on the means in the respective times. The spatial and quantitative analyses were done using K_{Loc} and K_{Histo} kappa statistics.

The individual monthly/yearly spatial data were compared against their means for the period under study. Kappa statistics evaluation for this study was based on the 0.50 threshold which generated binary data of “Not Similar” (0.00 to 0.49) and “Similar” (0.50 to 1.00). The number of months with similarity were then expressed as percent and plotted in a graph.

3.2.3 Rangeland Livestock Carrying Capacity Data

The determination of the rangelands livestock carrying capacity was done by seeking the relationship between rainfall and dry matter per hectare per year (DM ha^{-1} yr^{-1}). Both rainfall and dry matter data used in the equation generation were sourced from FAO (1995). The resultant equation, DM (kg) = 123.00 + 1.81 (rainfall), significant at, $p \leq 0.006$, with $r^2 = 0.926$ was applied to the rainfall datasets to generate the dry matter yield per hectare per year for all the three climatic periods. Further, the dry matter per hectare per year datasets were refined by multiplying with corresponding grass niche suitability levels datasets. The Tropical Livestock Unit (TLU) was obtained by dividing the obtained data by the 250 kg the approximated and standardized livestock live-weight of each TLU. The obtained data was then converted to the land carrying capacity in ha/TLU.

3.2.4 Analysis of Kenyan Government Policies and Legislation in Relation to Climate Change

A detailed systematic review and analysis of Kenya government policy documents and legislations was done with respect to climate change on rangeland carrying capacity, wildlife and tourism management. The examination of the documents focussed on the government of Kenya development agenda in the ASALs and whether climatic issues were considered in their development. The analysis listed the policies and legislations in the ASALs and examined their efficacy in relation to climate change. The approach used consisted of the following data collection methods: (1) literature review, (2) primary document review, and (3) conducting Key Informant interviews.

The literature search focussed on the policies and legislations made from the years 1999 to 2018 at the national government level. The search were done in several computerized databases, including the Kenya Law, NEMA, East African Community, Kenya Wildlife Service, Kenya Forest Service and the line ministries. The search terms were mainly key words comprising “Climate change and livestock”, “Climate change and wildlife”, “Climate change and tourism”, “Climate change and forest”, “Climate change and development” and the names of documents of interest e.g., “Constitution of Kenya 2010” and “Kenya’s Vision 2030”. In addition, other terms such as “climate change coping strategies” were used and returned valuable documents.

All the accessed policies and legislations were reviewed. Those found to be relevant were flagged for further scrutiny based on the criteria that it contains information on climate change and/or sustainable development. The selection of flagged articles was based on the primary objective and scope of the review process. The professions of the KIs were as follows; Environment (1 participant), Kenya Wildlife Service (1 participant), Livestock officer (1 participant), Rangeland Ecologist (1 participant), Resource Economist (1 participant), Tourism officer (1 participant), Kenya Forest Service (1 participant), Meteorologist (1 participant), Plant Breeder (1 participant) and Politician (1 participant). The Key Informants were visited individually where interviews were conducted as described by Marshal (1996). The Key Informants questions (Appendix 5) comprised of; comment on the number of climate change policies and legislations; indicate whether the policy/legislation is weak or strong; the strength/weakness and level of policies and legislations implementations; comment on the modelled projected climate change impacts on the ASALs livestock CC given, the nature and location of the impacts;

what could be the secondary impacts associated with a decline in pasture; and recommend the response of stakeholders to the changing livestock CC.

The data analysis for the KIs, followed the (Marshal, 1996) procedures from semi-structured interviews. The steps involved were identification and writing the main themes, classification of information based on the topics addressed, identification of ideas in each topic, identification and classification of the most critical points and validation of the findings among other professionals in the various fields.

CHAPTER FOUR

RESULTS

4.1 Spatial-Temporal Trend of Rainfall and MODIS NDVI

4.1.1 Rainfall Spatial-Temporal Trends

The monthly mean rainfall pattern (Figure 4.1) shows the spatial distribution of mean monthly rainfall ranged from 0 to 389 mm classified into five categories (0 to 80 mm, 80 to 160 mm, 160 to 240 mm, 240 to 320 and 320 to 400 mm). The months of January, February and September mean rainfall ranged from 0 to 80 mm with March, June – October and December receiving 0 to 160 mm. The other months of April and November mean rainfall ranged between 0 to 320 mm while the month of May recorded the highest value of 389mm.

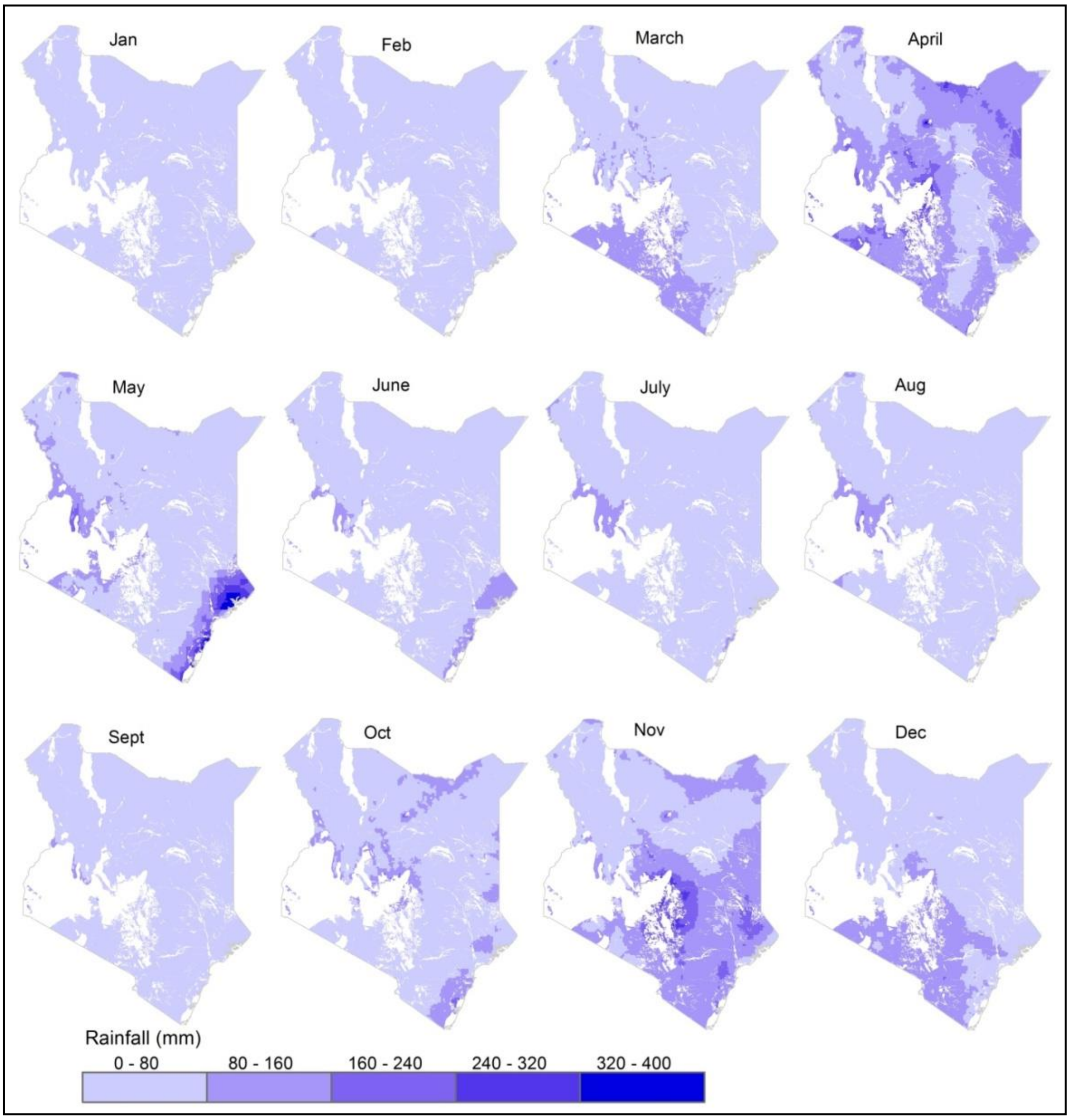

Figure 4.1: Mean monthly rainfall distribution in the period under study in Kenya ASALs.

The monthly rainfall trends in the 15 years period (Figure 4.2) showed that there were both positive and negative values though with different magnitudes. The trend ranged between -15 to 20 mm in the months of January in central region and May in the coastal regions respectively. The mean monthly rainfall trends by percent area (Table 4.1) show that a large percentage of the country monthly rainfall trends lie between -0.5 to 5 mm. January had the highest area of 84.5% under declining trend with rest of the country specifically in the north eastern and north coast regions indicating increasing rainfall trend. Other months with more than 50% of the area showing a declining rainfall trend though with different spatial distribution pattern include May (68.9%), June (55.8%), August (52.5%) and December (55.5%). The months with positive rainfall trend covering more than 50% of the areas are February (81.6%), March (69.3%), April (55.5%), July (64.3%), September (65.7%), October (70.7%) and November (78.3%).

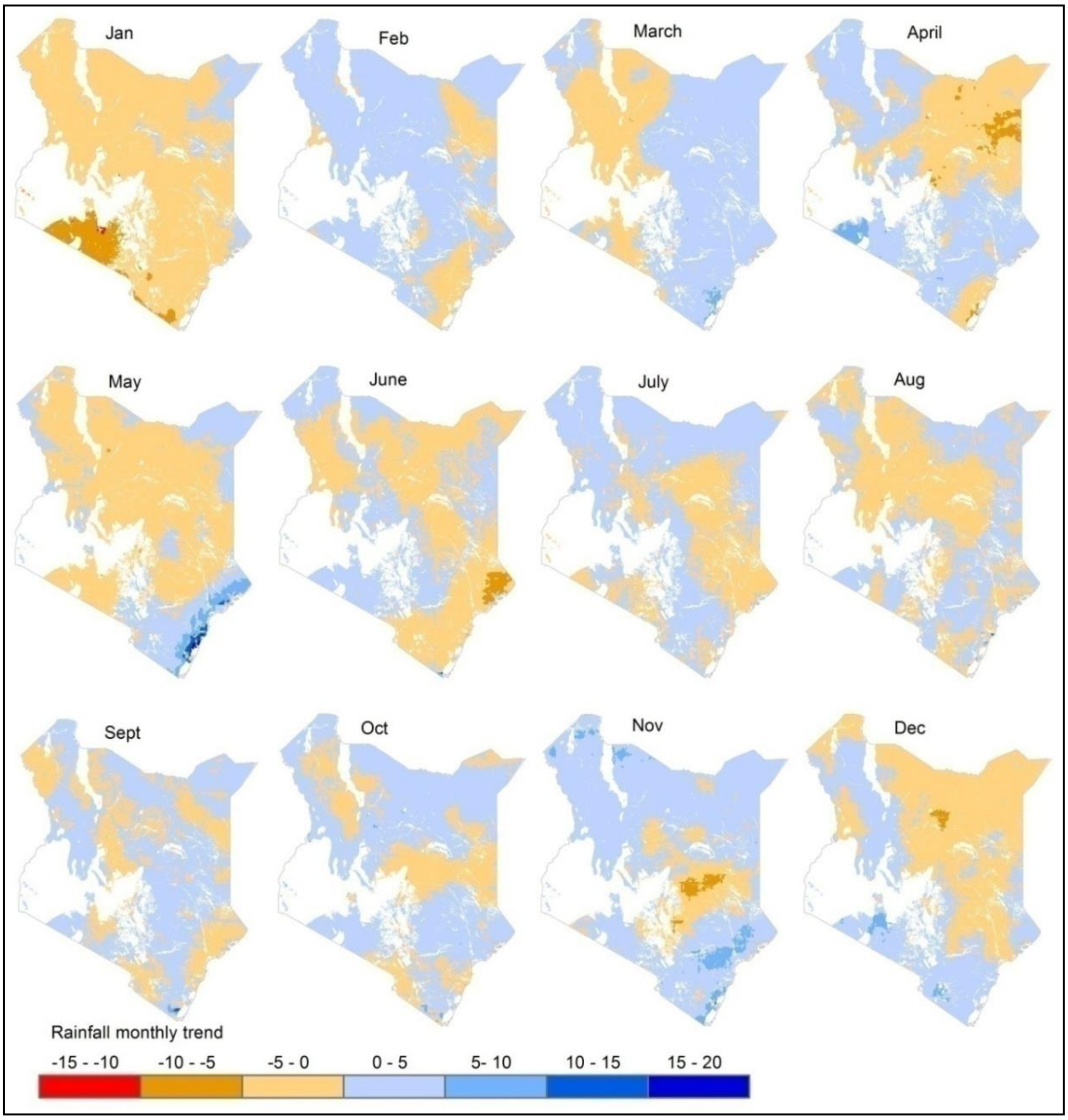

Figure 4.2: The mean monthly spatial rainfall trend.

Table 4.1: Monthly rainfall (mm) trend by percent area.

Trend (mm)	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
-15 - - 10	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-10 - -5	6.7	0.0	0.0	2.5	0.1	1.5	0.0	0.0	0.0	0.0	1.5	0.6
-5 - 0	84.5	18.4	30.1	40.4	68.9	55.8	35.7	52.5	34.1	29.1	16.2	55.5
0 - 5	8.7	81.6	69.3	55.5	27.3	42.6	64.3	47.4	65.7	70.7	78.3	42.9
5 - 10	0.0	0.0	0.6	1.5	3.0	0.1	0.0	0.1	0.1	0.2	3.9	1.0
10 - 15	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0
15 - 20	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The monthly rainfall similarity analysis (Table 4.2) is the Kappa statistics expressed as percent (Figure 4.3). The K_{Loc} statistic had a similarity pattern of zero and low similarities between the months of January to April with a maximum of 100.00% similarities from June to September. The similarity then reduces to less than 20.00% in October before becoming zero in December. The K_{Histo} maintained similarities of more than 60% with May, June, July, August and September having 100.00%. The high percent similarity observed indicate that the rainfall aspects of location and area covered are more or less the same from May – September. The other months of January – April and October – December have the lowest percent similarities a pointer to erratic and spatial shift rainfall patterns.

Table 4.2: Monthly rainfall Kappa statistics.

Month	Kappa Stat	Year															
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Counts ≥0.50
Jan	K_{Loc}	0.45	**0.59**	0.29	0.17	**0.65**	0.32	**0.60**	0.32	**0.52**	0.33	0.40	0.12	**0.63**	0.18	0.31	5
	K_{Histo}	**0.81**	**0.81**	**0.50**	**0.63**	**0.84**	**0.58**	**0.80**	**0.66**	**0.89**	**0.85**	**0.64**	0.39	**0.82**	0.37	0.45	12
Feb	K_{Loc}	0.32	0.38	**0.50**	**0.52**	0.30	0.49	0.46	0.49	0.36	0.34	**0.54**	0.42	0.36	0.47	**0.53**	4
	K_{Histo}	**0.75**	**0.58**	**0.75**	**0.74**	**0.67**	**0.88**	**0.78**	**0.62**	**0.72**	**0.65**	**0.76**	**0.80**	**0.66**	**0.83**	**0.76**	15
March	K_{Loc}	0.33	0.31	0.22	0.15	0.09	0.35	0.19	0.39	-0.41	-0.10	-0.01	-0.42	0.07	0.16	0.00	0
	K_{Histo}	**0.98**	**0.73**	**0.72**	**0.64**	**0.51**	**0.58**	**0.68**	**0.66**	0.28	0.35	**0.58**	0.32	0.42	**0.77**	**0.73**	11
April	K_{Loc}	0.37	0.22	0.10	0.32	0.24	0.43	0.14	0.35	0.10	0.31	-0.06	0.10	0.05	0.14	0.08	0
	K_{Histo}	**0.84**	**0.80**	**0.70**	**0.88**	**0.68**	**0.72**	**0.77**	**0.75**	0.43	**0.78**	0.29	**0.78**	**0.60**	**0.72**	**0.64**	13
May	K_{Loc}	**0.48**	**0.54**	**0.47**	**0.41**	**0.50**	**0.61**	**0.56**	**0.53**	**0.68**	**0.59**	**0.58**	**0.51**	**0.69**	**0.52**	**0.62**	12
	K_{Histo}	**0.53**	**0.77**	**0.74**	**0.72**	**0.77**	**0.91**	**0.93**	**0.51**	**0.89**	**0.81**	**0.72**	**0.86**	**0.72**	**0.80**	**0.85**	15
June	K_{Loc}	**0.63**	**0.63**	**0.69**	**0.58**	**0.72**	**0.73**	**0.54**	**0.64**	**0.64**	**0.74**	**0.61**	**0.64**	**0.68**	**0.64**	**0.68**	15
	K_{Histo}	**0.91**	**0.94**	**0.92**	**0.84**	**0.92**	**0.88**	**0.86**	**0.93**	**0.89**	**0.96**	**0.93**	**0.92**	**0.93**	**0.95**	**0.94**	15
July	K_{Loc}	**0.77**	**0.57**	**0.82**	**0.73**	**0.69**	**0.75**	**0.52**	**0.70**	**0.59**	**0.64**	**0.76**	**0.67**	**0.76**	**0.74**	**0.57**	15
	K_{Histo}	**0.94**	**0.92**	**0.83**	**0.83**	**0.96**	**0.86**	**0.85**	**0.86**	**0.75**	**0.93**	**0.86**	**0.86**	**0.94**	**0.97**	**0.94**	15
Aug	K_{Loc}	**0.76**	**0.62**	**0.69**	**0.75**	**0.71**	**0.59**	**0.61**	**0.77**	**0.67**	**0.77**	**0.68**	**0.68**	**0.73**	**0.71**	**0.64**	15
	K_{Histo}	**0.90**	**0.94**	**0.86**	**0.91**	**0.90**	**0.90**	**0.86**	**0.88**	**0.84**	**0.92**	**0.92**	**0.88**	**0.91**	**0.89**	**0.85**	15
Sept	K_{Loc}	**0.70**	**0.62**	**0.68**	**0.64**	**0.67**	**0.59**	**0.57**	**0.74**	**0.67**	**0.74**	**0.70**	**0.70**	**0.64**	**0.72**	**0.67**	15
	K_{Histo}	**0.84**	**0.90**	**0.86**	**0.90**	**0.86**	**0.92**	**0.82**	**0.89**	**0.75**	**0.94**	**0.85**	**0.87**	**0.78**	**0.91**	**0.85**	15
Oct	K_{Loc}	0.25	0.48	0.37	**0.56**	0.33	0.29	0.46	0.37	0.44	0.34	0.13	0.45	0.42	0.33	**0.54**	2
	K_{Histo}	0.49	**0.85**	**0.66**	**0.86**	**0.50**	**0.67**	**0.78**	**0.72**	**0.69**	**0.53**	**0.56**	**0.89**	**0.64**	**0.61**	**0.94**	14
Nov	K_{Loc}	0.42	0.40	0.39	0.31	-0.14	0.04	0.38	-0.21	-0.01	0.13	0.04	0.44	0.35	**0.50**	0.29	1
	K_{Histo}	**0.75**	**0.71**	**0.87**	**0.88**	**0.52**	**0.55**	**0.80**	0.18	0.46	**0.64**	0.44	**0.79**	**0.94**	**0.85**	**0.68**	12
Dec	K_{Loc}	0.23	-0.04	0.32	0.39	-0.63	-0.09	0.09	-0.42	0.19	-0.14	0.29	0.25	0.26	0.35	0.38	0
	K_{Histo}	**0.64**	**0.54**	**0.71**	**0.79**	0.29	**0.59**	**0.63**	0.39	**0.66**	**0.57**	**0.63**	**0.72**	**0.59**	**0.76**	**0.71**	13

Note: Bolded figures in the months indicate presence of similarity and the unbolded figures had no similarity

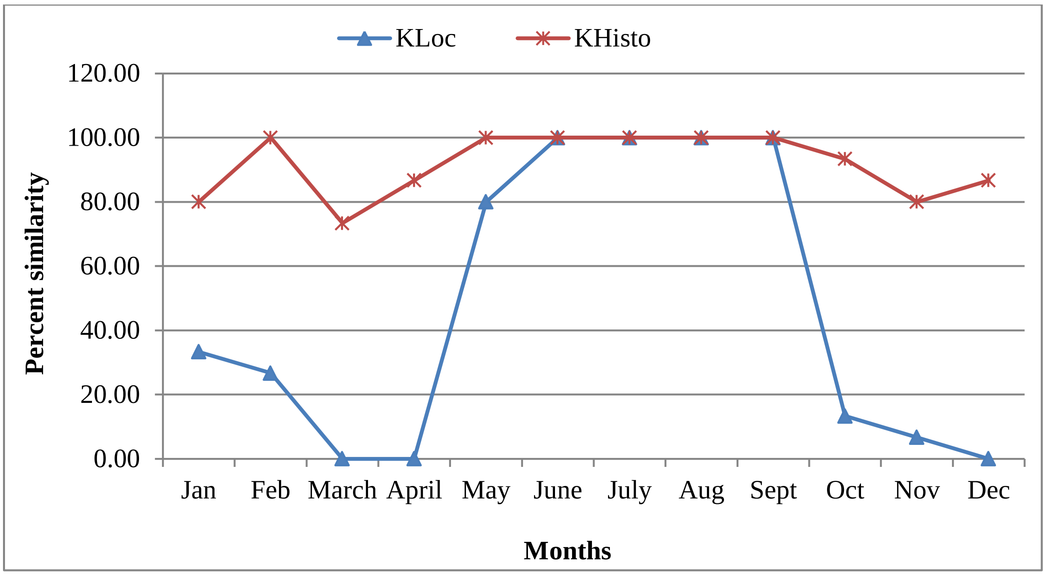

Figure 4.3: Mean monthly rainfall K_{Loc} and K_{Histo} percent similarity kappa statistics.

The annual spatial and temporal distribution patterns of rainfall (Figure 4.4) ranged from 16 to 2259 mm. In general the rainfall distribution was higher in the central, southern and coastal areas of the country. The northern, north eastern and eastern regions recorded low mean rainfall. The wettest years were 2002 and 2006 with maximums of 2000 to 2500 mm of rain in coastal and sections of central regions. The driest years during the study period comprised of 2008 and 2009 with maximum rainfall not exceeding 1500 mm. The mean rainfall of the years 2005, 2008 and 2009 ranged from 0 to1500 mm whereas it was between 0 to 2000 mm in the years 2001, 2002, 2003, 2004, 2007, 2011, 2014 and 2015 mainly restricted to the north and north eastern regions. The years whose maximum mean rainfalls were more than 2000 mm are 2006, 2010, 2012 and 2013 though this covered minimal areas covering the coastal and central regions of the country.

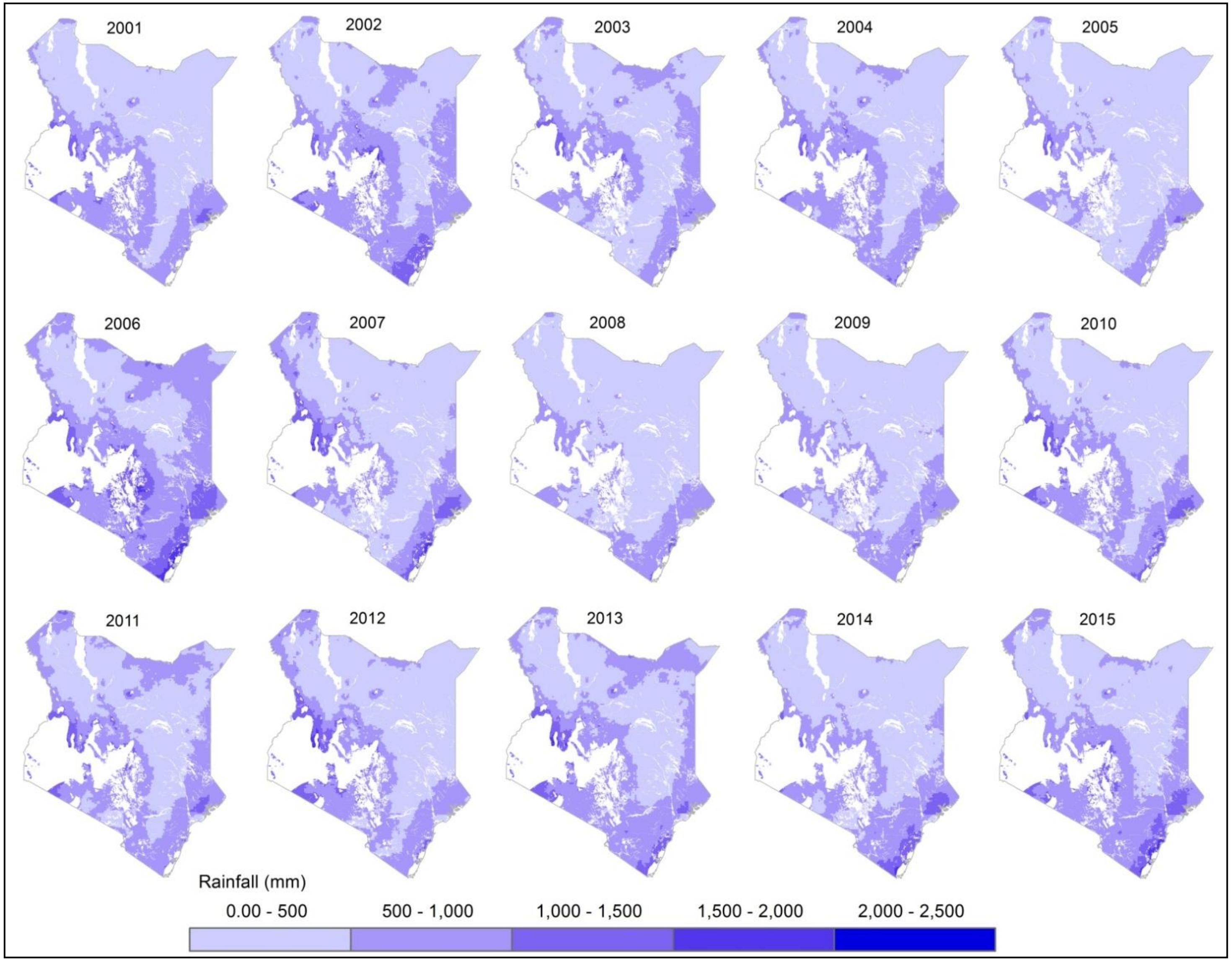

Figure 4.4: Mean annual rainfall spatial distribution.

The annual rainfall spatial trend analysis based on CHIRPS data for the 15 years illustrate that the entire country experienced a negative trend ranging from -6 to 0 mm (Figure 4.5). In the northwest, northern and north eastern sections which constitute about 60.8% of the country by area, the rainfall trend ranged from -2 to 0 mm. The regions of central, southern and coastal areas decreased by -4 to -2 mm and represented 37.4% of Kenya’s area. The areas with the most reduced rainfall trend by -6 to 4 mm were scattered in the central, southern and coastal regions covering a small area of 1.8% of the area.

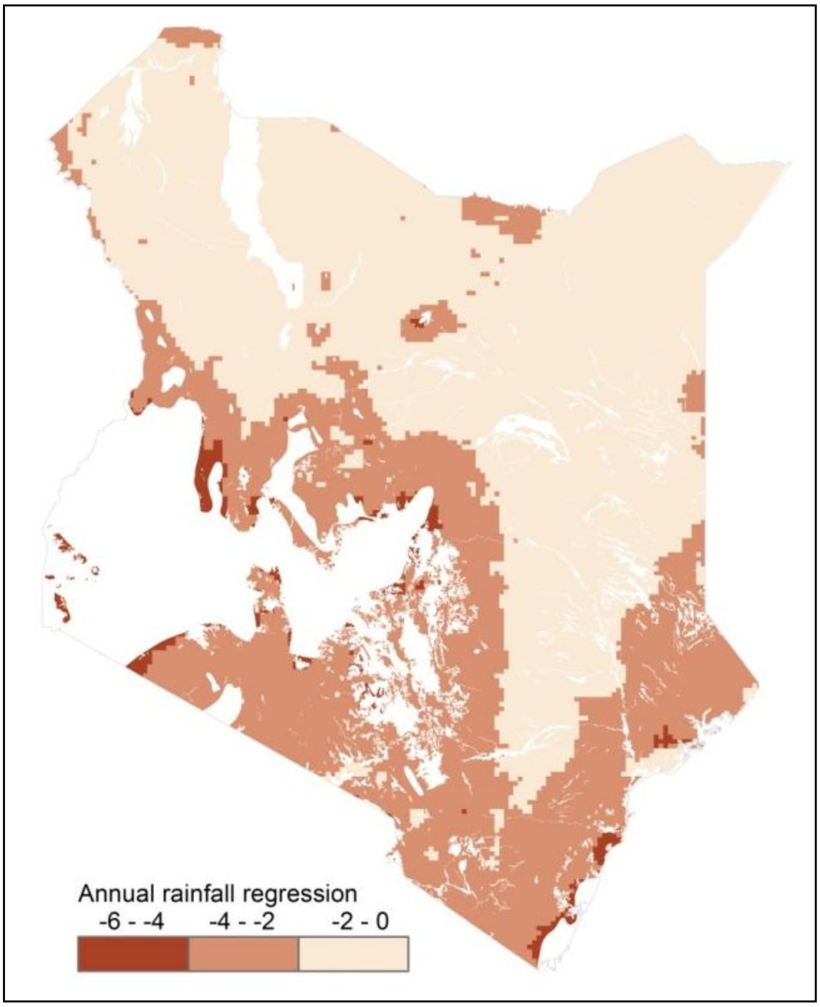

Figure 4.5: Annual rainfall trend 2001 to 2015.

The annual rainfall K_{Loc} and K_{Histo} kappa statistics percent similarities are presented (Figure 4.6). The K_{Loc} percent similarity ranged between 33.33% in 2001 to 58.33% in 2015, with the other years ranging between 40.00 to 50.00%. The K_{Histo} values were all more than 75.00% with the least in 2009 and the highest in 2002, 2004, 2006 and 2007 at 100.00%.

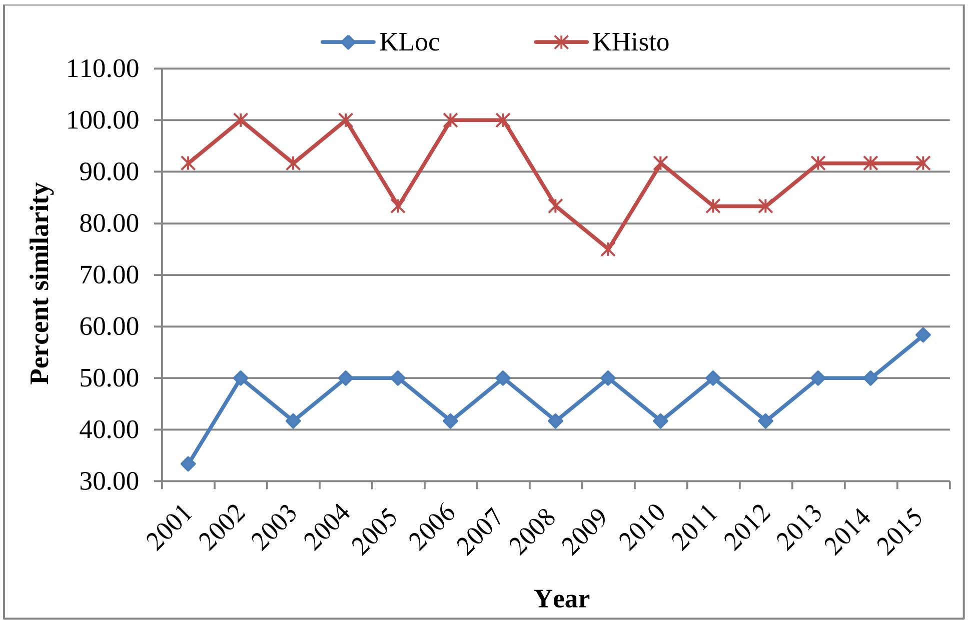

Figure 4.6: The annual rainfall K_{Loc} and K_{Histo} percent similarity kappa statistics.

4.1.2 MODIS NDVI Spatial-Temporal Analysis

The MODIS NDVI trend analysis was done at spatial-temporal scale on both monthly and annual basis for the period (2001 to 2015). The MODIS NDVI is the mean biomass production over the period at pixel value presented as mean for both monthly and yearly basis. The monthly MODIS NDVI distribution (Figure 4.7) is represented as a spatial pattern. The MODIS NDVI pattern shows that most of the coastal, central and southern regions have higher values compared to the northern and north eastern regions. This is an indication that there is a spatial variation of vegetation distribution in Kenya. The lower the MODIS NDVI the poorer the vegetation status or the less the vegetation cover in the area.

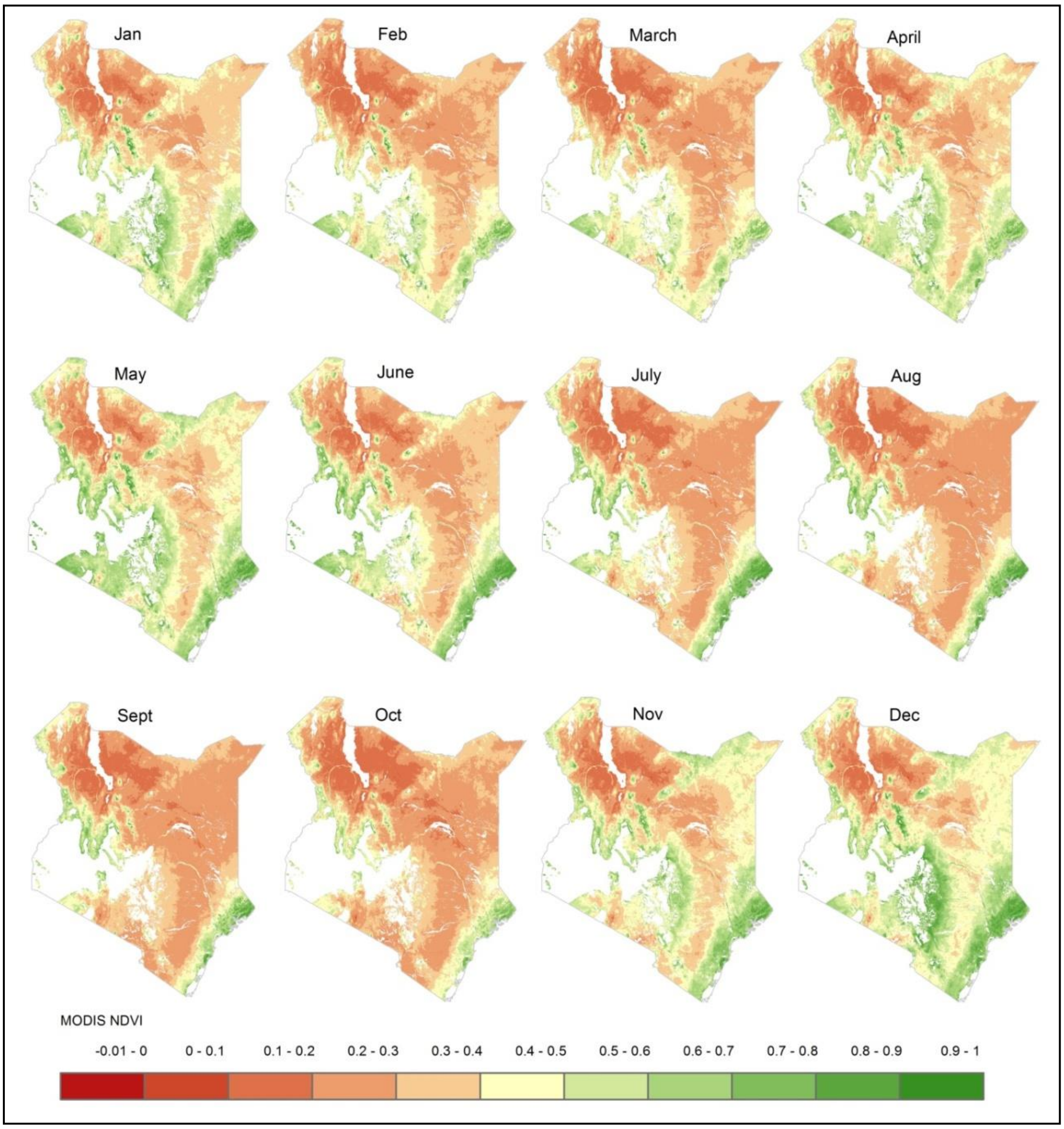

Figure 4.7: Mean monthly MODIS NDVI.

The monthly MODIS NDVI trend analysis showed both increasing and decreasing trends of between -0.0620677 to 0.060 (Figure 4.8) differing with the months. The lowest negative trend of -0.0620677 was recorded in the month of November while 0.0559023 was the highest positive trend in October. The month of

December recorded extreme MODIS NDVI values in both directions which ranged from -0.0588346 to 0.0572932.

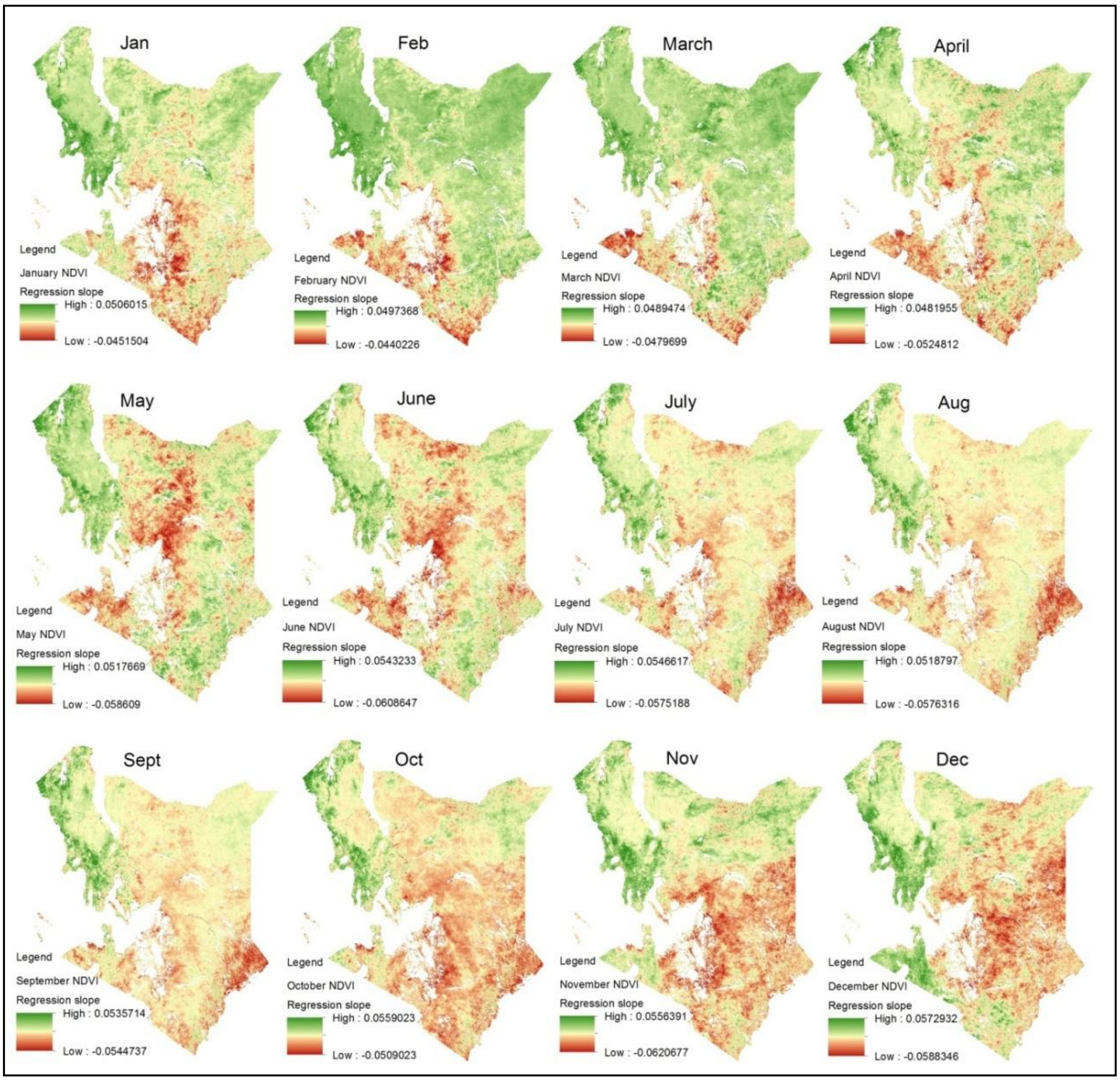

Figure 4.8: MODIS NDVI monthly trend.

The percent areas under decreasing trend (Table 4.3) ranged from 42.35% (March) to 70.97% (June). The months with decreasing trend covering more than 50.00% include January (52.26%), February (68.83%), May (67.76%), June (70.97%), July (69.19%), August (67.74%), September (59.70%), October (50.98%) and December (51.13%) with March (57.65%) and November (51.20%) recorded a declining trend.

This seasonal variation in MODIS NDVI trends indicates that there is a net loss of vegetation in the country though at different locations and magnitudes.

Table 4.3: Monthly MODIS NDVI trend by percent area.

	Months											
Trend	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
-0.065–0	52.26	68.83	42.35	43.83	67.76	70.97	69.19	67.74	59.70	50.98	48.80	51.13
0 – 0.060	47.74	31.17	57.65	56.17	32.24	29.03	30.81	32.26	40.30	49.02	51.20	48.87

The spatial depiction of the monthly MODIS NDVI trends is captured in (Figure 4.9). In all the months, the north western region of the country had positive trends. Other months of January – April and June – December showed increasing trends in the northern and north-eastern tip. The majority of the southern parts had a decreasing trend with exception of some few areas in south western parts in the months of January and September – December.

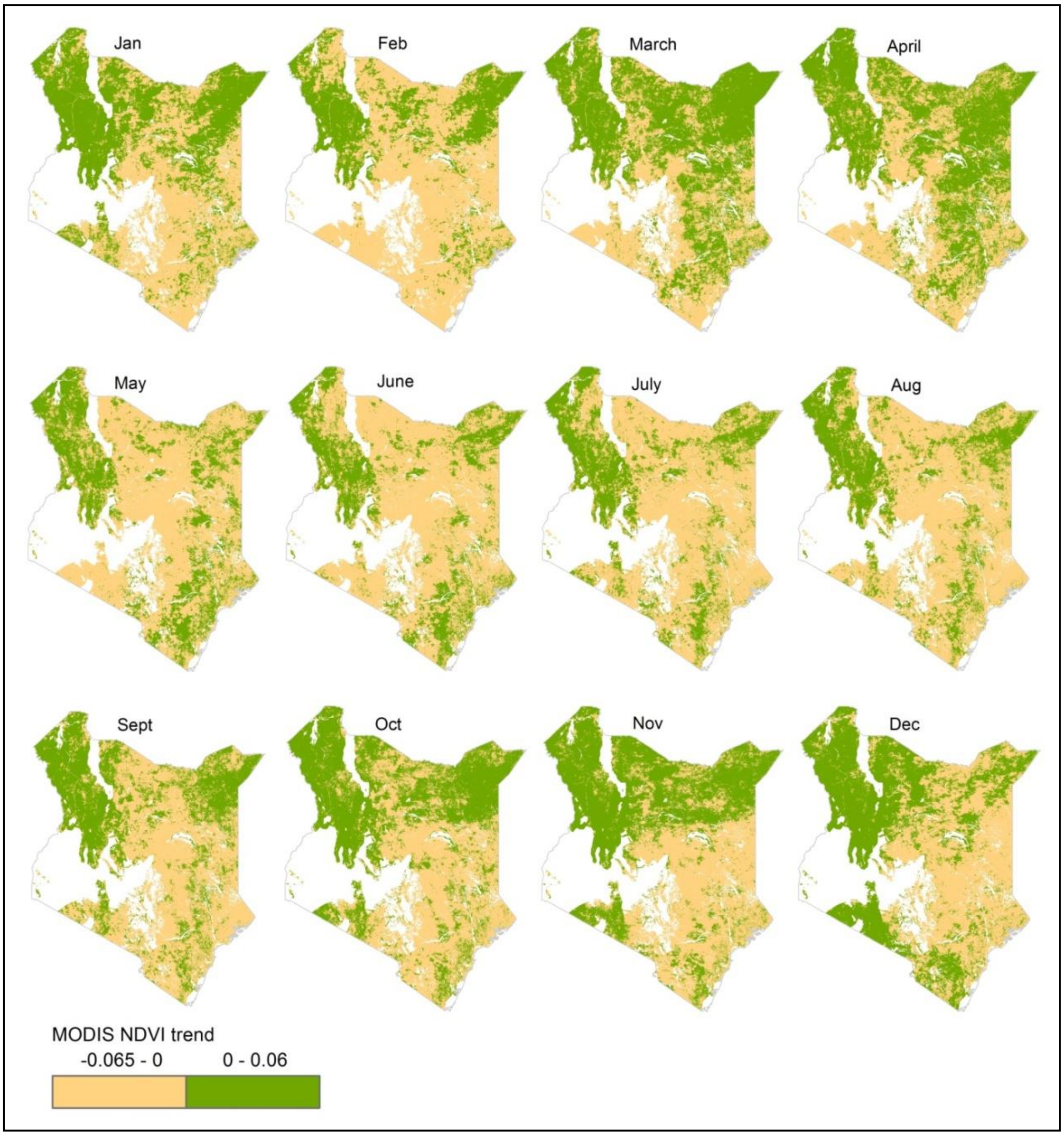

Figure 4.9: Binary monthly MODIS NDVI spatial temporal trend.

The monthly MODIS NDVI similarity analysis used Kappa statistics (K_{Loc} and K_{Histo}) for each year (Table 4.4) and presented in figure 4.10. The K_{Loc} percent similarity fluctuated between 86.67 to 100.00% from January – September before reducing to 66.68% in October, then 0.00% in November then increasing to 73.33% in December. The K_{Histo} statistic had similarity pattern of 100.00% throughout except in the moths of January and March which were also more than 80.00%. These monthly percent similarity patterns indicate stability of both location and sizes of areas of rangeland vegetation. However, in the month of November the percent similarity was 0.00%, an indication that the rangeland vegetation shift in location was very high though the sizes of the areas under the different categories remained the same.

Table 4.4: The MODIS NDVI kappa statistics of K_{Loc} and K_{Histo}.

		Year															
Months	Kappa	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Counts ≥0.50
Jan	K_{Loc}	**0.75**	**0.72**	**0.58**	**0.66**	**0.74**	**0.45**	**0.07**	**0.78**	**0.62**	**0.71**	**0.80**	**0.55**	**0.73**	**0.78**	**0.76**	13
	K_{Histo}	**0.67**	**0.85**	**0.79**	**0.92**	**0.86**	**0.65**	0.47	**0.85**	**0.74**	**0.88**	**0.82**	**0.75**	**0.85**	**0.86**	**0.94**	14
Feb	K_{loc}	**0.77**	**0.81**	**0.74**	**0.71**	**0.79**	**0.67**	**0.39**	**0.76**	**0.73**	**0.71**	**0.75**	**0.73**	**0.80**	**0.80**	**0.73**	14
	K_{Histo}	**0.75**	**0.84**	**0.91**	**0.93**	**0.96**	**0.71**	**0.65**	**0.92**	**0.82**	**0.92**	**0.72**	**0.87**	**0.88**	**0.91**	**0.76**	15
March	K_{loc}	**0.81**	**0.77**	**0.82**	**0.82**	**0.83**	**0.80**	**0.67**	**0.84**	**0.72**	**0.60**	**0.80**	**0.78**	**0.77**	**0.73**	**0.73**	15
	K_{Histo}	**0.84**	**0.84**	**0.94**	**0.90**	**0.93**	**0.82**	0.31	**0.89**	**0.82**	**0.74**	**0.80**	**0.85**	**0.97**	**0.91**	0.36	13
April	K_{loc}	**0.66**	**0.72**	**0.72**	**0.72**	**0.72**	**0.75**	**0.73**	**0.72**	**0.51**	0.45	**0.57**	**0.70**	**0.51**	**0.65**	**0.59**	14
	K_{Histo}	**0.82**	**0.87**	**0.90**	**0.81**	**0.78**	**0.84**	**0.88**	**0.83**	**0.68**	**0.69**	**0.66**	**0.80**	**0.69**	**0.90**	**0.92**	15
May	K_{loc}	**0.66**	**0.55**	**0.55**	**0.64**	**0.66**	**0.70**	**0.68**	**0.59**	0.44	**0.62**	0.46	**0.52**	**0.54**	**0.59**	**0.65**	13
	K_{Histo}	**0.83**	**0.77**	**0.75**	**0.85**	**0.83**	**0.78**	**0.79**	**0.86**	**0.68**	**0.83**	**0.61**	**0.82**	**0.78**	**0.83**	**0.88**	15
June	K_{loc}	**0.71**	**0.59**	0.47	**0.73**	**0.60**	**0.73**	**0.73**	**0.66**	**0.72**	**0.69**	**0.70**	**0.59**	**0.72**	**0.72**	**0.72**	14
	K_{Histo}	**0.73**	**0.82**	**0.74**	**0.94**	**0.92**	**0.88**	**0.87**	**0.92**	**0.75**	**0.93**	**0.71**	**0.87**	**0.93**	**0.84**	**0.94**	15
July	K_{loc}	**0.79**	**0.72**	**0.66**	**0.75**	**0.71**	**0.80**	**0.67**	**0.75**	**0.79**	**0.74**	**0.77**	**0.66**	**0.70**	**0.82**	**0.80**	15
	K_{Histo}	**0.78**	**0.85**	**0.83**	**0.94**	**0.96**	**0.88**	**0.88**	**0.95**	**0.75**	**0.97**	**0.75**	**0.89**	**0.98**	**0.87**	**0.91**	15
Aug	K_{loc}	**0.81**	**0.72**	**0.76**	**0.81**	**0.83**	**0.82**	**0.64**	**0.82**	**0.75**	**0.78**	**0.80**	**0.68**	**0.72**	**0.85**	**0.83**	15
	K_{Histo}	**0.91**	**0.93**	**0.89**	**0.91**	**0.88**	**0.89**	**0.86**	**0.90**	**0.66**	**0.98**	**0.79**	**0.93**	**0.97**	**0.88**	**0.87**	15
Sept	K_{loc}	**0.81**	**0.71**	**0.80**	**0.80**	**0.85**	**0.78**	**0.70**	**0.81**	**0.77**	**0.82**	**0.75**	**0.69**	**0.81**	**0.78**	**0.79**	15
	K_{Histo}	**0.95**	**0.90**	**0.87**	**0.96**	**0.93**	**0.97**	**0.76**	**0.96**	**0.72**	**0.94**	**0.88**	**0.94**	**0.90**	**0.95**	**0.91**	15
Oct	K_{loc}	**0.63**	0.39	**0.57**	**0.54**	**0.69**	0.49	0.39	**0.54**	**0.51**	**0.70**	0.41	0.49	**0.66**	**0.55**	**0.56**	10
	K_{Histo}	**0.91**	**0.86**	**0.91**	**0.87**	**0.87**	**0.86**	**0.82**	**0.90**	**0.93**	**0.90**	**0.75**	**0.89**	**0.92**	**0.91**	**0.98**	15
Nov	K_{loc}	0.39	0.37	0.36	0.41	0.21	0.35	0.48	0.37	0.35	0.26	0.25	0.39	0.41	0.42	0.47	0
	K_{Histo}	**0.84**	**0.82**	**0.78**	**0.86**	**0.65**	**0.77**	**0.88**	**0.91**	**0.86**	**0.68**	**0.70**	**0.85**	**0.91**	**0.83**	**0.91**	15
Dec	K_{loc}	**0.61**	**0.62**	**0.59**	**0.58**	0.39	0.25	**0.64**	**0.66**	**0.64**	0.40	0.29	**0.66**	**0.63**	**0.62**	**0.59**	11
	K_{Histo}	**0.86**	**0.84**	**0.85**	**0.87**	**0.64**	**0.56**	**0.84**	**0.84**	**0.82**	**0.69**	**0.56**	**0.88**	**0.94**	**0.87**	**0.89**	15

Note: Bolded and unbold figures indicate presence of similarity and no similarity respectively

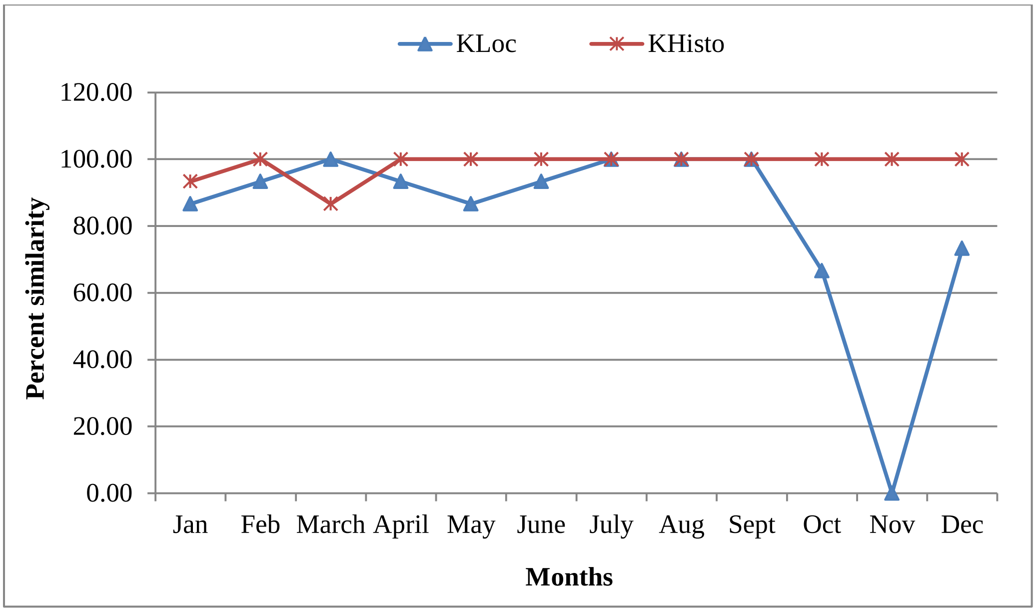

Figure 4.10: Mean monthly MODIS NDVI K_{Loc} and K_{Histo} percent similarity kappa statistics.

The annual MODIS NDVI spatial distribution patterns (Figure 4.11) are more or less the same as monthly and ranged between -0.01 to 1.00. The regions with high MODIS NDVI are coastal, southern and central with the north eastern and northern parts having low values. However, there are patches of areas with high MODIS NDVI in the regions with predominantly low values.

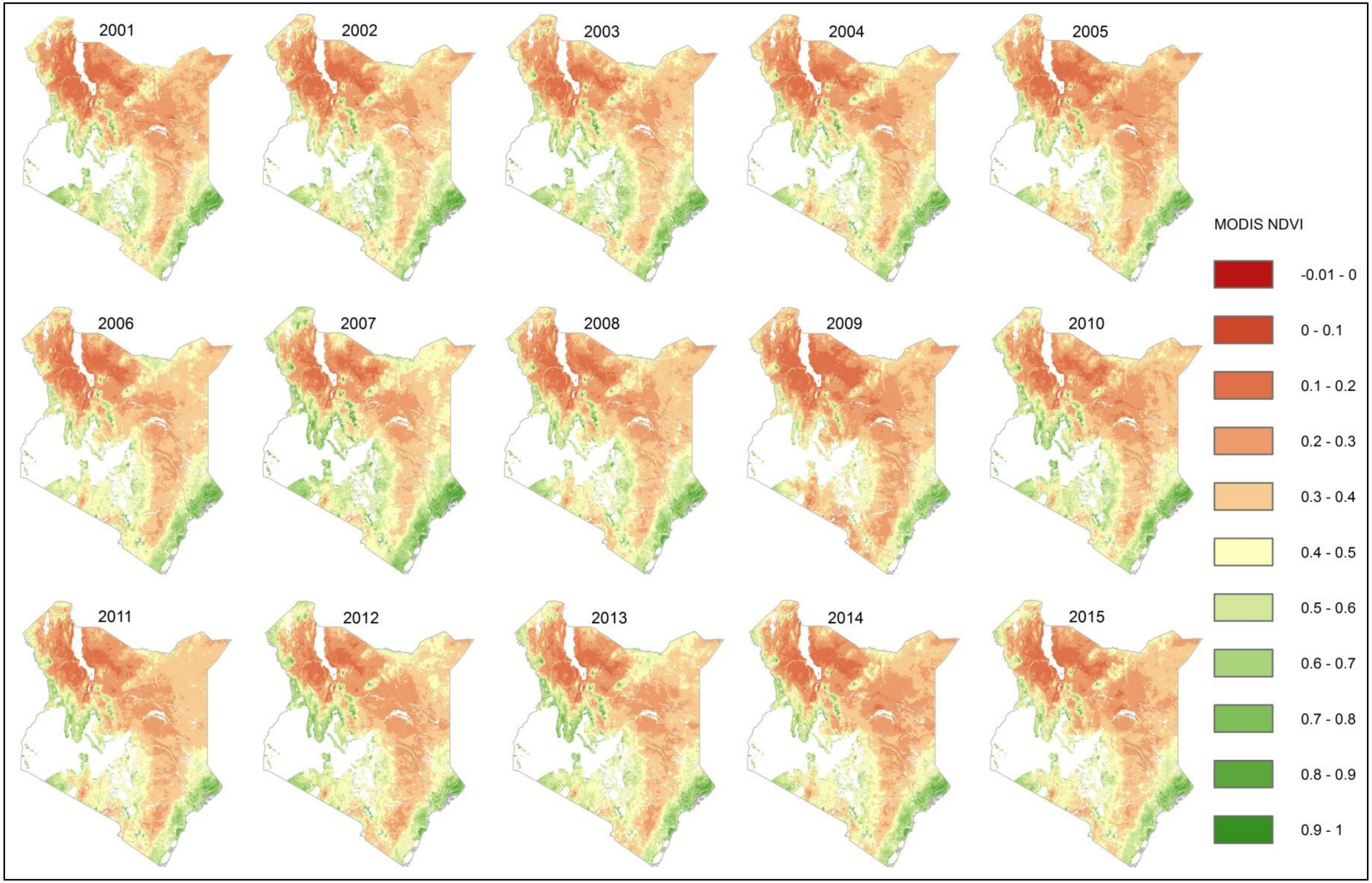

Figure 4.11: Mean annual MODIS NDVI.

The annual MODIS NDVI analysis also indicated that the country experienced both negative (decrease) and positive (increase) trends for different regions ranging from between -0.0495927 to 0.0468138. The north western area and the north eastern tip of the country had an increasing MODIS NDVI trend (Figure 12). The areas with decreasing MODIS NDVI trend was more in the eastern, coastal, southern parts and also scattered all over the country. The binary analysis (Figure 4.13) indicated that 38.01% of the country experienced a positive trend with the rest, 61.99% having negative trend.

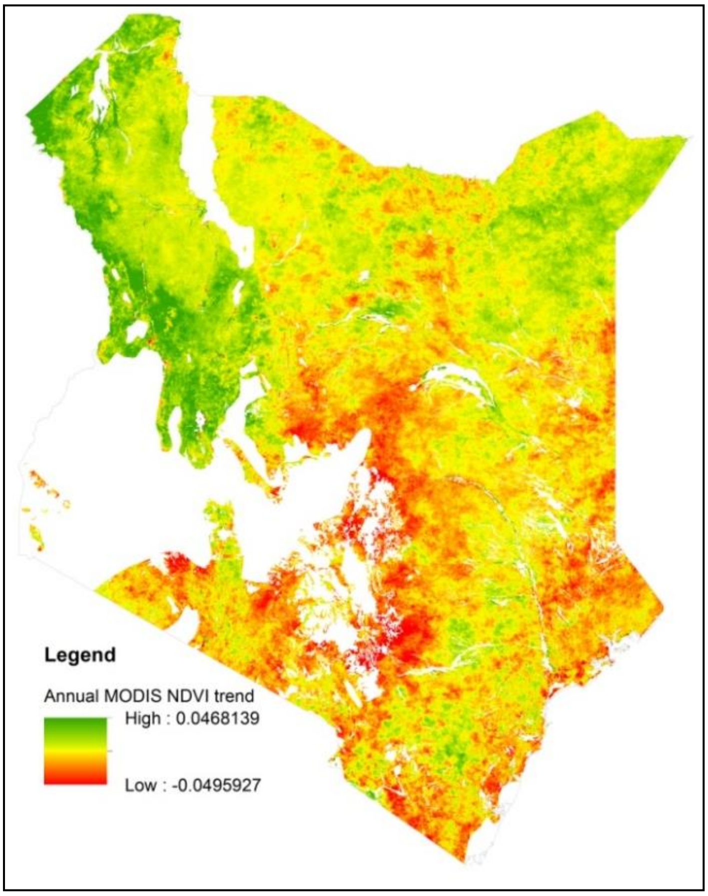

Figure 4.12: Annual MODIS NDVI spatial trend.

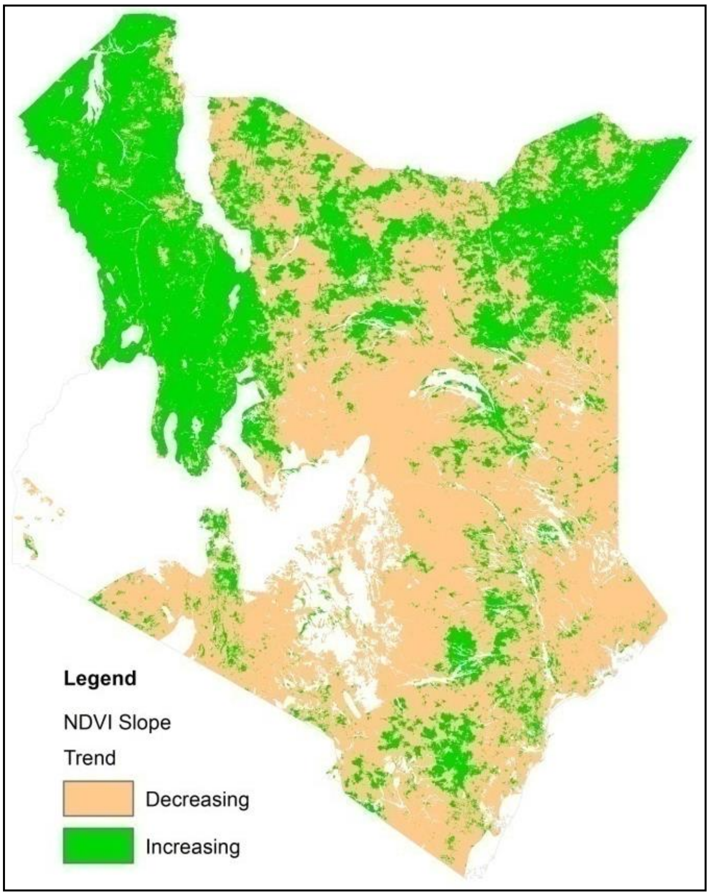

Figure 4.13: Annual MODIS NDVI binary spatial trend.

The annual MODIS NDVI percent similarities for both K_{Loc} and K_{Histo} kappa statistics were all more than 60.00% (Figure 4.14). The K_{Loc} ranged from 66.67% for years 2006, 2007 and 2011 to 91.67% in 2001, 2004, 2008, 2013, 2014 and 2015. The other years' percent similarities are within these low and high ranges. These values point out that both the location and areas of the rangeland vegetation are stable an indication of consistency. The K_{Histo} percent similarity indicated that all the years were similar with a least of 84% in the year 2007 followed by 91% in 2015 and rest of the years were 100%. With all the similarities more that 50%, it is shows that the sizes (areas) of the different categories of MODIS NDVI have not changed within the 15 years.

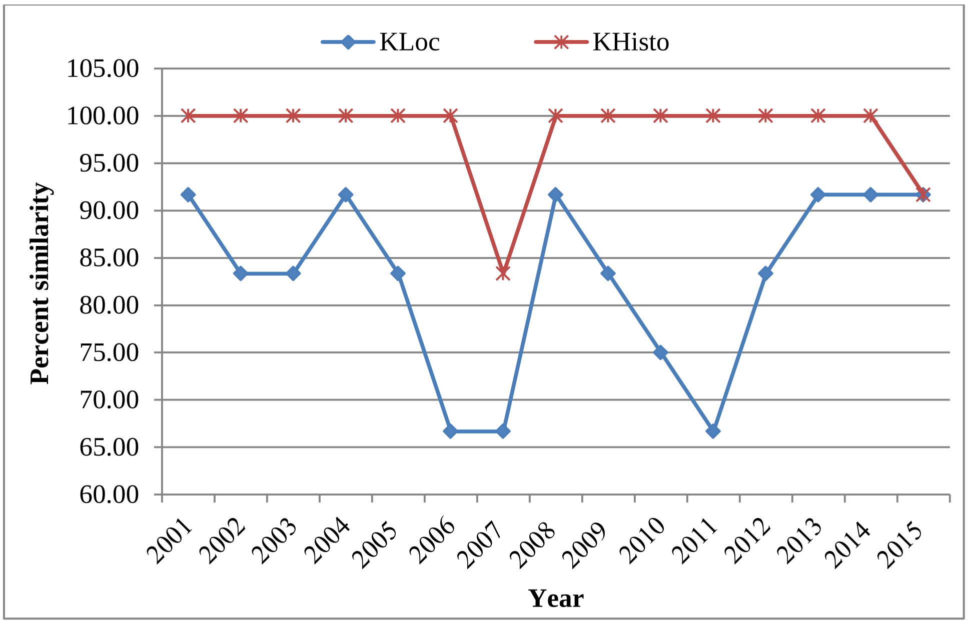

Figure 4.14: The annual MODIS NDVI K_{Loc} and K_{Histo} percent similarity kappa statistics.

4.1.3 Rainfall and MODIS NDVI Regression Analysis

The relationship between annual mean rainfall and annual mean MODIS NDVI for the study period was determined through linear regression analysis in Geoda software. Results in table 4.5 summarised the linear regression analysis for all the individual years and the mean of the fifteen years under study. All the results indicate that there was a significant relationship between the rainfall and MODIS NDVI, $p \leq 0.000$. The coefficient of determination ranged between 0.541 in the year 2002 and 0.763 in 2006 for the individual years and was 0.617 for the fifteen years mean (2001 to 2015). These results indicate that within the fifteen years (2001 to 2015), the vegetation (MODIS NDVI) was dependent on the rainfall.

Table 4.5: Annual and 15 year mean spatial regression between rainfall and MODIS NDVI.

Year	*p*-value	T	r^2 (adjusted)	Equation
2001	0.000	246.381	0.763	NDVI = 0.155 + 0.00052(Rain)
2002	0.000	149.186	0.541	NDVI = 0.163 + 0.00050(Rain)
2003	0.000	214.683	0.709	NDVI = 0.150 + 0.00054 (Rain)
2004	0.000	183.537	0.641	NDVI = 0.211 + 0.00053(Rain)
2005	0.000	190.746	0.658	NDVI = 0.133 + 0.00034 (Rain)
2006	0.000	162.749	0.584	NDVI = 0.217 + 0.00037(Rain)
2007	0.000	209.197	0.699	NDVI = 0.218 + 0.00062(Rain)
2008	0.000	212.610	0.705	NDVI = 0.171 + 0.00055(Rain)
2009	0.000	179.799	0.631	NDVI = 0.162 + 0.00037(Rain)
2010	0.000	184.350	0.643	NDVI = 0.137 + 0.00049 (Rain)
2011	0.000	165.596	0.592	NDVI = 0.204 + 0.00036 (Rain)
2012	0.000	173.842	0.616	NDVI = 0.161 + 0.00042 (Rain)
2013	0.000	158.549	0.571	NDVI = 0.210 + 0.00041(Rain)
2014	0.000	186.222	0.648	NDVI = 0.159 + 0.00039 (Rain)
2015	0.000	227.553	0.733	NDVI = 0.143 + 0.00049(Rain)
Mean (15yrs)	0.000	174.323	0.617	NDVI = 0.149 + 0.00042(Rain)

Climate change and its impacts have been widely studied though there are still many gaps of knowledge due to scientific uncertainties. However, analysis of the past climatic variables trends such as rainfall can give evidence on the tendency and magnitude of variability within a given period. Along with the analysis of rainfall is how the trend has influenced vegetation, a critical support of the major economic activity in Kenya. Kenya's land area is divided into AEZs each with distinct climatic characteristics. The agroecological zones IV – VI, which is classified as the arid and semi-arid lands (ASALs) are characterised by low and highly variable rainfalls of different amounts.

4.2 Modelled Spatial and Temporal Rangeland Vegetation Distribution

4.2.1 Base-Year Climatic Period Grass Niche Range

The Maxent unsuitable and suitable grass niche areas were different in all the AEZs (Table 4.6). The modelled suitable grass niche covered different fractions in each AEZ with 76.16% and the 23.84% being unsuitable and suitable respectively in the country. The percent of suitable grass niche increased from a minimum of 23.84% in AEZ IV to a maximum of 80.12% in AEZ VII. The others were 39.64% for AEZ V and 68.61% for AEZ VI.

Table 4.6: Base-year climatic period grass niche binary range by area.

	AEZ IV	AEZ V	AEZ VI	AEZ VII
		Area (km^2)		
Unsuitable	29522	57414	45846	60539
Suitable	9239	37713	100184	243977
10 percentile Threshold	0.2856	0.3499	0.3407	0.4325
		% area		
Unsuitable	76.16	60.36	31.39	19.88
Suitable	23.84	39.64	68.61	80.12

Note: The 10 percentile threshold were generated by the model

The generated binary raster for all the AEZs shows the distribution of both suitable and unsuitable grass niche in Kenya in the base-year (Figure 4.15). The analysis was based on the spatial extent of each AEZ with the corresponding 10 percentile training presence logistic threshold obtained from the Maxent models.

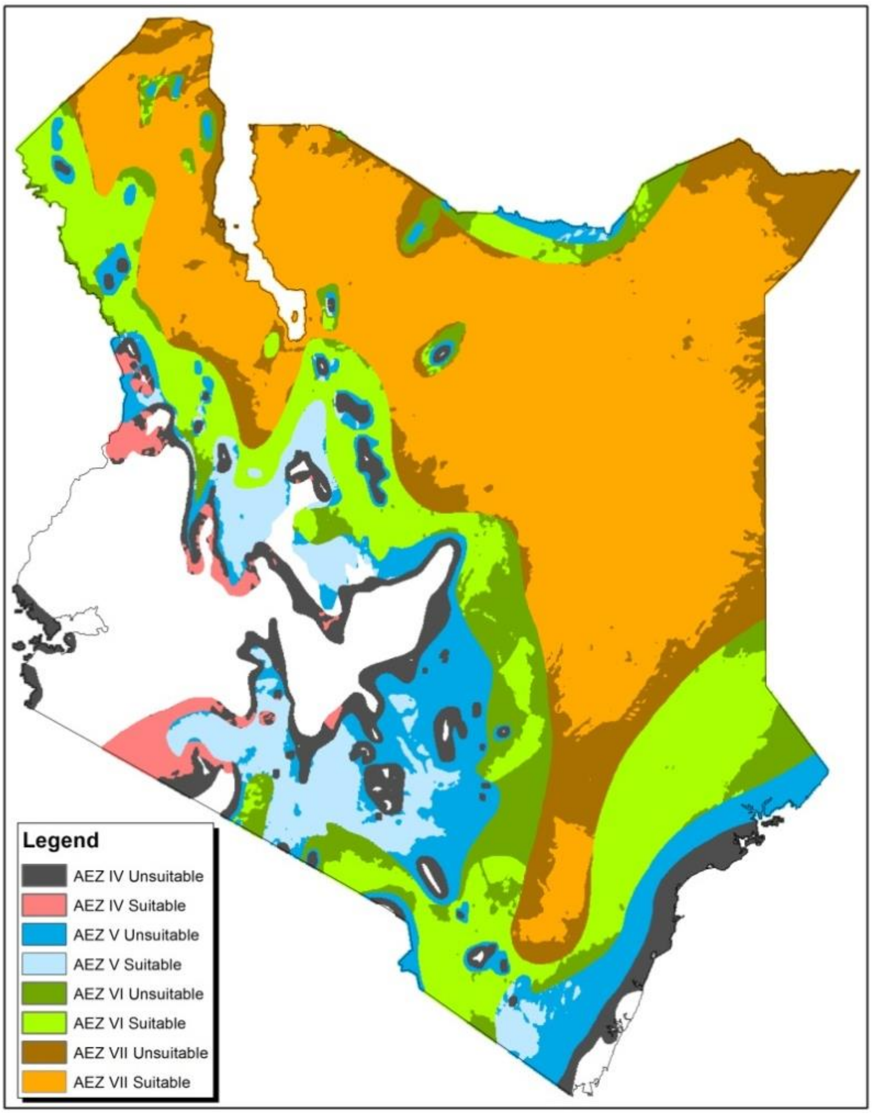

Figure 4.15: Base-year climatic period modelled binary grass niche suitability by AEZ.

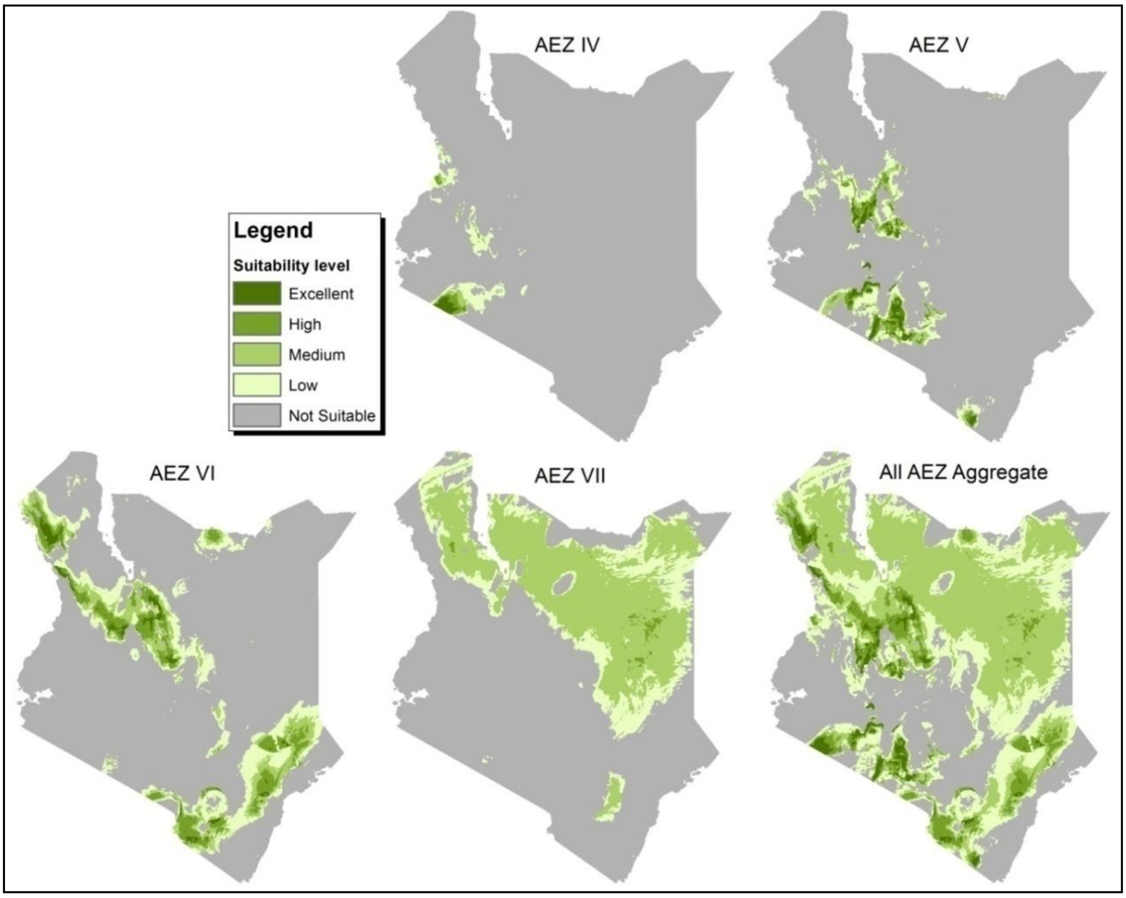

Figure 4.16: The base-year climatic period modelled base-year grass niche suitability levels.

Further analysis of the aggregated raster was done by introduction of scale of suitability level ranging from 0 (least suitable) to 1.0 (most suitable). The specific scale values were 0 to 0.2327 (unsuitable), 0.2327 to 0.5 (low suitability), 0.5 to 0.6 (medium suitability), 0.6 to 0.7 (high suitability) and 0.7 to 1.0 (excellent suitability) (Table 4.7). Also contained in the same table are population estimates and densities in each suitability level category.

Table 4.7: Base-year climatic period summary of grass niche suitability categories by area and human population.

Suitability level	Area (km^2)	% Area	Population	% Population	Pop Density
Unsuitable	198,471	33.96	24,770,458	79.74	124.81
Low	134,563	23.02	3,384,883	10.90	25.15
Medium	192,397	32.92	1,900,477	6.12	9.88
High	43,611	7.46	685,879	2.21	15.73
Excellent	15,393	2.63	324,123	1.04	21.06

The aggregated base-year climatic period modelled grass niche suitable area covered 385,964 km^2 representing 66.04% while the area classified as unsuitable was 198,471 km^2 covering 33.96% of Kenya. The first category of 0 to 0.2327 represents the unsuitable areas from zero to 10 percentile threshold suitability in the aggregated raster data and comprised 198,471 km^2 (33.96%) of the total area. Most regions in this category are the high potential areas restricted to the AEZs I to III with different climatic regimes compared to the AEZs IV to VII. The excellent grass niche suitability category represents 2.63% of the area covering 15,393 km^2spreading out across all the AEZs (Table 4.7). A region of 43,611 km^2 representing 7.46%of the area was under high grass niche suitability category followed by medium category at 192,397 km^2 (32.92%). This medium category together with low category covering 134,563 km^2 (23.02%) is restricted to the north and north eastern parts of the country. Apparently, these are the areas where pastoralism and wildlife-based tourism are largely practised as the main economic activities.

The Kenya's total population in the year 2000 was 31,065,820 (PopulationPyramid.net, 2015) whose distribution and density differ with the grass niche suitability levels. Among the suitable areas, the excellent category had the highest population of 24,770,458 (79.74%) with a density of 124.81per square kilometre. The high suitability category population was 685,879 (2.21%) with 15.73 persons per square kilometre density while the medium category had a population of 1,900,477 (6.12%) and a density of 36.3. Further, the low suitability category population was 3,384,883 (10.90%) whose density was 25.15 people per square kilometre.

4.2.2 The 2050 Climatic Period Modelled Projected Potential Grass Niche Range

The 2050 climatic period projected potential grass niche suitabilities were generated for each AEZ and analysed as aggregated data for the whole country (Figure 4.17). The aggregated spatial data show that the grass niche suitable areas are mostly in parts of northern, north eastern, southern and the coastal regions.

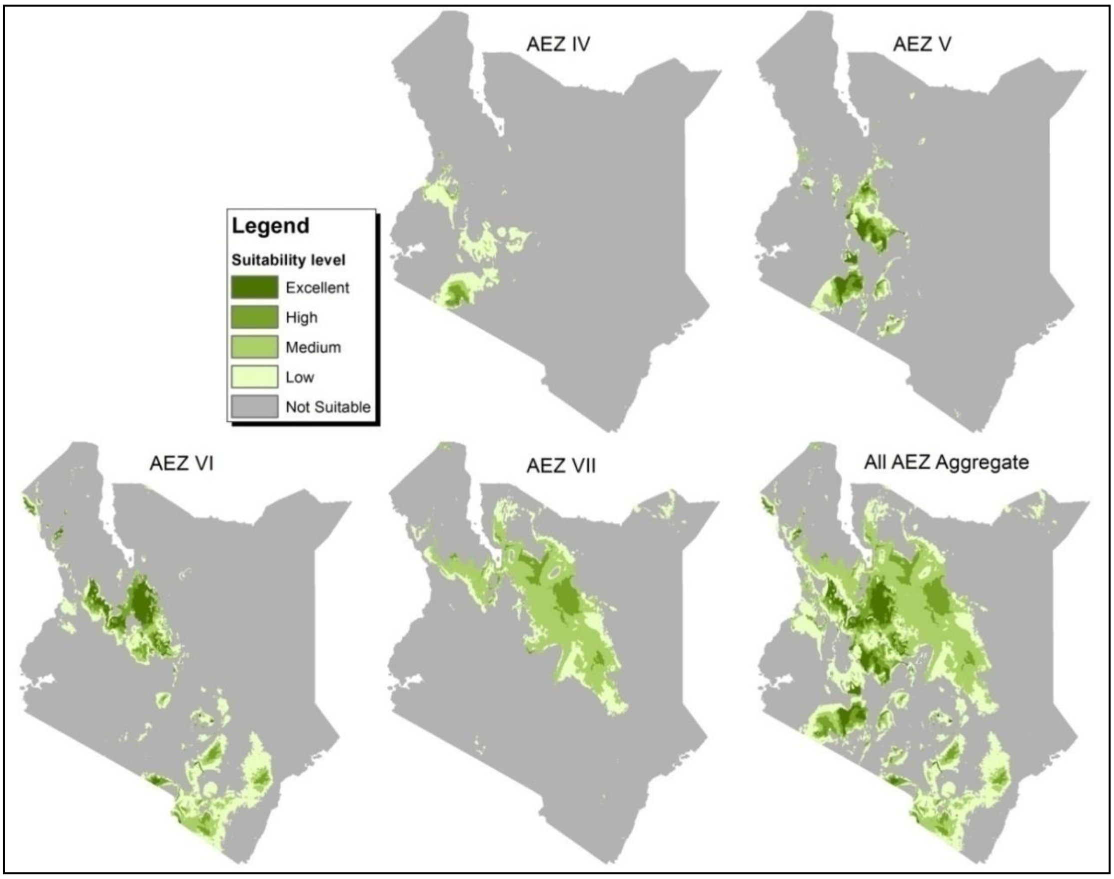

Figure 4.17: The modelled 2050 climatic period grass niche suitability.

The Maxent output grass niche suitability levels (Table 4.8) summarises the modelled grass niche suitabilities, their respective areas (km^2) and populations. The unsuitable areas cover a total of 373,104 km^2 (63.84%) of the country. These regions consist mainly the current AEZs I – III whose climatic conditions of more rainfall and lower temperatures are not favourable for grass growth. The other regions comprising many parts of the eastern, north eastern and northern parts of the country climatic conditions are harsher to support grass growth. The modelled grass niche suitable areas ranged from a minimum of 14,632 km^2 (2.50%) to a maximum of 86,718 km^2 (14.84%) in excellent and low suitability categories respectively. The other categories of high grass niche suitability covered 30,647 km^2 (5.24%) with the medium suitability occupying an area of 79,334 km^2 (13.57%).

Table 4.8: The 2050 modelled grass niche suitability categories with areas and human population.

Suitability category	Area (km^2)	% area	Population	Pop density
Not suitable	373,104	63.84	70,573,051	189.15
Low	86,718	14.84	13,198,372	152.20
Medium	79,334	13.57	6,277,632	79.13
High	30,647	5.24	3,936,102	128.43
Excellent	14,632	2.50	1,519,479	103.85

Grass niche suitability change analysis between the base-year and 2050 climatic periods revealed that changes will be both in the negative and positive directions. Some regions will change in the positive, others will experience a decrease while in some cases there will be no changes in the grass niche suitability levels. The nature, magnitude and spatial extent of the grass niche suitability changes (Figure 4.18) indicate a net decline of grass niche suitability in Kenya. These changes ranged from -1 to 1 and were scaled from 0 to 0.2327, 0.2327 to 0.5, 0.5 to 0.6, 0.6 to 0.7, and 0.7 to 1.0 in both positive and negative directions. The regions with declining grass niche consist of northern, north eastern, coastal and southern parts of the country. The central region of the country registered an increase in grass niche suitability though in a scattered pattern. Further, some regions will not experience any changes and are spread all over the country. The Kenya's population in the year 2050 is estimated to be 95,504,636 (PopulationPyramid.net, 2015) and assuming that the distribution will be more or less the same as in the year 2000, the population distribution with grass niche suitability level is summarised in table 4.8.

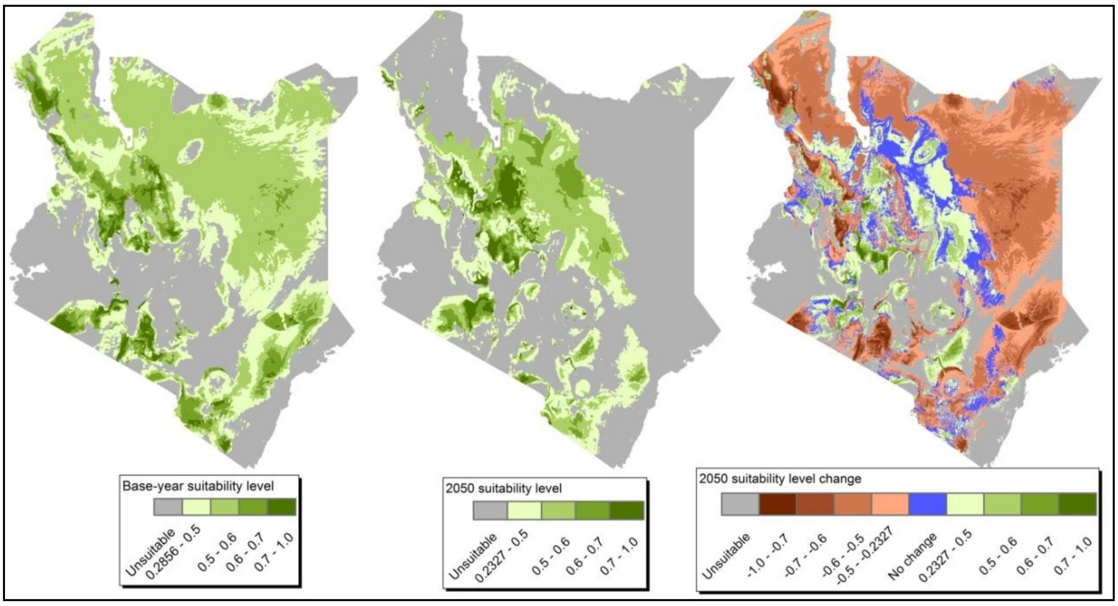

Figure 4.18: Change in grass niche suitability in 2050 climatic period.

The specific 2050 grass niche suitability changes (Table 4.9) are presented per suitability category compromising unsuitable, no change, increased and decreased ranging from values of -1 to 1. The spatial coverage and areas change analysis was based on the area classified as suitable in the base-year climatic period. A total of 150,560 km^2 (25.76%) of Kenya was classified unsuitable for grass niche which had a population of 62,854,621 (65.81%). An area of 269,110 km^2 (46.06%) containing a population of 9,756,821 (10.22%) showed a decline of grass niche suitability level. The no change category covered 61,762 km^2 (10.75%) while a combined total area of 103,003 km^2 (17.62%) pointed towards an increase in grass niche suitability with a population of 18,344,933 (19.21%).

Table 4.9: The grass niche suitability and area changes in the 2050 climatic period.

Suitability category	Area (km^2)	% Area	Population	% Pop
Unsuitable	150,560	25.76	62,854,621	65.81
-1.0 - -0.7	5,155	0.88	406,686	0.43
-0.7 - -0.6	20,420	3.49	1,098,226	1.15
-0.6 - -0.5	134,117	22.95	3,221,139	3.37
-0.5 - -0.2627	109,419	18.72	5,030,770	5.27
No change	61,762	10.57	4,548,261	4.76
0.2627 - 0.5	73,274	12.54	11,681,212	12.23
0.5 - 0.6	20,663	3.54	4,256,513	4.46
0.6 - 0.7	6,237	1.07	1,744,662	1.83
0.7 - 1.0	2,829	0.48	662,546	0.69

4.2.3 The 2070 Climatic Period Modelled Projected Potential Grass Niche Range

The 2070 climatic period projected potential grass niche distribution modelling was done at AEZ levels (Figure 4.19). Aggregated data for the whole country was generated for analysis using mosaic by maximum values option. Also included in the analysis is the projected year 2070 Kenya's human population of 125,137,459 (PopulationPyramid.net, 2015). The suitable grass niche area in this climatic period is projected to shrink and will be restricted to the north, eastern, southern and some pockets of coastal regions.

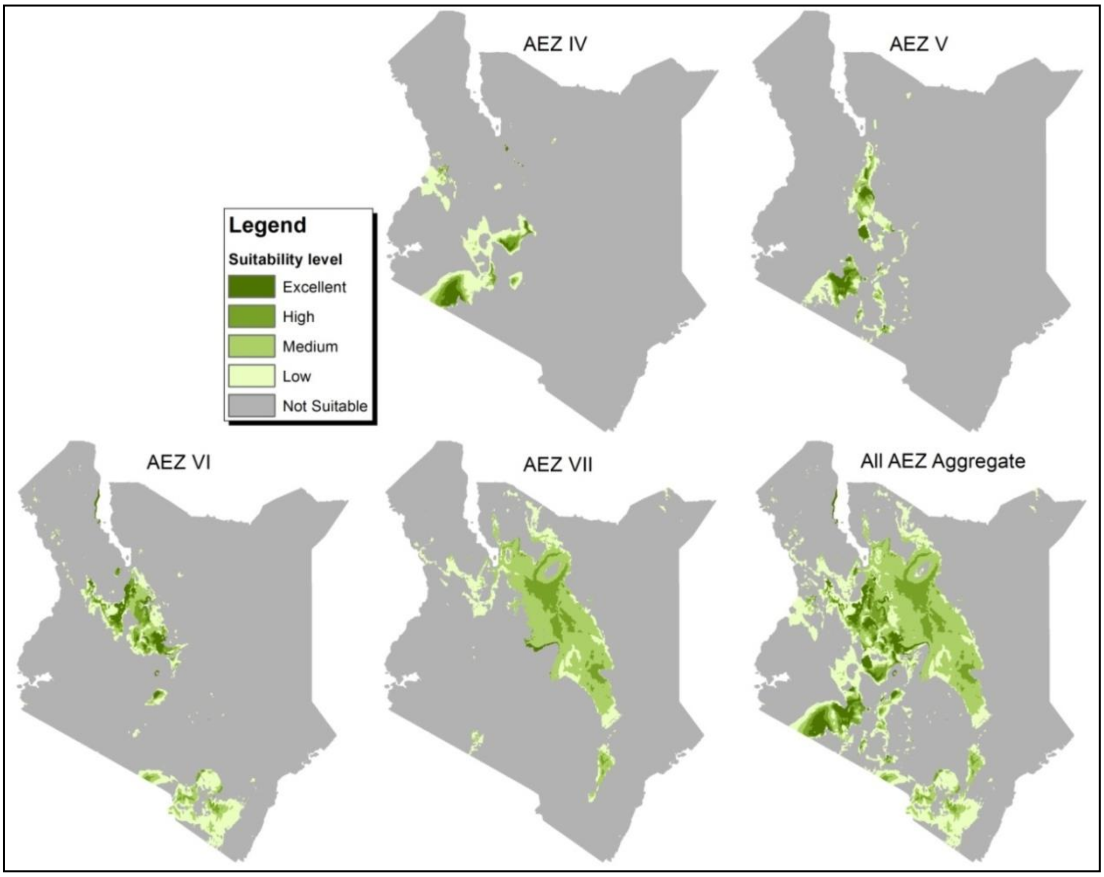

Figure 4.19: Modelled scaled 2070 grass niche suitability.

The Maxent output of grass niche suitability levels (Table 4.10) summarises the areas and percent changes compared to the base-year climatic period. The combined suitable areas cover 171,930 km^2 (29.42%) with a projected population of 23,160,068. The rest of the country was classified as unsuitable for the grass and covered an area of 412,505 km^2 (70.58%). The suitable grass niche categories had four groups of excellent and high suitability categories covering 12,779 km^2 (2.19%) and 28,457 km^2 (4.87%) respectively with the two having a combined population of 4,465,171 people. The other categories were medium category occupying 66,674 km^2 (11.41%) and a population of 4,934,794 and low category covering 64,020 km^2 (10.95%) having 13,760,103 people.

Table 4.10: The 2070 modelled grass niche suitability categories with areas and population.

Suitability category	Area (km^2)	% area	Population	Pop density
Not suitable	412,505	70.58	101,977,391	247.22
Low	64,020	10.95	13,760,103	214.93
Medium	66,674	11.41	4,934,794	74.01
High	28,457	4.87	2,811,017	98.78
Excellent	12,779	2.19	1,654,154	129.44

The grass niche suitability change analysis in the 2070 climatic period compared to the base-year climatic period revealed that some regions will be suitable for grass growth while others will not. Some areas will not change with others becoming unsuitable. The grass niche suitability spatial change in the 2070 climatic period shows the location, nature and magnitude of change (Figure 4.20). These changes ranged from -1 to 1 and were scaled from 0 to 0.2633, 0.2633 to 0.5, 0.5 to 0.6, 0.6 to 0.7, and 0.7 to 1.0 in the positive and negative direction. The negative changes will be in northern, north eastern, coastal and southern parts of the country. The central region of the country will register an increase in grass niche suitability though in patches while some areas will not show any changes.

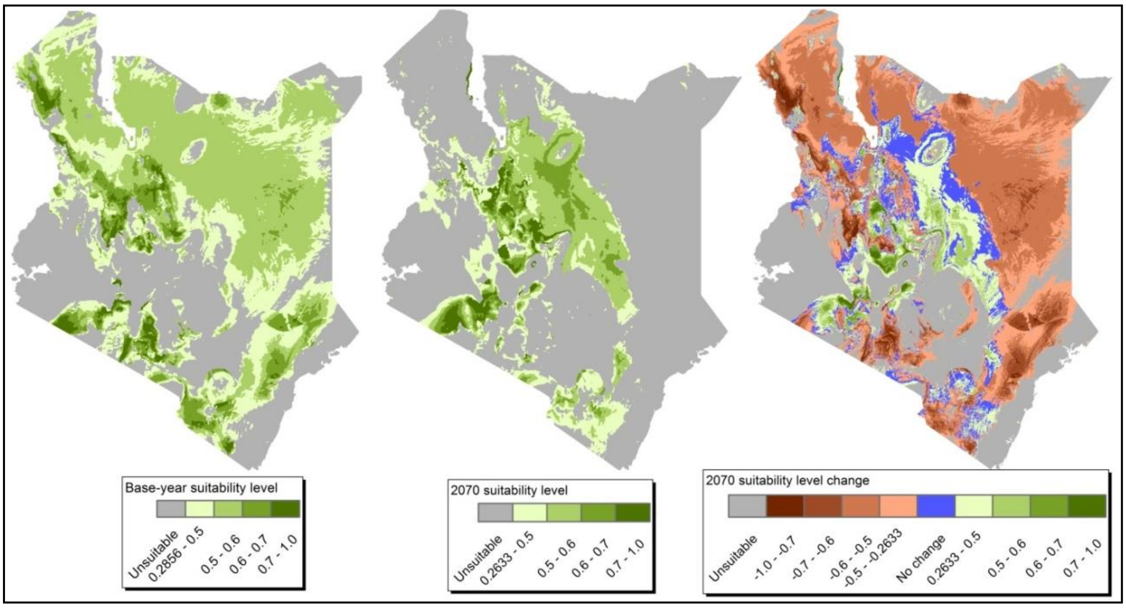

Figure 4.20: Change in grass niche suitability in 2070 climatic period.

Particular changes in the 2070 climatic period modelled results (Table 4.11) revealed variations in both location and coverage of suitability categories in comparison to the base-year climatic period. The area that had an increased suitable grass niche covered 14.36% (83,910 km^2) with a population of 15,278,909 (12.21%). The area showing declining grass niche suitability will cover the highest area of 285,045 km^2 (48.77%) which will have a projected population of 18,092,762 (14.46%). The no change category will occupy an area of 51,893 km^2 (8.88%) which contained a population of 4,502,582 (3.60%). The results of this study show that the net influence of climate on the future distribution and suitability of grass niche is a decline in two future climatic periods 2050 and 2070 though the shrinking will be more in the 2070 climatic period.

Table 4.11: The grass niche suitability and area changes in the 2070 climatic period.

Suitability Category	Area (km^2)	% Area	Population	% Pop
Unsuitable	163,587	27.99	87,263,206	69.73
-1.0 - -0.7	5,813	0.99	385,545	0.31
-0.7 - -0.6	25,214	4.31	1,615,445	1.29
-0.6 - -0.5	146,465	25.06	5,781,681	4.62
-0.5 - -0.2633	107,552	18.40	10,310,091	8.24
No change	51,893	8.88	4,502,582	3.60
0.2633 - 0.5	56,507	9.67	9,227,926	7.37
0.5 - 0.6	19,154	3.28	3,507,991	2.80
0.6 - 0.7	5,341	0.91	1,602,246	1.28
0.7 - 1.0	2,908	0.50	940,746	0.75

4.2.4 Modelled Potential Grass Niche Suitability Similarity Analysis

The applied Categorical Kappa method revealed different Kappa Location (K_{Loc}) and Kappa Histogram (K_{Histo}) similarities between the base-year and the future levels of grass niche suitability. The comparison between the base-year and 2050 suitability levels returned K_{Loc} of 0.233 and 0.536 for K_{Histo}. The base-year and 2070 comparison statistic indicated that the K_{Loc} similarity was 0.222 with a K_{Histo} of 0.440. The generated maps were in five categories at intervals of 0 to 0.2327, 0.2327 to 0.5, 0.5 to 0.6, 0.6 to 0.7 and 0.7 to 1.0 representing different levels of grass niche suitability.

4.2.5 BIOCLIM Variables Analysis

The Maxent models used all the 19 Bioclim data which contributed differently to the modelled grass niche suitability in each AEZ and climatic periods. The three climatic periods of precipitation, minimum and maximum temperature were used to derive the 19 Bioclim variables. These three variables showed variability with the climatic periods (Table 4.12).

Table 4.12: Trend in the precipitation, minimum and maximum temperatures in the three climatic periods.

	Base-year		2050		2070	
Variable	Min	Max	Min	Max	Min	Max
Precipitation (mm)	172	2625	160	2256	194	2636
Minimum temperature (^{O}C)	-4.6	23	-2.9	25.1	-2.6	25.7
Maximum temperature (^{O}C)	8.6	40.2	11.2	41.9	11.2	42.3

The precipitation in the base-year has a minimum of 172 mm which is projected to decrease to 160 mm in 2050 and increase to 194 mm in 2070 climatic periods. The maximum precipitation which is 2625 mm in the base-year is projected to decrease to 2256 mm in 2050 before increasing to 2636 mm in the 2070 climatic period. These changes in the precipitation and temperature varied spatially (Figure 4.21) in the different climatic periods with precipitation reducing in amounts and coverage in the projected both 2050 and 2070 future climatic periods. Both minimum and maximum temperatures indicate an increasing trend with more or less the same spatial distribution. The least minimum temperature was -4.6 ^{O}C in the base but increased to -2.9 ^{O}C and -2.6% in 2050 and 2070 climatic periods respectively. The same pattern is replicated in the highest minimum temperature, lowest and highest maximum temperatures. The highest maximum temperature of 42.3 ^{O}C was observed in the 2070 climatic period in the north eastern regions.

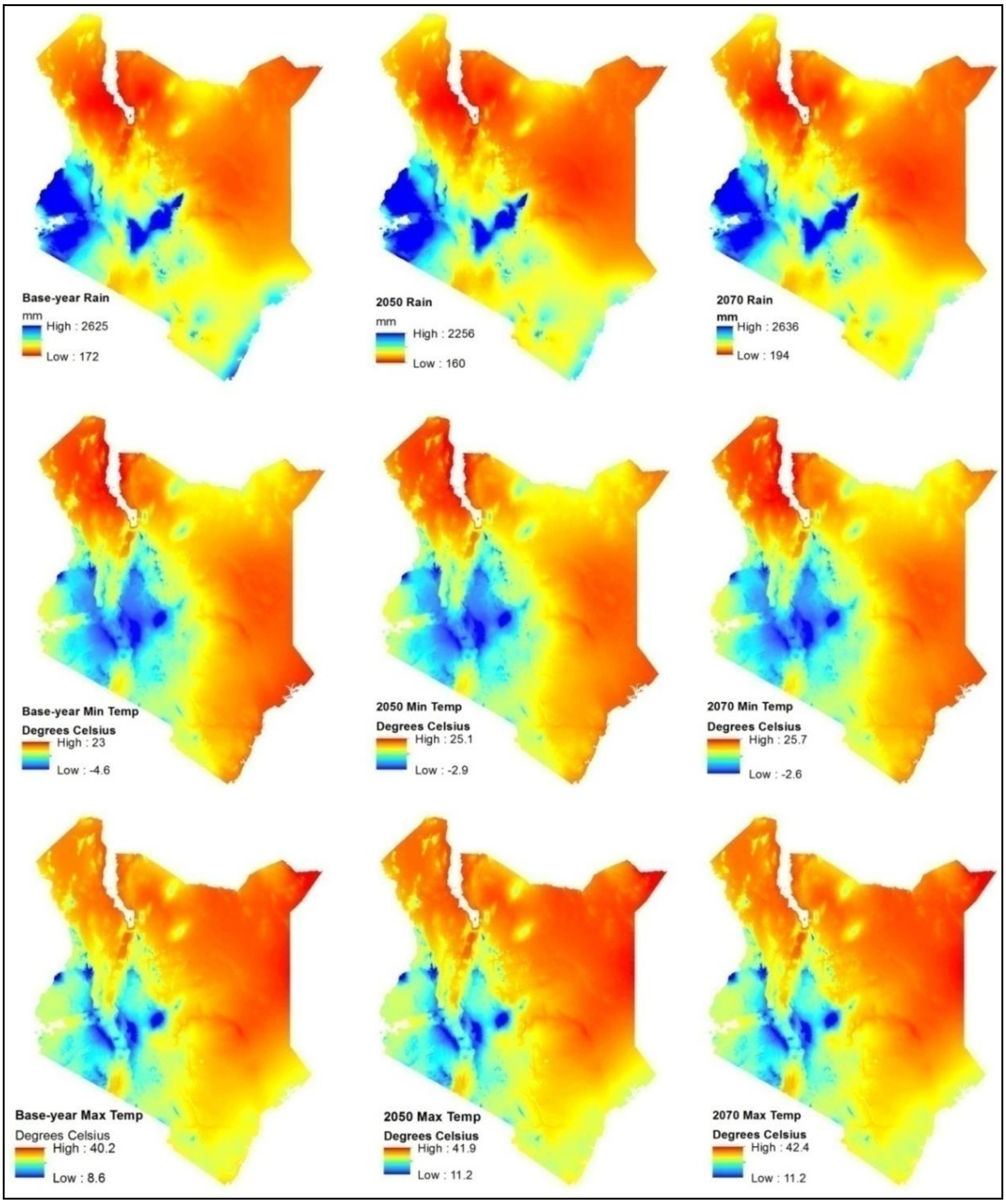

Figure 4.21: Base-year and the future potential rain, minimum and maximum temperature distribution.

Further analysis of climatic parameters by AEZs and grass niche suitability levels was conducted and presented in (Table 4.13). The same trend as rainfall is also observed here of a decrease from base-year to 2050 and then an increase. This pattern is observed in the AEZs IV-VII and does not apply to the unsuitable grass niche regions. The unsuitable grass niche had both high and low rainfall regions and which also decreased with the AEZs.

Table 4.13: Mean rainfall (mm) by suitability levels and AEZs.

Climatic Period	AEZ	Excellent	High	Medium	Low	Unsuitable
Base-year	AEZ IV	926	868	823	854	893
	AEZ V	623	631	662	677	745
	AEZ VI	481	544	531	547	597
	AEZ VII	563	362	334	404	416
2050	AEZ IV	914	843	781	809	809
	AEZ V	572	582	617	632	679
	AEZ VI	447	500	489	501	555
	AEZ VII	530	314	290	367	387
2070	AEZ IV	934	887	851	877	870
	AEZ V	646	661	686	694	734
	AEZ VI	497	551	537	546	600
	AEZ VII	570	356	343	412	430

Various changes are also expected in both maximum and minimum temperatures. In both projected climatic periods, the least minimum temperature was 13.0 ^{O}C in 2050 in AEZ IV with excellent suitability level (Table 4.14). The highest minimum temperature was 22.2 ^{O}C in 2070 climatic period in AEZ VII in the high category suitability level.

Table 4.14: Mean minimum temperature (^{O}C) by suitability levels and AEZs.

Climate Period	AEZ	Excellent	High	Medium	Low	Unsuitable
Base-year	AEZ IV	13.6	13.8	14.0	13.7	16.2
	AEZ V	14.7	15.0	15.7	16.4	18.0
	AEZ VI	19.6	19.5	20.0	19.8	19.5
	AEZ VII	19.8	22.2	21.8	21.5	21.5
2050	AEZ IV	13.0	13.1	13.3	13.1	15.6
	AEZ V	14.1	14.3	15.1	15.8	17.4
	AEZ VI	18.9	18.9	19.3	19.1	18.9
	AEZ VII	19.1	21.5	21.1	20.8	20.9
2070	AEZ IV	13.6	13.8	14.0	13.7	16.2
	AEZ V	14.7	15.0	15.7	16.4	18.0
	AEZ VI	19.6	19.5	20.0	19.8	19.5
	AEZ VII	19.8	22.2	21.8	21.5	21.5

The least maximum temperature increased with the AEZs in all the grass niche suitability levels in the different climatic periods. The least minimum temperature was 27.6 ^{O}C in base-year in AEZ IV with excellent grass niche suitability level having the highest at 38.6 ^{O}C (Table 4.15). This high temperature is also observed in AEZ VII under medium grass niche suitability in 2070 climatic period.

Table 4.15: Mean maximum temperature (^{o}C) by suitability levels and AEZs.

Climatic Period	AEZ	Excellent	High	Medium	Low	Unsuitable
Base-year	AEZ IV	27.6	28.3	28.8	28.6	29.7
	AEZ V	29.6	30.1	30.4	30.8	31.6
	AEZ VI	33.4	33.2	33.5	33.6	33.3
	AEZ VII	33.5	35.9	36.3	35.9	36.0
2050	AEZ IV	29.9	30.5	31.2	31.1	31.7
	AEZ V	31.9	32.4	32.6	32.9	33.5
	AEZ VI	35.6	35.2	35.5	35.7	35.3
	AEZ VII	35.6	38.0	38.4	38.0	38.0
2070	AEZ IV	30.3	30.9	31.5	31.3	32.0
	AEZ V	32.2	32.7	32.9	33.2	33.8
	AEZ VI	35.9	35.5	35.8	35.9	35.5
	AEZ VII	35.8	38.2	38.6	38.2	38.2

The assessment further revealed the nature and magnitude of the projected changes (Table 4.16) and spatial variability (Figure 4.22). In both projected climatic periods, precipitation (rainfall) increased and decreased in different places. The increase in 2050 by a maximum of 18 mm is in four distinctive areas of the north western, north eastern tip, the eastern and south western parts of the country. The precipitation during the same period will reduce by 370 mm in central and coastal regions. The 2070 precipitation will increase and reduce by up to 199 mm and 342 mm respectively. The minimum and maximum temperature projections indicate a general increase of different magnitudes. The minimum temperature in 2050 will increase between 1.3 to 2.9 ^{O}C with the coastal regions having the least and western parts the highest change. More or less the same pattern of change is observed 2070 minimum temperature except that the change ranges from 1.9 to 3.6 ^{O}C. The maximum temperature changes vary between 1.4 to 2.7 ^{O}C and 1.6 to 3.0 ^{O}C in 2050 and 2070 climatic periods. Within these periods, the western region will have the highest increase with the coastal and some section of north eastern having the least increase.

Table 4.16: Projected changes in precipitation, minimum and maximum temperatures.

	2050 change		**2050% change**		**2070 change**		**2070% change**	
Variable	Min	Max	Min	Max	Min	Max	Min	Max
Precipitation (mm)	-370	18	-25.5	5.6	-342	199	-24.5	23.3
Minimum temperature (^{O}C)	1.3	2.9	-2000	2000	1.9	3.6	-2400	2400
Maximum temperature (^{O}C)	1.4	2.7	4.1	30.2	1.6	3.0	4.8	30.2

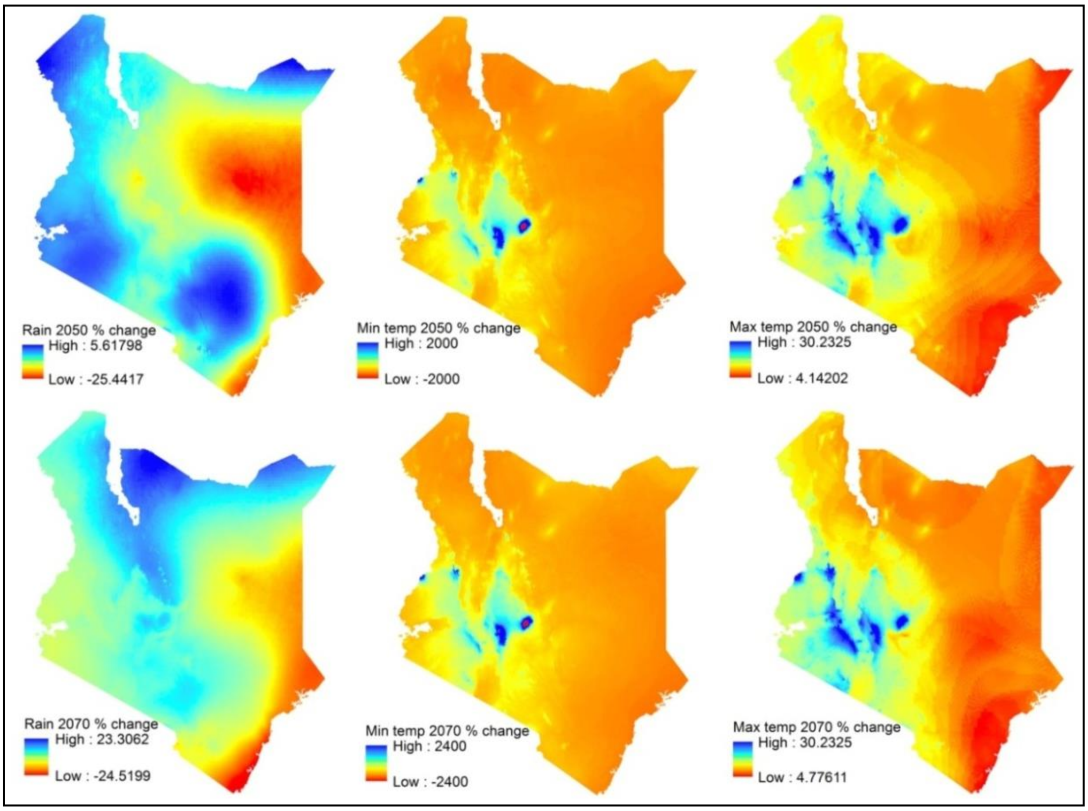

Figure 4.22: Percent potential change in rain, minimum and maximum temperatures in the future climatic periods.

The Maxent model output includes the percent contribution of each parameter used as input. It ranked all the 19 Bioclim parameters from the most to the least contributing to the grass niche suitability. The first five Bioclim parameters by percent contribution in the Maxent models output for each AEZ in the three climatic periods were listed (Table 4.17). These variables appearing in no particular order were BIO1 = Annual Mean Temperature, BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp)), BIO3 = Isothermality (BIO2 /BIO7) * (100), BIO5 = Max Temperature of Warmest Month, BIO8 = Mean Temperature of Wettest Quarter, BIO10 = Mean Temperature of Warmest Quarter, BIO11 = Mean Temperature of Coldest Quarter, BIO12 = Annual Precipitation, BIO14 = Precipitation of Driest Month, BIO16 = Precipitation of Wettest Quarter, BIO17 = Precipitation of Driest Quarter, and BIO19 = Precipitation of Coldest Quarter.

Table 4.17: The first five Bioclim parameters by percent contribution for each climatic period in the AEZs.

Climatic period	AEZ IV		AEZ V		AEZ VI		AEZ VII	
	Variable	% Contribution	Variable	% Contribution	Variable	% Contribution	Variable	% Contribution
Base-year	BIO14	28.9	BIO 8	23.9	BIO14	24.5	BIO 5	36.7
	BIO2	20.7	BIO1	9.5	BIO5	22.6	BIO11	24.6
	BIO17	17.6	BIO14	8.9	BIO2	10.7	BIO1	11.1
	BIO10	9.4	BIO5	7.9	BIO19	7.5	BIO16	6.2
	BIO16	6.3	BIO2	6.9	BIO11	7.2	BIO3	5.5
2050	BIO14	28.9	BIO8	23.9	BIO14	24.5	BIO5	36.7
	BIO2	20.7	BIO1	9.5	BIO5	22.6	BIO11	24.6
	BIO17	17.6	BIO14	8.9	BIO2	10.7	BIO1	11.1
	BIO10	9.4	BIO5	7.9	BIO19	7.5	BIO16	6.2
	BIO16	6.3	BIO2	6.9	BIO11	7.2	BIO3	5.5
2070	BIO14	32.8	BIO8	23.9	BIO14	24.5	BIO5	36.7
	BIO2	20.8	BIO1	9.5	BIO5	22.6	BIO11	24.6
	BIO12	15.3	BIO14	8.9	BIO2	10.7	BIO1	11.1
	BIO10	8.4	BIO5	7.9	BIO19	7.5	BIO16	6.2
	BIO19	5.9	BIO2	6.9	BIO11	7.2	BIO3	5.5

4.2.6 Model Performance

4.2.6.1 Base-Year Model Performance

Model performance was carried out using two methods; the first is inbuilt within the Maxent model and the second is "Overlap" method in ArcMAP (Appendix 6). The Maxent model performance is derived from AUC and has a range of 0 to 1 with a threshold of 0.5. The model performances were all significant (Table 4.18) for the base-year model. The highest average test AUC for the replicate runs was 0.962 with standard deviation of 0.037 in AEZ IV and the least was 0.754 with standard deviation of 0.001 in AEZ VII.

Table 4.18: Base-year climatic period AUC results from the Maxent models.

AEZ	AUC	SD
IV	0.962	0.037
V	0.942	0.001
VI	0.886	0.003
VII	0.754	0.001

The "Overlap" method involved calculation of percent of grass niche areas overlapping of the known areas of grass and the modelled areas of grass niche suitable areas spatial coverage. The accuracy by AEZ (Table 4.19) indicate that the accuracies were different and ranged from 42.20% - 85.48%. The lowest accuracy was in the AEZ IV (42.20%), with intermediate accuracy values of AEZs V and VI of 65.77% and 79.96% respectively. The highest accuracy was registered in AEZ VII at 85.48%. Overall, the mean accuracy level of the modelled base-year grass suitability niche was 68.35%.

Table 4.19: Base-year climatic period "Overlap" method model accuracy levels.

AEZ	% overlap
IV	42.20
V	65.77
VI	79.96
VII	85.48

4.2.6.2 Future Model Performance

The future climatic periods Maxent models performances were all significant (Table 4.20). The AEZ IV in 2070 had the highest AUC of 0.973 and standard deviation of 0.018. The AEZ VII in both climatic periods had identical AUC and standard deviation of 0.754 and 0.001 respectively.

Table 4.20: The projected 2050 and 2070 climatic periods AUC results.

Climatic Period	AEZ	AUC	SD
2050	IV	0.963	0.018
	V	0.942	0.001
	VI	0.886	0.003
	VII	0.754	0.001
2070	IV	0.973	0.018
	V	0.942	0.001
	VI	0.886	0.003
	VII	0.754	0.001

4.3 Rangeland Livestock Carrying Capacity Analysis

The analysis of rangeland livestock carrying capacity (CC) was based on the Tropical Livestock Unit (TLU) standard. The relationship between rainfall (mm) and weight (kg) of dry matter (DM) per year per hectare was obtained from FAO (1995) data. The equation generated, DM ha^{-1} yr^{-1} = 123.00 + 1.81 (rainfall), was significant $p \leq 0.006$, with an adjusted $R^2 = 0.926$. The carrying capacities were grouped into four categories for ease of analysis and ranged from 0 to 11 in all the climatic periods although the distributions were not uniform (Table 4.21). The base-year climatic period, has the majority of the area accounting for more than 40% of Kenya ranging between a carrying capacity of 0 to 1 TLU ha^{-1} and more than 21% of the area had TLU ha^{-1} of 2 to 3. The rest of the areas comprising about 2% had CC ranging from 3 to 11 TLU ha^{-1}.

Table 4.21: The modelled base-year, 2050 and 2070 climatic periods carrying capacities.

	Base-year		**2050**		**2070**	
TLU Range	Area (km^2)	% Area	Area (km^2)	% Area	Area (km^2)	% Area
0-1	242,757	41.54	107,015	18.31	55,864	9.56
2-3	130,995	22.41	94,186	16.12	97,955	16.76
3-5	10,509	1.80	9,941	1.70	17,342	2.97
5-11	767	0.13	612	0.10	1,301	0.22

Since the grass niche suitability levels of the future climatic periods shrunk, less area of Kenya was analysed for carrying capacities. In the projected climatic periods of 2050 and 2070, the areas of Kenya by percent suitable for grass niche will be 35.40% and 28.84% respectively. In both future climatic periods, most of the areas will have a carrying capacity of 0 to 3 TLU ha^{-1} with spatial distribution depicted in figure 4.23. The carrying capacity spatial coverage conformed to the modelled grass niche suitability thresholds for both the base-year and the future climatic periods. The base-year carrying capacity was low in the north and north eastern, but high in some areas at the coast, southern and some sections of the northern regions of the country. The future carrying capacity spatial distribution was lower in the northern, western, southern, eastern and coastal regions of the country.

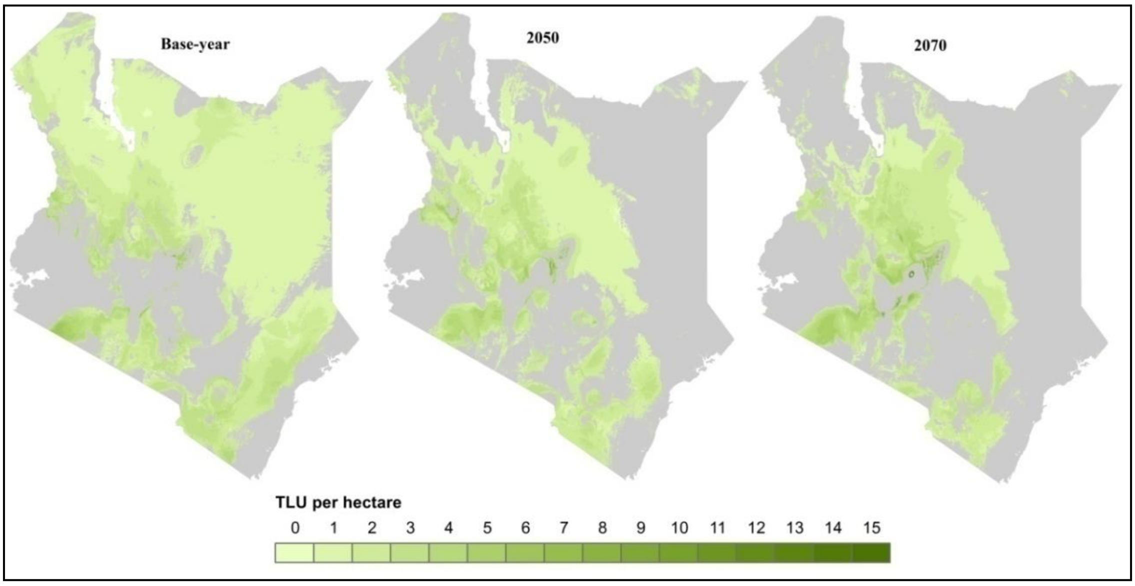

Figure 4.23: The spatial distribution of carrying capacity in the base-year, 2050 and 2070 climatic periods.

The potential carrying capacity changes in the future climatic period revealed three scenarios of decrease, no change and an increase though different in the extent covered with the climatic periods (Table 4.22). In both future climatic periods, the carrying capacity declined between -8 to -1 covering combined areas of 265,469 km^2 (44.99%) and 270,268 km^2 (45.78%) in 2050 and 2070 respectively. The no change category in carrying capacity covered 131,994 km^2 (22.37%) in 2050 and 100,544 km^2 (17.00%) in 2070 climatic periods while combined areas with increased TLU ha^{-1} were 17,582 km^2 (2.98%) and 44,233 km^2 (7.50%) for the respective periods.

Table 4.22: Projected carrying capacity changes in the future climatic periods.

	2050		2070	
TLU Change	**Area (km^2)**	**% Area**	**Area (km^2)**	**% Area**
-8 - -5	551	0.09	55	0.0
-4 - -3	9,223	1.56	9,413	1.6
-2 - -1	255,695	43.33	260,800	44.2
No change (0)	131,994	22.37	100,544	17.0
1 – 2	17,298	2.93	43,340	7.3
3 – 4	284	0.05	889	0.2
5 – 7	0	0	5	0.0

The spatial distribution patterns of carrying capacity changes reveals differences in locations and areas with reduced, no change and increased CC (Figure 4.24) with no particular pattern. The 2050 climatic period increase in CC was scattered in the southern and northern parts while the no change was spread out though more restricted to the northern, eastern and southern parts of the country. The regions that indicated the decline in the CC was spread throughout across the country covering the northern, north eastern and southern parts where the least decline was projected. In the 2070 climatic period, the CC had the same pattern as the 2050 climatic period though the increase in CC the northern and south western regions. The no change and areas showing declining carrying capacity patterns but were different in extents.

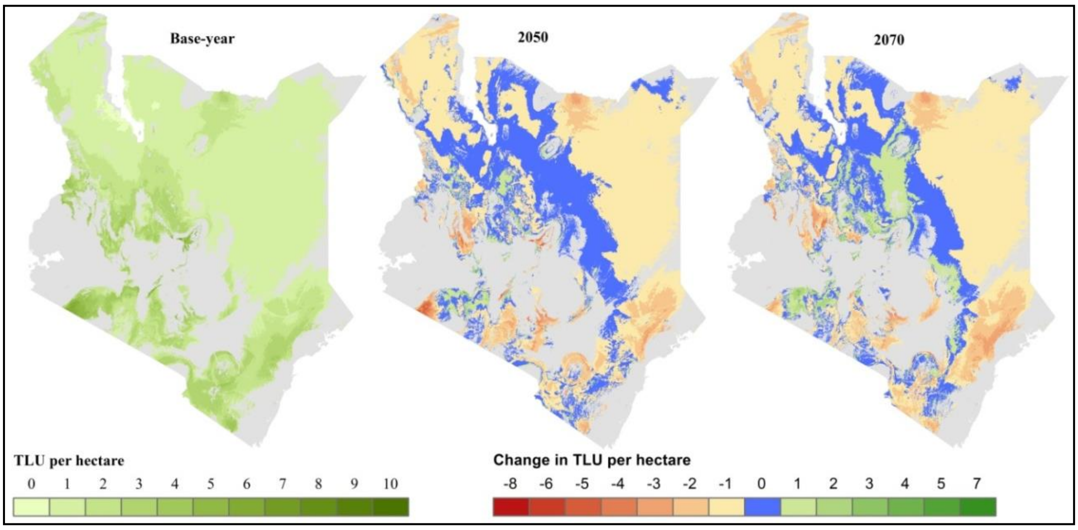

Figure 4.24: The TLU ha^{-1} changes in the future climatic periods.

4.4 Kenya Government Policies and Legislations on Climate Change, Pastoralism, Wildlife and Tourism

A total of twenty one (21) policy/legal documents (Table 4.23) relating to climate change were reviewed in the final analysis. The policies and legislations were reviewed under the following sub-headings: Agriculture (3 documents); Wildlife, Forestry and Tourism (5 documents); Climate Change (6 documents); Environment (2 documents); and Other Important Policies and Legislations (5 documents).

Table 4.23: List of reviewed climate change and related policies and legislations.

Sector	Policy and Legislation
Agriculture	The National Livestock Policy (2008)
	Agricultural Sector Development Strategy (ASDS) (2010 – 2020)
	Kenya Climate Smart Agriculture Strategy (CSA) (2017 – 2026)
Wildlife, Forestry and Tourism	The Wildlife Conservation and Management Act (2013)
	The Forest Act (2005)
	Forest Conservation and Management Act (2016)
	Tourism Act (2011)
	National Tourism Strategy (2013-2018)
Climate Change	National Climate Change Action Plan (2013 – 2017)
	Climate Change Act (2016)
	The National Climate Change Response Strategy (NCCRS) (2010)
	Threshold 21 (T21) Kenya
	Kenya National Adaptation Plan (NAP) (2015 - 2030)
	East African Community Climate Change Master Plan (EACCCMP)
Environment	The National Environment Action Plan (NEAP) (2009-2013)
	Environmental Management and Coordination Act (EMCA) (2015)
Other Important Policies and Legislations	The Economic Recovery Strategy (ERS) for Wealth and Employment Creation (2003 – 2007)
	Kenya Vision 2030
	Constitution of Kenya 2010
	The National Policy for the Sustainable Development of Northern Kenya and other Arid Lands
	The National Disaster Management Policy (2012)

4.4.1 Agriculture

4.4.1.1 The National Livestock Policy (2008)

The National Livestock Policy (2008) (GoK, 2008) focuses on the challenges faced in the livestock industry within the context of livestock breeds, livestock nutrition and feeds, pest and diseases management, value addition of livestock and marketing of livestock products, and livestock related research and extension. The policy specific objectives in relation to climate issues are: succeeding in livestock management systems for sustainable development; improvement and conservation of available animal genetic resources; actively control livestock pests and diseases; and address various cross-cutting issues that impact on the livestock sub-sector. Among the issues identified are water, land, environment, infrastructure, insecurity and livestock-wildlife interactions.

4.4.1.2 Agricultural Sector Development Strategy (ASDS) (2010 – 2020)

The Kenyan government adopted the agriculture sector development strategy (ASDS) policy in 2010 applicable from 2010 – 2020 (GoK, 2010a). The ASDS set out a plan to strengthen Kenya's agricultural output and economic growth. The vision of the ASDS is "a food secure and prosperous nation". This strategy was aimed at increasing the growth and productivity of agriculture; improvement of food security situation and equity; promotion of irrigation to stabilize agricultural output; intensification and commercializing agricultural production; and development of a suitable and all-inclusive policy formulation process and environmental sustainability.

4.4.1.3 Kenya Climate Smart Agriculture Strategy (CSA) (2017 – 2026)

The Kenya Climate Smart Agriculture Strategy (CSA) (2017 – 2026) (GoK, 2017) identified the many challenges facing agricultural production resulting from climate change. These challenges include inadequate polices, insufficient legislations, low level of regulations enforcement, and commonality of mandates among institutions involved in regulation in addition to poor coordination and collaboration among them. Moreover, mutual issues cutting across the sector such as insufficient financing; low capability of women, youth, and vulnerable groups to actively take part in the climate change related activities; wasteful natural resource exploitation, use and management; inadequate skilled labour to undertake climate change mitigation and adaptation measures; inadequate and incomplete climate change research; poor technological development and innovations; and scarce data and information on climate change issues have led to poor understanding and response to climate change on agriculture.

This strategy aims to transform the country's agriculture systems to be more productive and resilient with reduced greenhouse gas emissions. The CSA offers an outstanding platform for the revolution by bringing together development, agriculture and climate change under a common agenda through integrating the three dimensions of sustainable development by conjointly looking at food security issues and climate change issues. Subsequently, this key sector requires a comprehensive and empowering CSA approach that will concurrently assure high productivity and food security while addressing climate change adaptation and mitigation.

4.4.2 Wildlife, Forestry and Tourism

4.4.2.1 The Wildlife Conservation and Management Act (2013)

The Wildlife Conservation and Management Act (2013) (GoK, 2013c) is the principle instrument of the Government of Kenya for the conservation and management of Wildlife and utilization (GoK, 2013b). It also provides for the relevant institutional framework for the wildlife conservation and management including the establishment of the Kenya Wildlife Service (KWS) a designated national body for the conservation and management of wildlife. Part 1 Section 5 of the Act states that "The national wildlife conservation and management strategy shall prescribe the principles, objectives, standards, indicators, procedures and incentives for the protection, conservation, management sustainable utilization and control of wildlife resources….." The strategy number (n) directly addresses the threats of climate change and covers adaptation and mitigation measures to avert adverse impacts of climate change on wildlife resources and its habitats.

4.4.2.2 The Forest Act (2005)

The Forest Act (2005) was enacted in 2005 (GoK, 2005b) and sought to attend to the threats to Kenyan forests and to expand the forest country's forest cover to 10% of the land surface. It recognizes the key played by citizens in the management of forest resources by empowering communities to dynamically take part in the forest management through the formation of 'Community Forest Associations'. These associations manage and/or co-manage public and community forests, by permitting rights to the local communities over forest resources. The policy further identifies the role of forest resources in poverty reduction and safeguards the rights of customary local communities to sustainably continue using the forest resources.

In addition, this policy identifies the critical role played by forests in the provision of ecosystem services (provisioning, regulating, supporting and cultural and spiritual functions). Furthermore, it takes applies environmental impact assessments and multiyear result-oriented forest management agreements and provides for the introduction and adoption of climate change mitigation strategies.

4.4.2.3 Forest Conservation and Management Act (2016)

Forest Conservation and Management Act (2016) (GoK, 2016c) overall goal is to promote forest sustainability, management, utilization and conservation of forest resources and equitable sharing of accrued benefits for the present and future generations of the people of Kenya. The specific policy objectives in relation to climate change are: increasing and maintenance of tree and forest cover of at least 10% of the country's land surface; establishment of an supportive legislative and institutional framework for development of this key sector; supporting research in forest resources, educating masses on the benefits of forest resources, training to increase skilled labour availability, generate and distribute forest information to the masses, and transfer of useful technology for sustainable development; endorse public-private and community contribution and involvement in forest sector development; promotion of commercial tree growing investments, forest industry and trade; and improvement of forest resources management for ecosystem (soil, water and biodiversity) conservation.

4.4.2.4 Tourism Act (2011)

The Tourism Act (2011) provides for the development, management, marketing and regulation of sustainable tourism and tourism-related activities and services, and for connected purposes in Kenya (GoK, 2011). Among the National Tourism Strategies outlined in Part II section 3 (2) of the Act, is "(i) adaptation and mitigation measures to avert adverse impacts of climate change on tourism and tourism products and services" This is a clear indication of measures to address climate variability and change uncertainty to the industry.

4.4.2.5 National Tourism Strategy (2013-2018)

The Kenya National Tourism Strategy (2013-2018) was designed to provide planned interventions under identified five key strategic themes (GoK, 2013d). The five key strategic themes are: operative tourism product development and deployment approach; enhancement of Kenyan tourism products marketing; insufficient funding and improvement of the tourism business environment; application of research and information collection and management; and focusing on skilled personnel, legal, policy and institutional frameworks. The strategy recognises a number of developments affecting tourism among them being climate change. It states that global warming is expected to play a major role in how the tourism and travel industry develops and operates. This strategy prioritizes the best practices in coastal and marine preservation, ecological management, and waste management systems in the industry as a reaction to climate change issues. The issues of changing climate impacts on tour resorts, the carbon footprint of air travel and the impacts of sea level changes on shoreline developments all show how important it is for proper planning, monitoring and policy mechanisms to ensure sustainability in this economically important industry.

The strategy further acknowledge that Kenya‘s tourism is highly dependent on its wilderness and wildlife, which are all under threat from global climate change. It states that "In nearly all the national parks, the wildlife depend on natural rivers or manmade wells and dams for their survival. Seventy-five percent of Kenya‘s wildlife is found in the dry lands and 92% of Kenya‘s Protected Area estate (Parks and Reserves) are found in rangelands. Rangelands also form important conservation areas of wildlife in Kenya outside protected areas. It is estimated that currently nearly 80% of all wildlife in Kenya is found outside protected areas". The national parks and game reserves are the basis of Kenya‘s thriving wildlife safari tourism.

4.4.3 Climate Change

4.4.3.1 National Climate Change Action Plan (2013 – 2017)

The National Climate Change Action Plan (2013 – 2017) was developed to enable Kenya to reduce vulnerability to climate change and to improve the country‘s ability to take advantage of the opportunities that climate change offers (GoK, 2013e). It is a comprehensive and elaborate document setting out the effort to achieve low carbon and climate resilient development in Kenya. The Action Plan, apart from proposing actions for climate change adaptation and mitigation, also give a road map for the essential supporting circumstances in the form of policy, legislation and institutional frameworks.

The plan addresses the following components: Continuing national low carbon development pathway; supporting policy and regulatory framework; national adaptation approaches; applicable mitigations measures; climate change technology achievement strategy; performance and benefits measurement; information management and capacity improvement; and finance. The document touches on a wide range of issues on climate comprising the following: Climate Change Action Planning in Kenya; Preparation of Kenya's Climate Change Action Plan; Low Carbon Climate Resilient Development; Adaptation; Mitigation; Financing

Implementation of the Action Plan; Enabling Policy, Legislative and Institutional Framework; Knowledge Management and Capacity Development; Technology; and National Performance and Benefit Measurement Framework

4.4.3.2 Climate Change Act (2016)

The Climate Change Act (2016) provides a framework for promoting climate resilient low carbon economic development (GoK, 2016b). The Act is applicable in all the sectors of economic development, management, implementation and regulation of mechanisms to improve climate change adverse impacts resilience and promote low carbon foot print development in Kenya. The Act will further inform the county to: infuse climate change responses into the country's economic plan, aid in decision making and execution; promote climate change resilience and increase adaptive capability; development of programs and ideas to improve the resilience and adaptive capacity of human and ecological systems to the adverse impacts of climate change; mainstream and strengthen climate change risk decrease into approaches and activities of all stakeholders; mainstream intergenerational and gender equity in all aspects of adverse climate change response plans; offer enticements and responsibilities for private sector inputs in realizing a reduced carbon climate robust development; encourage low carbon technologies, increase effectiveness and lessen productions through enabling approaches and use of technology that support low carbon, and climate robust development; enable capacity development for all stakeholders involvement in climate change responses through public education, discussion, representation and access to information; marshal support and manage funds for climate change; develop approaches for, and enable climate change research and development, skilled manpower development; inclusion of the principles of sustainable development into the preparation and decision making on climate change response; and assimilate climate change into all levels of governance, and to improve cooperative climate change governance in all government levels.

4.4.3.3 The National Climate Change Response Strategy (NCCRS) (2010)

The National Climate Change Response Strategy (NCCRS) (2010) was the first national policy document to fully acknowledge the reality of climate change (GoK, 2009a). The strategy is the framework that guides the integration of climate concerns into development priorities, government planning and budgeting. The Strategy provided evidence of climate impacts on different economic sectors and proposed adaptation and mitigation measures approaches. It addresses all the key sectors of the economy; climate change was viewed as a challenge that cuts across all sectors and segments of society in Kenya. The NCCRS highlights various measures for adaptation and mitigation to the impacts of climate change in all sectors of the economy. In agriculture, the strategy proposes the application of a range of innovative technologies such as irrigation, early maturing and high yielding crop varieties, drought and pest-resistant crop varieties, and disease-resistant livestock.

The NCCRS further advocates for diversification of livelihoods; adaptation of agricultural technologies; and enhancing early warning systems with drought monitoring and seasonal forecasts for better food security. The NCCRS aimed to guide the government in all activities and interventions geared towards addressing issues related to climate change; it consolidates all the national efforts and focus on climate change adaptation and mitigation. It will also support efforts toward the implementation of the Kenya Constitution 2010, attainment of Vision 2030 and encourages people-cantered development, ensuring that climate change actions help the country move toward its long-term development goals.

4.4.3.4 Threshold 21 (T21) Kenya

The Threshold 21 (T21) is a dynamic simulation tool designed to support comprehensive, integrated long-term national development planning (LEDS, 2018). The Threshold 21-Kenya model was developed to integrate the analysis of the risks and impacts of climate change across the major sectors of the economy, society and environment, in order to inform coherent national development policies that encourage sustainable development, poverty eradication, and increased well-being of vulnerable groups, especially women and children, within the context of Vision 2030.

4.4.3.5 Kenya National Adaptation Plan (NAP) (2015 - 2030)

The Kenya National Adaptation Plan (NAP) (2015 - 2030) vision is enhanced climate resilience towards the attainment of Vision 2030 (GoK, 2015a). In this NAP, enhanced climate resilience includes strong economic growth, resilient ecosystems, and sustainable livelihoods for Kenyans. It is also expected to result in reduced climate-induced losses and damages, mainstream disaster risk reduction approaches in various sectors, reduced costs of humanitarian aid, and improve knowledge and learning for adaptation and the future protection of the country. The objectives of the NAP are to: highlight the importance of adaptation and resilience building actions in development; integrate climate change adaptation into national and county level development planning and budgeting processes; enhance the resilience of public and private sector investment in the national transformation, economic and social and pillars of Vision 2030 to climate shocks; enhance synergies between adaptation and mitigation actions in order to attain a low carbon climate resilient economy; and enhance resilience of vulnerable populations to climate shocks through adaptation and disaster risk reduction strategies.

4.4.3.6 East African Community Climate Change Master Plan (EACCCMP)

The East African Community Climate Change Master Plan (EACCCMP) was published in September 2011 and aimed to guide climate change plans from 2011 – 2031 (EAC, 2014). The Master Plan aims to strengthen regional co-operation in addressing climate change impacts on shared resources. A summary of analysis of the climate, trends and projection of each of the five east African partner states (Kenya, Tanzania, Uganda, Burundi and Rwanda) is given as a basis for understanding the vulnerabilities and sensitivities to climate change.

The policy identifies tourism as one of the nine main regional economic activities most vulnerable to climate change in the region and therefore need priority. A number of climate change impacts have been highlighted as well as response strategies in the tourism sector. Eight pillars for increasing climate change resilience were identified among them adaptation, mitigation and technology transfer.

4.4.4 Environment

4.4.4.1 The National Environment Action Plan (NEAP) (2009-2013)

The National Environment Action Plan (NEAP) (2009 – 2013) was first published in 1994 and the second published in 2009 which covers the period 2009-2013 (GoK, 2009b). The National Environment Action Plan provided for a broad framework for the co-ordination of environmental policy and realization of the then Millennium Development Goals (MDGs) and Kenya's Vision 2030. The NEAP identified the climate change challenges and measures to combat it including mitigation and adaptation measures, improving stakeholders co-ordination, promoting sustainable land management, policy and legal frameworks. It further stressed on the need for research on impacts of climate change on environmental, social and economic sectors. The plan also aims to increase the Kenya's forest cover to 10% of more and adopt economic incentives for management of forest products.

4.4.4.2 Environmental Management and Coordination Act (EMCA) (2015)

The Environmental Management and Coordination Act (EMCA) (2015) is the principle instrument of the Kenya government for the management of the environment (GoK, 2015b). It provides for the relevant institutional framework for the co-ordination of environment management including the establishment of the National Environment Management Authority (NEMA). The United Nations Framework to Combat Climate Change has accredited NEMA to be the national implementing entity for the Climate Adaptation Fund. This accreditation gave NEMA the mandate to offer vetting, approval and supervision of projects financed by the Climate Adaptation Fund. Moreover, NEMA is implementing the Kenya Climate Change Adaptation Programme (KCCAP) funded by the Climate Adaptation Fund Board.

4.4.5 Other Important Policies and Legislations

4.4.5.1 The Economic Recovery Strategy (ERS) for Wealth and Employment Creation (2003 – 2007)

The Economic Recovery Policy (ERS) for Wealth and Employment Creation (2003 – 2007) provided the framework for economic growth (GoK, 2003). This development policy enabled for establishment of strategies to reform governance, raise the production levels of productive sectors, poverty reduction and creation of

500,000 jobs annually. Apart from addressing issues in other sectors, chapter 8 of the document specifically identified the proposed programs to be implemented in the ASALs of Kenya. It recognised the significant contribution of ASALs in both livestock and tourism to the county's GDP and proposed a number of development programs. The development objectives in the ASALs were to strengthen rural livelihoods through support to livestock and range management and eco-tourism among others.

4.4.5.2 Kenya Vision 2030

The Kenya Vision 2030 is a vehicle for facilitating accelerated transformation of the country to a rapidly industrializing middle-income nation by the year 2030 (GoK, 2006). It is anchored on three pillars: Economic, Social and Political Governance. The agriculture and tourism sectors are covered under the Economic Pillar. In Agriculture, the Vision2030 aims to promote an innovative, commercially-oriented, and modern agricultural sector to be accomplished through: transforming key institutions in agriculture and livestock to promote agricultural growth; increasing productivity of crops and livestock; introducing land use polices for better utilisation of high and medium potential lands; developing more irrigable areas in arid and semi-arid lands for both crops and livestock; and improving market access for smallholders through better supply chain management. The tourism sector is equally planned for by the Vision which aims to be one of the top ten long-haul tourist destinations in the world, offering a high-end, diverse, and distinctive visitor experience using the flowing strategies: aggressively developing Kenya's coast by establishing resort cities in two key locations; achieving higher tourist revenue yield by increasing the quality of service and charges in country's premium safari parks, and by improving facilities in all under-utilised parks; creating new high value niche products (e.g. cultural, eco-sports and water-based tourism); attracting high-end international hotel chains; and investing in new conference facilities to boost business tourism.

The Vision moreover recognizes threats posed by climate change and desertification as over 70% of natural disasters that affect the country are weather related. The economy is heavily dependent on climate sensitive sectors, and the means to cope with climate hazards is inadequate. It has been noted that in the recent past the frequency, magnitude and severity of disasters has been increasing with resulting negative impacts including loss of life and property and destruction of infrastructure. The approaches to disaster management are currently disaster response as opposed to a better way of disaster risk reduction.

4.4.5.3 Constitution of Kenya 2010

In 2010, Kenya promulgated a new Constitution, which provides for a devolved two-tier and a participatory system of government (GoK, 2010b). The environmental issues in the new Constitution are covered in Article 42. It claims the right to a clean and healthy environment for all citizens which include the right to have an environment protected for the benefit of the present and future generations through legislative and other measures. Further, Article 69 emphasizes the sustainable use, management and conservation of the environment and natural resources in order to ensure equitable sharing of the accruing benefits. It also encourages the people of Kenya to achieve and maintain a tree cover of at least 10% of the land area. Moreover, Article 70 of the Constitution enforces the right to a clean environment and recognizes actions that may be taken by responsible people in order to ensure a clean and healthy environment.

4.4.5.4 The National Policy for the Sustainable Development of Northern Kenya and other Arid Lands

The National Policy for the Sustainable Development of Northern Kenya and other Arid Landshad has several objectives (GoK, 2012c). On climate issues, the specific objective was to strengthen the climate resilience of communities in the ASALs and ensure sustainable livelihoods. It also aims at providing an enabling environment for accelerated investments in "foundations" to reduce poverty and build resilience and growth. In strengthening climate resilience of communities in the ASALs and ensure sustainable livelihoods, the policy proposed Drought management and climate change; Land and natural resource management; Livestock production and marketing; Promotion of dryland farming; Livelihood diversification; and Poverty and inequality. The establishment of the National Drought Management Authority (NDMA), the National Disaster Contingency Fund and the Council for Pastoralists education are provided for in this policy.

4.4.5.5 The Draft National Disaster Management Policy (2012)

The National Disaster Management Policy (2012) (GoK, 2012f) institutionalizes disaster management and mainstreams disaster risk reduction in the country's development initiatives. The policy aims to increase and sustain resilience of vulnerable communities to hazards. The policy also seeks to strengthen disaster management that focuses on minimizing risks: loss of life, economic loss and property. Climate change is one of the issues highlighted in the policy whose impacts that have affected the country being abnormally high rainfall, erratic rainfall, floods, landslides and droughts. The policy calls for preparedness to reduce the causes and negative impacts of climate change by promoting and encouraging sustainable development. The policy proposes that disaster risk reduction activities are mainstreamed in national and county plans and policies with appropriate budgetary allocation.

4.4.6 Key Informants Interviews

A total of 10 Key Informants (KIs) were interviewed from October 2017 to January 2018. The KIs unanimously agreed that Kenya has enough policies and legislations relating to climate change that are both reactive and proactive. Majority of the KIs further indicated that the policies and legislations were strong though, the levels of implementation were considered low to medium (Table 4.24) making them less effective. The least strength level was indicated by 6 KIs (Threshold 21) and the highest by 10 KIs (Agricultural Sector Development Strategy (ASDS) (2010 – 2020) and National Climate Change Action Plan (2013 – 2017)). The KIs noted consistently with concern the declining and shifting projected modelled ASALs livestock CC. The KIs added that the projected changing CC is invaluable information to the communities, ranchers, national and county governments that will aid in pasture resources management. They pointed out that some of the secondary impacts of changing ASALs CC will include; decline in income and loss of livelihoods; increase in pasture-based conflicts between pastoralists and between human and wildlife; and change of community culture and traditions among others.

Table 4.24: Summary of KIs response to the reviewed legislations and policies.

Policy/Legislation	**Strong (No. of respondents)**	**Weak (No. of respondents)**	**Level of implementation**
The National Livestock Policy (2008)	9	1	Low
Agricultural Sector Development Strategy (ASDS) (2010 – 2020)	10	0	Medium
Kenya Climate Smart Agriculture Strategy (CSA) (2017 – 2026)	8	2	Medium
The Wildlife Conservation and Management Act (2013)	7	3	Medium
The Forest Act (2005)	7	3	Medium
Forest Conservation and Management Act (2016)	9	1	Medium
Tourism Act (2011)	8	2	Low
National Tourism Strategy (2013-2018)	9	1	Medium
National Climate Change Action Plan (2013 – 2017)	10	0	Low
Climate Change Act (2016)	9	1	Low
The National Climate Change Response Strategy (NCCRS) (2010)	9	1	Low
Threshold 21 (T21) Kenya	6	4	Medium
Kenya National Adaptation Plan (NAP) (2015 - 2030)	7	3	Low
East African Community Climate Change Master Plan (EACCCMP)	9	1	Low
The National Environment Action Plan (NEAP) (2009-2013)	7	3	Low
Environmental Management and Coordination Act (EMCA) (2015)	8	2	Low
The Economic Recovery Strategy (ERS) for Wealth and Employment Creation (2003 – 2007)	8	2	Medium
Kenya Vision 2030	7	3	Medium
Constitution of Kenya 2010	8	2	Low
The National Policy for the Sustainable Development of Northern Kenya and other Arid Lands	9	1	Medium
The National Disaster Management Policy (2012)	7	3	Low

The recommendations made by the KIs in relation to the changing CC in ASALs were ten (10) (Table 4.25). Majority of the respondents (more than 6) recommended the first seven (7) which cover climate change impacts creation awareness, diversification of livelihoods and sharing the changes in CC with the relevant stakeholders. The least recommended were monitoring of both the ASALs CC and the pasture-based conflicts.

Table 4.25: Recommendations on climate mitigation measures in relation to the changing CC in the ASALs.

Recommendation	**Number of respondents**
Public awareness creation on how climate change will affect their livelihoods	10
Diversification of livelihoods away from livestock and wildlife based tourism in the ASALs	10
This research findings should be shared with the KWS, ranchers, county and national governments and communities in the ASALs	10
Adequate research be conducted before undertaking economic investments	9
Climate change research should focus on specific area and issue	8
Hybrid grass development for ASALs seeding	7
KWS to identify potential areas to be designated as game park/reserve	6
Capacity building at county level to be able to deal incorporate climate change issues in their development planning	6
Governments should be proactive in monitoring the ASALs CC	2
Pasture-based conflict monitoring	2

CHAPTER FIVE

DISCUSSION

5.1 Spatial-Temporal Trend of Rainfall and MODIS NDVI

The monthly rainfall trends show both increasing and decreasing pattern with different magnitudes in diverse regions of the country. The rainfall trend ranged between -15 to 20 mm in the months of January in central and May in the coastal regions respectively. January had the highest area of 84.5% under declining trend with rest of the country specifically in the north eastern and north coast regions indicating increasing rainfall trend. Other months with more than 50% of the area showing a declining rainfall trend though with different spatial distribution pattern include May (68.9%), June (55.8%), August (52.5%) and December (55.5%). The months with positive rainfall trend covering more than 50% of the areas are February (81.6%), March (69.3%), April (55.5%), July (64.3%), September (65.7%), October (70.7%) and November (78.3%). The K_{Loc} statistic had zero and low similarities between the months of January to April with a maximum of 100.00% similarities from June to September. The similarity then reduces to less than 20.00% in October before becoming zero in December. The K_{Histo} maintained similarities of more than 60% throughout the study period with May, June, July, August and September having 100.00%. The high percent similarity observed indicate that the rainfall aspects of location and quantity are most stable from May – September. The other months of January – April and October – December have the lowest percent similarities a pointer to erratic and spatial shift in rainfall patterns.

The annual rainfall spatial trend analysis for the 15 years illustrate that the entire country experienced a negative trend ranging from -6 to 0 mm. The north west, northern and north eastern sections constituting 60.8% of the country by area, the rainfall trend ranged from -2 to 0 mm. The other regions of central, southern and coastal areas decreased by -4 to -2 mm and represented 37.4% of Kenya's area. The areas with the most reduced rainfall trend by -6 to 4 mm were scattered in the central, southern and coastal regions covering 1.8% of the area. The K_{Loc} percent similarity was between 33.33% in 2001 to 58.33% in 2015, with the other years range between 40.00 to 50.00%. The K_{Histo} values were all more than 75.00% with the least in 2009 and the highest in 2002, 2004, 2006 and 2007 at 100.00%. These similarity indices are a demonstration of rainfall stability both monthly and annually.

The monthly MODIS NDVI trend analysis showed both increasing and decreasing trends of between -0.065 to 0.060 differing with the months. The month of December recorded extreme values in both directions ranging from -0.0588346 to 0.0572932. The K_{Loc} percent similarity fluctuated between 86.67 to 100.00% from January – September before reducing to 66.68% in October, then 0.00% in November before increasing to 73.33% in December. The K_{Histo} statistic had similarity pattern of 100.00% throughout except in the moths of January and March which were also more than 80.00%. The monthly percent similarity patterns of MODIS NDVI indicate stability of both location and quantity of rangeland vegetation. However, in the month of November where the percent similarity was 0.00%, an indication that the rangeland vegetation shift in location is very high. The annual MODIS NDVI analysis also indicated that the country experienced both negative and positive trends for different regions ranging from between -0.0495927 to 0.0468138. The north western area and the north eastern tip of the country had positive trend. The negative trend distribution was more in the eastern parts and scattered all over the country. The binary analysis indicated that 38.01% of the country experienced a positive trend with the rest, 61.99% having negative trend. The annual MODIS NDVI similarities for both K_{Loc} and K_{Histo} kappa statistics were all more than 60.00%. The K_{Loc} ranged from 66.67% for years 2006, 2007 and 2011 to 91.67% in 2001, 2004, 2008, 2013, 2014 and 2015. The other years' percent similarities are within these low and high ranges. These values specify that both the spatial and quantitative aspects of the rangeland vegetation are stable. The linear regression indicated that the annual mean rainfall and annual mean MODIS NDVI for the study period was significant, $p \leq 0.000$. The coefficients of determination ranged between 0.541 in the year 2002 and 0.763 in 2006 for the individual years. The coefficient of determination for the fifteen years mean was 0.617 which was also significant, $p \leq 0.000$.

Numerous climate change impacts on plants have been conducted by many researchers the world over including Kiers *et al.* (2010) who reported phenological shifts in flowering plants and insect pollinators. This will result in mismatches between plant and pollinator populations, a detrimental manifestation. They concluded that this variance will lead to the extinctions of both the plant and the pollinator with expected negative consequences on the structure of plant–pollinator networks. Climate change impacts on cool conifer forests, tundra, scrubland, savannahs and boreal forest study by (Sala *et al.*, 2005) projected shifts of 5–20% of Earth's terrestrial ecosystems. Further, Lapola *et al.* (2009) indicated that large portions of Amazonian rainforest could be replaced by tropical savannahs while Root *et al.* (2003) concluded that the mean response across all species responding to climate change was a shift in key phenological events of 5.1 days earlier per decade over the last 50 years. Other studies resulting in more climate change adverse conclusion was reported by Bakkenes *et al.* (2002). They established that more than 16% of European landmass would have local species losses exceeding 50% by 2050.

The modelled potential grass niche suitability was compared in both category and location according Visser and de Nijs (2004) using the MCK. Hagen (2003) demonstrated usefulness and recommended the application of MCK in spatial analysis where map comparison is required. The obtained results from this study showed that location similarity of the grass niche categories were 23.3% and 53.6% in quantitative (area) similarity aspects. The modelled grass niche suitability apart from shifting location by 76.7% will also experience a change in category area of 46.4% in the 2050 climatic period. The base-year and 2070 climatic period similarities denote that the grass niche location similarities were 22.2% while quantitative (area) similarity was 44.0%. These Kappa statistics can also be interpreted as that the grass niche suitability levels shifted by 77.8% and 66.0% quantitatively (area). For the purpose of judging the Kappa values obtained, Altman (1991) proposed a benchmark scale of five categories ranging from poor to very good. The classes are 0 to 0.2 standing for "Poor", 0.21 to 0.40 denoting "Fair" and 0.41 to 0.60 indicating "Moderate". The other scales are "Good" and "Very Good" represented by 0.61 to 0.80 and 0.81 to 1.00 respectively. Using this scale, it was therefore concluded that in both future climatic periods, the K_{Loc} and K_{Histo} the grass niche suitability levels falls under categories "Fair" and "Moderate" similarities respectively. This projected variability in grass niche suitability concluded a spatial and quantitative change and will affect both livestock and wildlife.

5.2 Modelled Spatial and Temporal Rangeland Vegetation Distribution

The modelled grass niche generated both unsuitable and suitable areas in the different AEZs for all the three climatic periods. The modelled base-year climatic period suitable grass niche covered different fractions in each AEZ with 76.16% and the 23.84% being unsuitable and suitable respectively of the country's ASALs. In the 2050 climatic period the suitable grass niche will cover 36.16% with the unsuitable extending to 63.84% of the ASALs. Though the spatial distributions differ, more or less the same values were observed for the 2070 climatic period modelled grass niche. The percentage areas were 27.99% and 71.01% for suitable and unsuitable grass niche respectively. The modelled grass niche suitability apart from shifting location by 76.7% will also experience suitability level of 46.4% in the 2050 climatic period. In the 2070 climatic period, the situation will be 77.8% and 66.0% for spatial shift and quantitative changes. The Maxent models used all the 19 Bioclim data which contributed differently to the modelled grass niche suitability in each AEZ and climatic periods. The three models for AEZ in each climatic period were all significant with the least AUC of 0.754 in the AEZ VI.

The current study showed that the spatial and temporal distribution of vegetation (MODIS NDVI) is dependent on climate (rainfall and temperature) within the fifteen years (2001 – 2015) of study. The rainfall trend analysis by GoK (2010) reported that south eastern region Kenya is slowly registering a shift in the seasonal rainfall pattern. This shift in rainfall pattern is supported by a study of rainfall variability in arid and semi-arid lands of Kenya by Shisanya *et al.* (2011) who concluded that the September – December season is becoming more reliable than the March-May season. Further, analysis by GoK (2012d) pointed out that annual rainfall was below the long-term average during 2008, 2009 and 2010 and in the first half of 2011. Moreover, (GoK, 2012d) synthesis of monthly rainfall made the following conclusions; the mean monthly rainfall in 2008 was below average 67% of the time; in 2009, the number of months showing less rainfall than the long-term monthly average increased to 75% of the time; in 2010, the number of rainfall deficit months decreased to 62% of the time; and in the first half of 2011, it was 72% of the time. FEWSNET (2010), made a number of conclusions too with respect to Kenya climate trend analysis study including but not limited to a 100 mm decline in Kenya's central region long rains since mid-1970s and a drying tendency.

The rainfall variability is as a result of both natural and man-induced activities (Wilby and Dawson, 2007). However many studies have documented unusual variability in seasonal and annual rainfall patterns in aspects of location and amounts (IPCC, 2007; Settele *et al.,* 2014). The observed variability in the rainfall patterns follows that the vegetation will also change in more or less the same direction and magnitude. Studies on the causes of variations in vegetation have shown that climatic factors, particularly precipitation and temperature, significantly influence vegetation dynamics (Allen *et al.,* 2010; Crimmins *et al.,* 2011). Tagesson *et al.* (2015) reported a strong link between rainfall distribution in a semi-arid savannah grassland and inter-annual variation in plants species composition in West Africa region. In 2005-2006 Kenya faced a prolonged dry spell due to failure of rain, particularly the October to December short rains in 2005 (Oludhe *et al.*, 2007) which affected 3.5 million people mainly from the pastoralist region. Other examples of negative climatic impact studies are long-term decrease in precipitation linked to anthropogenic climate change (Biasutti and Giannini, 2006) in Sahel region and extreme drought in North Africa (Touchan *et al.,* 2008) is linked to severe mortality of Atlas cedar (*Cedrus atlantica*) from Morocco to Algeria. These vegetation dynamics resulting from climate influence at regional levels are best analysed using MODIS NDVI data.

The use of MODIS NDVI to quantify vegetation change is now a norm in many vegetation related studies by many researchers after extensive studies (Gray and Taple, 1985). The relationship between rainfall and MODIS NDVI is linear and normally sought through regression analysis. The analysis of Kenya's rainfall and MODIS NDVI relationship established significant and strong relationship for all the years a situation also concluded by other researchers such as Shisanya *et al.* (2011), Zeng *et al.* (2013), and Brando *et al.* (2010). Further, Boschetti *et al.* (2013) demonstrated that both rainfall and MODIS NDVI are useful in identifying hot spots and degraded areas.

5.3 Rangeland Livestock Carrying Capacity

The relationship between rainfall (mm) and weight (kg) of dry matter (DM) per year per hectare was obtained from the equation, DM ha^{-1} yr^{-1} = 123.00+1.81(rainfall) that was significant. The carrying capacities in all climatic periods ranged from 0 to 11 though the distributions were not uniform. The base-year climatic period, had the majority of the area accounting for more than 40% area of Kenya having 0 to 1 TLU ha^{-1} and more than 21% of the area with TLU ha^{-1} of 2 to 3. The rest of the areas comprising about 2% had CC of 3 to 11 TLU ha^{-1}. The future climatic periods will have reduced grass niche suitable areas analysed for CC at 35.40% in 2050 and 28.84% in 2070 climatic periods. In the two future climatic periods, most of the areas will have a CC of 0 to 3 TLU ha^{-1}. The potential CC changes in the future climatic period revealed three scenarios of decrease, no change and an increase. It was observed that the future climatic periods, the CC will decline by between -8 to -

1 covering areas of 265,469 km^2 (44.99%) and 270,268 km^2 (45.78%) in 2050 and 2070 respectively. The no change category in CC will covered 131,994 km^2 (22.37%) in 2050 and 100,544 km^2 (17.00%) in 2070 climatic periods while areas with increased TLU ha^{-1} was 17,582 km^2 (2.98%) and 44,233 km^2 (7.50%) for the respective periods.

The rangeland CC analysis measured ecosystem productivity using organic matter (biomass) produced per unit area. The TLU ratio has been mostly applied in the eastern Africa rangeland ecosystem productivity studies. The relationships between precipitation and biomass yield have often been used to predict forage availability in the rangelands. Food and Agriculture Organization (1995) provided tabulated data rainfall and DM ha^{-1} yr^{-1} and recommended its application in biomass yield studies. Sinclair (1979) recorded average biomass yields of 4 to 6 kg DM ha^{-1} per mm in the Serengeti Plains while others focussed on seasonal biomass yields. Van Wijngaarden (1985) recorded 4 to 7 kg DM ha^{-1} mm^{-1}, increasing with rainfall, for *Themeda* grasslands in Tsavo National Park (as cited in Bekure *et al.,* 1991). Bekure *et al.* (1991) further cited Potter (1985) to have shown daily seasonal growth rates of 20 to 30 kg DM ha^{-1} for rainfall of 300 to 400 mm per season and 10 to 15 kg DM ha^{-1} per day for rainfall of 150 to 250 mm per season. Regression of standing biomass in Kajiado, on plant cover indicated yields of 3 tons DM ha^{-1} at 80% plant cover, similar to values observed by van Wijngaarden (1985) for a seasonal rainfall of 250 mm (as cited in Bekure *et al.*, 1991).

The dependence of rangeland biomass production on climate has been clearly demonstrated by various researchers in various regions. In the phase of climate variability, a corresponding change of biomass production is expected. Many scientists have been working on this to project the future potential changes in ecosystem biomass production with the probable future climate change. Fan *et al.* (2010) and Gao *et al.* (2016) indicated that climate change is the main driver of the interannual fluctuations in the grassland biomass in Tibet. Further, Zhang *et al.* (2017) found that climate change was a major factor that leads to fluctuations in the Tibetan grassland biomass variation by 26.4%. They additionally concluded that the total grassland biomass reduced significantly under the future climate change scenarios.

Future climatic change will have a substantial impact on the spatial distribution and the productivity of switch grass in the Midwest USA Behrman *et al.* (2013). A large percentage of the study area able to produce the most biomass is expected to decrease with climate change although average biomass per area remains fairly constant. This is due to a large increase and large decrease of local biomass potential in different areas expected by 2080 to 2090. This increase in biomass potential corresponds to locations where minimum temperature and precipitation are expected to increase the most.

It is logical that warmer and wetter climate favour biomass production compared to the hotter and dryer climate. The carrying capacity in the future climatic periods are expected to change positively or negatively but in some situations, no changes are expected. Spatially, the future climate influence on the known grassland includes expansion, shrinkage and shift to other regions as adaptations might allow. These changes will have a direct influence on the carrying capacity which is also expected to vary in the same magnitude and direction. This information is critical for the purposes of planning for investments in livestock keeping and wildlife-based tourism for individuals, ranches and at both county and national governments. Making informed decision in relation to potential future climate change will promote sustainable development and wise use of limited resources, a key objective of current development paradigm for both national and county governments.

Limited guidelines are available for judgement of the Maxent model ROC values. Pontius and Schneider (2001) stated that any value of AUC more than 0.50 is statistically better than random while a value of 0.7 is considered acceptable for land use land cover modelling. Further, Hosmer and Lemeshow (2000) classified AUC values beyond 0.8 as excellent and more than 0.9 as outstanding. Using these guidelines, the generated Maxent models for AEZs IV and V were outstanding, AEZ VI excellent and AEZ VII acceptable for all climatic periods.

5.4 Kenya Government Policies and Legislations on Climate Change, Pastoralism, Wildlife and Tourism

The Kenyan government has responded adequately to climate change through several policies, legislations and strategic plans in all the areas of economic sector. A total of twenty one (21) policy and legal documents relating to climate change were reviewed in the final analysis. The review of these documents was done under the following sub-headings: Agriculture (3 documents); Wildlife, Forestry and Tourism (5 documents); Climate Change (6 documents); Environment (2 documents); and Other Important Policies and Legislations (5 documents). Virtually, all the relevant areas of economy anticipated to be affected by climate change are adequately dealt with. Some documents exclusively address climate change, others partly address it while others tackle it indirectly.

The conducted KIs interviews acknowledged the government of Kenya efforts to combat climate change apart from making their recommendations which were: the need for more localised climate change research; strengthening diversification of livelihoods; public education on climate change, socio-economic disruptions related to climate change, and mitigation and adaptation measures.

The analysis showed that existing policies and legislation are adequate to respond to climate change. The pastoral and livestock activities are well covered and so are the tourism and wildlife sectors though limited action has been taken possibly due to institutional weaknesses and challenges (Petursson *et al.,* 2011). The Key Informants were concerned that there are many climate change policies and legislations under different government implementing agencies. This could be a source of conflict in the institutions and there is need for coordination of climate change activities to avoid duplication and promote wise use of the limited resources. Petursson *et al.* (2011) pointed out that such conflicts are closely linked to institutional weaknesses and challenges. In this regard, the KIs underscored the need for establishment of a government agency to streamline all the climate change activities from research to implementation of mitigation and adaptation measures in the critical sectors of the country's economy as described by Fankhauser *et al.* (2018) on the UK's Climate Change Act (2008).

The level of dependence of spatial distribution of grass was established and that its future distribution will both decline and shift to different regions of ASALs. The modelled spatial grass niche and CC distribution maps of Kenya clearly indicate the regions, the levels of grass suitability and CC. The results further show whether the grass suitability and CC levels have decreased, remained the same, increased and to what extent have their locations changed. From this study, it will be possible for Kenya to device specific actions for each location such that the positive benefits of climate change can be enhanced while mitigating and promoting adaptation measures for the negative impacts.

In the future projected grass niche suitability levels were positive in scattered areas distributed in the northern, central and southern regions totalling 17,582 km^2 (2.98% of AOI) in 2050 and 44,229 km^2 (7.50% of AOI) in 2070. The regions projected to be negative were in the northwest, northern, north eastern, eastern and southern regions having combined areas of 265,469 km^2 (44.98% of AOI) and 270,268 km^2 (45.80% of AOI) for 2050 and 2070 climatic periods respectively. The decline in grass niche suitability in Maasai Mara game reserve should be a big concern for all. This will set-off a chain reaction as the wildlife will decline in numbers, the tour attractions will no longer be appealing as before, the hotel industry will suffer, the income and tax will decline and there will be a general disruption of socio-economics of the region. In British Columbia, a rangeland seeding manual developed by Dobb and Burton (2013) has successfully been applied which resulted in higher livestock CC. The danger of pasture-based conflicts between the communities was as well addressed by the KIs. They pointed out that the projected situation of declining pasture is a recipe for conflicts between the communities utilizing the pasture and water resources as has been the case over the years Rohwerder (2015).

Mendelsohn (2000) advised that to enable effective adaptation measures, governments as well as non-government organizations, must consider integrating climate change in their planning and budgeting in all levels of decision making. The projected changes in the grass niche suitability indicate that the national parks and national reserves in the threatened areas are Sibiloi, Maralal, Maasai Mara, Chyulu, Amboseli, Tsavo East and Tsavo West (Figure 5.1). Equally to be affected are the pastoralists in these regions who sometimes depend on the protected areas for dry season grazing pasture reserves as reported by Rohwerder (2015).

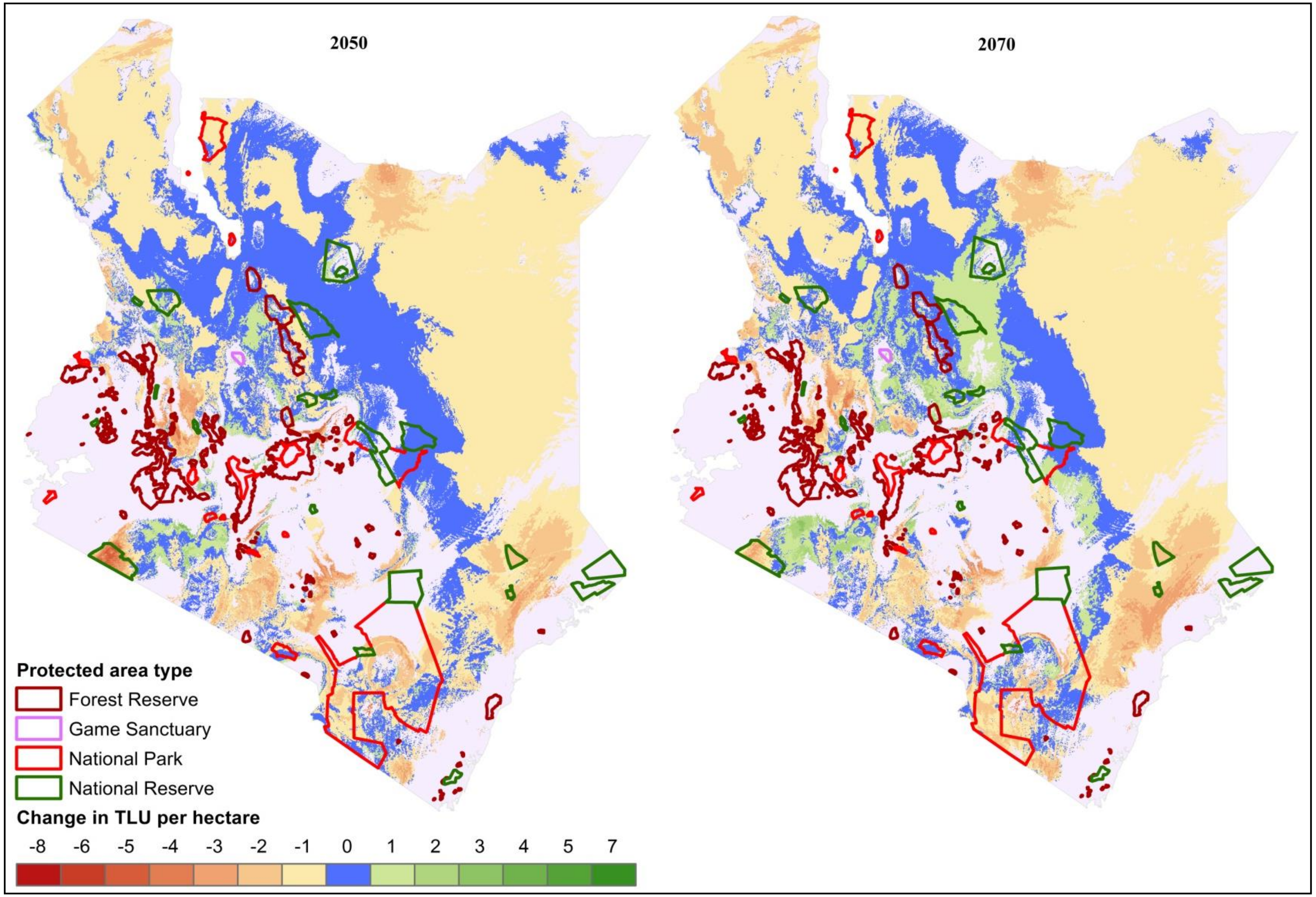

Figure 5.1: The distribution of protected areas and change in TLU ha^{-1}.

Though the human population density in the ASAL regions is low compared to the other parts of the country, the economic contributions are enormous to the GDP (KIPRA, 2014). The Kenya's livestock industry and most wildlife-based tourism activities are located in these regions (KWS, 1996) where large scale investments from both county and national governments are being implemented. The execution of these investments should take climate change which Hegerl *et al.* (2007) projected it will affect Kenya adversely. This climate consideration will ensure wise use of limited resources and maximum benefits to the communities and the nation at large thus promoting sustainable development.

The general picture of projected future climate indicates that most of these regions are anticipated to experience less rainfall and higher temperatures than long term means, a disastrous situation. The repercussion of this is shortage of pasture, intensive migration by pastoralists and increase in conflicts (Rohwerder, 2015). The conflicts will not only be between the local communities but will also be between the government and the local communities and the local communities' verses wildlife. The pastoralists are known to invade areas where pasture is available with or without permission from the owner(s). Such areas could be large-scale ranches or the national and game reserves where restrictions by the government exist as witnessed in the year 2017 in Laikipia County (Njuguna, 2017). The pastoralists on migration forced their entry into private ranches, grazed their livestock, killed ranch owners and employees, killed wildlife, vandalised and burnt structures before the government intervened. The animosity then shifted to between the pastoralists and the government security personnel leading to further loss of life and damage to property (Owino, 2017).

The impacts of climate change are localised, sector specific and should inform the adaptation and mitigation measures to put in place by application of “science of adaptation” (Smit, *et al.,* (2000). The government of Kenya and other stakeholders in the wildlife-based tourism regions need to understand the implications of climate change on pasture and take appropriate action. Such measures include gazetting the potential new national parks and game reserves as the current locations will be less suitable for grass growth. As much as the county governments in the ASAL regions need to develop the supporting infrastructure of livestock and tourism, they equally need to be informed of the projected localised climate change impacts. Their development decisions not only need to be political but also be based on the climate, the critical economic activity driver in these regions (Allen *et al.,* 2010; Crimmins *et al.,* 2011).

In reference to the projected grass niche suitability results, the KIs agreed that there is need to share the same with all the stakeholders especially the local communities, the ranchers, the county and national governments since they are the major stakeholders. Theses stakeholders keep livestock in their communal lands, both livestock and wildlife animals are located in their ranches, thus is useful in pasture management. The county and national governments roles are to enhance the benefits from both pastoral and wildlife activities practised in the region. Moreover, KALRO need to be engaged to develop hybrid grass species for seeding in the ASALs. The seeding will provide an adaptation measure against the declining pasture thereby enabling the ASALs maintain or even increase the current livestock CC.

The KIs acclaim findings of this research be used to drive the development agenda in relation to livestock keeping and wildlife-based tourism economic activities. An example given here is the use of the results by KWS, Ministry of Tourism and both national and county governments in game parks and game reserves management. They further opined that, though it may look generalized for the whole country, the specific activities to be undertaken should be dictated more by the localised impacts of climate change hence the need to invest in more and long-term research.

The looming pasture-based conflicts should be monitored. The development and deployment of pasture-based conflict monitoring mechanism for early detection (based on rainfall data) and resolution was recommended by KIs. For example, a significant decline in rainfall should raise a red flag and set off a conflict monitoring mechanisms. A similar mechanism known as tracking was proposed by ICRC (2005). Other measures to reduce climate change vulnerability in the ASALs include: Diversification of livelihoods from pastoralism only to incorporate, establishment of irrigation schemes, supporting business establishments of both individuals and organised groups; educating the local communities on climate change impacts on their livelihoods and engaging them in the design and deployment of mitigation measures; and development of other non-wildlife-based tourism activities.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The spatial and temporal trends of climate (rainfall) and MODIS NDVI from 2001 – 2015 analysis was based on spatial data and made the following conclusions:

i. There were significant spatio-temporal variations in both rainfall and MODIS NDVI in some months with no change detected in the fifteen years mean for both parameters. The annual mean rainfall is reducing for the ASALs and dependence by MODIS NDVI was significant.

ii. The 2050 climatic period grass niche suitability level will decrease by 44.99% while the unsuitable will increase by 87.01% with a spatial shift of 76.7% and 46.4% in areas under the different categories used. The 2070 climatic period grass niche suitability will shrink by 55.21% with an increase to 106.80% of the unsuitable category. Moreover the 2070, the spatial shift of grass suitability levels will be 77.8% with extent of overage change of 66.0%.

iii. The impact of future climatic period is reduction in CC by -2 to -1 TLU ha^{-1} in 43.33% in 2050 and 44.20% in 2070 climatic periods respectively. Other areas CC will not change while an increase by 1 to 2 TLU ha^{-1} will cover 2.93% in 2050 and 7.30% in 2070 climatic periods. In both future climatic periods, the ASALs CC spatial shifts and extent of coverage will follow the grass niche suitability levels patterns.

iv. The reviewed climate change policies and legislations demonstrated that Kenya has responded adequately to climate change but the multiplicity of mandates in different government agencies can lead to chaos. The policies and legislations cover not only agriculture, wildlife and tourism but all areas of economic development both directly and indirectly. The KIs revealed that the policies and legislations implementations are low to moderate and underscored the need to share the research findings with all the relevant stakeholders.

6.2 Recommendations

The research findings of the study make the following recommendations:

i. Further research specifically concerning the following: use of more refined spatial climate (rainfall)data from the current 1000m to 500m; inclusion of other growth factors which comprise soil depth, soil type and land surface characteristics (slope, plain, e.t.c) among others in the Maxent model; and modelling seasonal future grass niche suitability and livestock carrying capacity will be very beneficial.

ii. There is need to redo the Kenya AEZs to reflect the variability in climate and the projected climate change conditions

iii. The use of other future climate projection scenarios for comparison of how the grass niche suitabilities will change

iv. and the policy and legislation level, there is necessitate invest in more research to monitor the localised impacts of climate variability on grass/pasture rather than generalization

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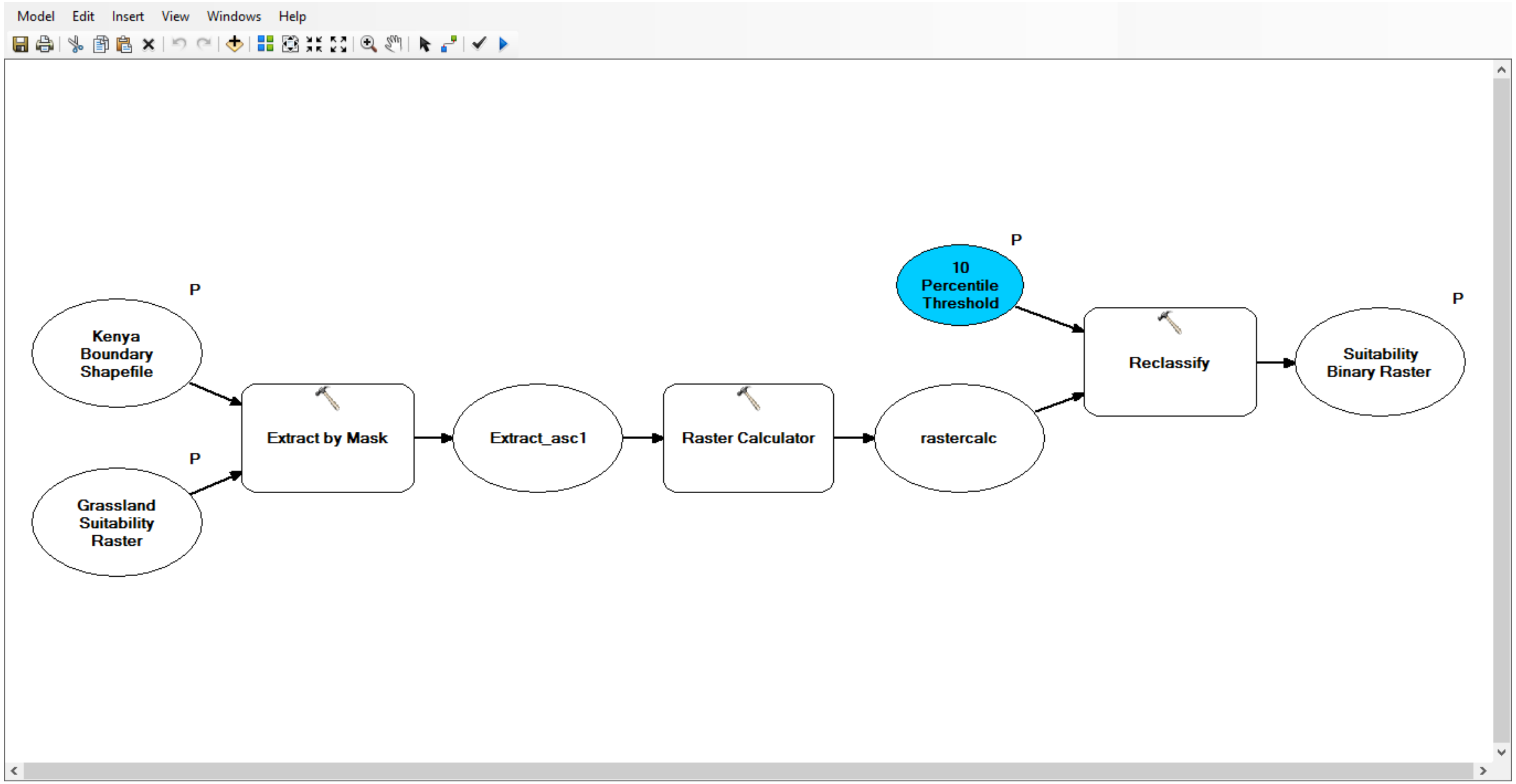
APPENDICES

Appendix 1: ArcMap Model for Generating AEZ Binary Data.



Appendix 2: Africover Data Description.

SPATIALLY AGGREGATED MULTIPURPOSE LANDCOVER DATABASE FOR KENYA – AFRICOVER ISO19115/19139 XML

Identification info

Title: Spatially Aggregated Multipurpose Landcover Database for Kenya - AFRICOVER

Date: 2003-03-28T00:00:00

Date type Publication: Date identifies when the resource was issued

Edition: First

Presentation form: Digital map: Map represented in raster or vector form

Abstract

This dataset is a spatially reaggregated version of the original national Africover multipurpose database. The original full resolution land cover has been produced from visual interpretation of digitally enhanced LANDSAT TM images (Bands 4,3,2) acquired mainly in the year 1999. The data was aggregated by eliminating polygons below a certain area threshold to give priority to the classes belonging to Agriculture. This threshold corresponds to approximately a 30% reduction in the polygon count. The dataset was then re-aggregated based on area threshold values. For more information on the area thresholds used to spatially aggregate the land cover data.

The land cover classes have been developed using the FAO/UNEP international standard LCCS classification system.

The data set is intended for free public access.

The shape main attributes correspond to the following fields:

Note: the document Kenya Classifiers Used, is a list of all the LCCS classifiers used in the study area. They are grouped under the 8 major land cover types. In addition to the standard classifiers contained in LCCS the user may find “user defined” classifiers used by the map producer to add additional information to a specific class, not available in LCCS. The user-defined attributes are always coded with the letter “Z”.

Purpose: The purpose of the Africover land cover database is to provide the information required for natural resource assessment and management, environmental modelling and decision-making.

Status Completed: Production of the data has been completed

Point of contact

Individual name: Antonio Di Gregorio

Organisation name: FAO-UN

Position name Senior Remote Sensing and Land Cover Mapping Expert

Role Originator: Party who created the resource

Electronic mail address: digregorio@iao.florence.it

Point of contact

Individual name: Charles Muchoki

Organisation name: Ministry of Environment and Natural Resources

Position name: NFPI - Kenya

Role Owner: Party that owns the resource

Voice: 254-2-609013/27/79

Facsimile: 254-2-606962
Delivery point: PO box 47146
City: Nairobi
Administrative area: Nairobi
Country: Kenya
Electronic mail address: kenya@africover.org
Point of contact
Individual name: John Latham
Organisation name: FAO-UN
Position name Senior Environment Officer
Role Distributor: Party who distributes the resource
Delivery point: Viale delle terme di Caracalla
City: Rome
Postal code: 00153
Country: Italy
Electronic mail address: John.Latham@fao.org
Maintenance and update frequency As needed: Data is updated as deemed necessary
Descriptive keywords: environment, natural resources, agriculture, forest, rangeland, management, AFRICOVER and land cover.
Use constraints Copyright: Exclusive right to the publication, production, or sale of the rights to a literary, dramatic, musical, or artistic work, or to the use of a commercial print or label, granted by law for a specified period of time to an author, composer, artist, distributor.
Other constraints: The data remains full property of the owners. It can be accessed, reproduced and distributed given that the owner information is explicitly acknowledged and displayed in the copyright information (I.E. Produced by FAO - Africover). The Authors do not assume any responsibilities for improper use of the data.
Spatial representation type: Vector data is used to represent geographic data
Equivalent scale
Denominator
Scale: 200000
Language: English
Character set UTF8: 8-bit variable size UCS Transfer Format, based on ISO/IEC 10646
Supplemental Information
The spatially aggregated landcover dataset is part of the Multipurpose Africover Database for the Environmental Resources (MADE) which was produced by the Africover Project to establish a digital georeferenced database on land cover at a 1:200,000 scale (1:100,000 for small countries and specific areas), and a geographic referential for the whole of Africa including: geodetical homogeneous referential, toponomy, roads and hydrography.
The Africover project was prepared in response to a number of national requests for assistance to the development of reliable and georeferenced information on natural resources at sub-national, national and regional levels. The Eastern Africa module is the first operational component of the Africover Project; it was formulated to meet several African countries request for assistance in the set-up of reliable and georeferenced data-bases on natural resources. It is part of FAO assistance to the Nile Basin countries.
Africover Eastern Africa foresees the creation of a MADE for each of the 10 countries who joined the Project: Burundi, Democratic Republic of Congo, Egypt, Eritrea, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda. The Project has been operational in the period 1995-2002 and was signed by ten countries:

FAO AFRICOVER Project Code: GCP/RAF/287/ITA
Online resource: Africover website
Data for download: Spatially Aggregated Multipurpose Landcover Database for Kenya - AFRICOVER
Data for download: LCCS Glossary
Reference System Information: Geographic Coordinate System: GCS_WGS_1984
Data quality info
Hierarchy level: Dataset: Information applies to the dataset
The original land cover was interpreted from LANDSAT imagery (Bands 4,3,2) acquired mainly in the year 1999, verified by field work, digitised, checked for topological and attribute errors and mosaiced.
This database can be analyzed in the GLCN software Advanced Database Gateway (ADG), which provides a user-friendly interface and advanced functionalities to breakdown the LCCS classes in their classifiers for further aggregations and analysis. The ADG software is available for download on the GLCN web site at http://www.glcn.org/sof_7_en.jsp.
Metadata
File identifier: 7b07bb4c-bf31-4487-8615-3a6a32643b1f
Metadata language: English
Character set: UTF8: 8-bit variable size UCS Transfer Format, based on ISO/IEC 10646
Date stamp: 2013-10-08T17:41:20
Metadata standard name: ISO 19115:2003/19139
Metadata standard version: 1.0
Maintenance and update frequency: As needed: Data is updated as deemed necessary

Appendix 3: Bioclim Data Description.

Methods

This page describes the methods used for WorldClim data.

For a complete description, see:

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.

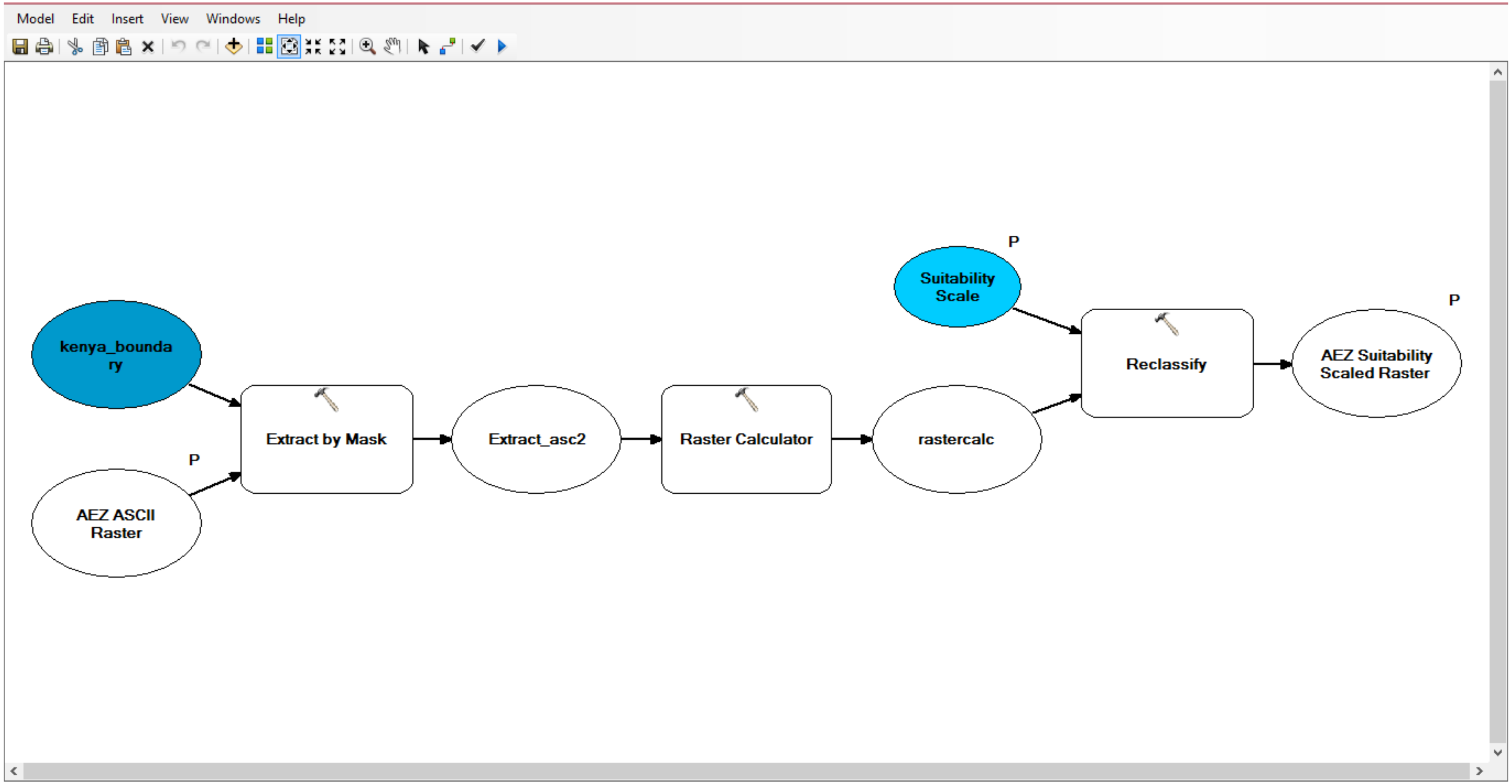
The data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km^2" resolution). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables.

The WorldClim interpolated climate layers were made using:

- Major climate databases compiled by the Global Historical Climatology Network (GHCN), the FAO, the WMO, the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, among others.
- The SRTM elevation database (aggregeated to 30 arc-seconds, "1 km")
- The ANUSPLIN software. ANUSPLIN is a program for interpolating noisy multi-variate data using thin plate smoothing splines. We used latitude, longitude, and elevation as independent variables.

For stations which records for multiple years, were available calculation averages for the 1960-90 period was done. Records of data used must have been at least 10 years. In some cases extended the time period to the 1950-2000 period to include records from areas for which we had few recent records available (e.g., DR Congo) or predominantly recent records (e.g., Amazonia). After removing stations with errors, the database consisted of precipitation records from 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations.

Appendix 4: ArcMap Model for Generating AEZ Scaled Data.



Appendix 5: Key Informants Questionnaire.

Masinde Muliro University of science and technology,
Department of Biological Science,
P. O. Box 190 – 50100
Kakamega Kenya

Dear Sir/ Madam,
I am a graduate student at Masinde Muliro University of Science and Technology carrying out a study on **'Impacts of climate change on the Spatio-temporal rangeland vegetation distribution in Kenya'**. I have done two tasks; reviewed a total of 21 policies and legislations relating to climate change (see the attached table for details) and modelled the future livestock carrying capacity changes in Kenya's arid and semi-arid lands (see attached map for details).
I request your indulgence under the following:

- Comment on the number of climate change policies and legislations;
- Indicate the implementation status of the policies and legislations as low, medium or high
- Indicate whether the policy/legislation is weak or strong;
- Remark on the modelled projected climate change impacts on the ASALs livestock CC
- What could be the secondary impacts associated with a decline in pasture; and
- Recommendations to the stakeholders on the changing livestock CC in the arid and semi-arid lands.

Thank you for participating!

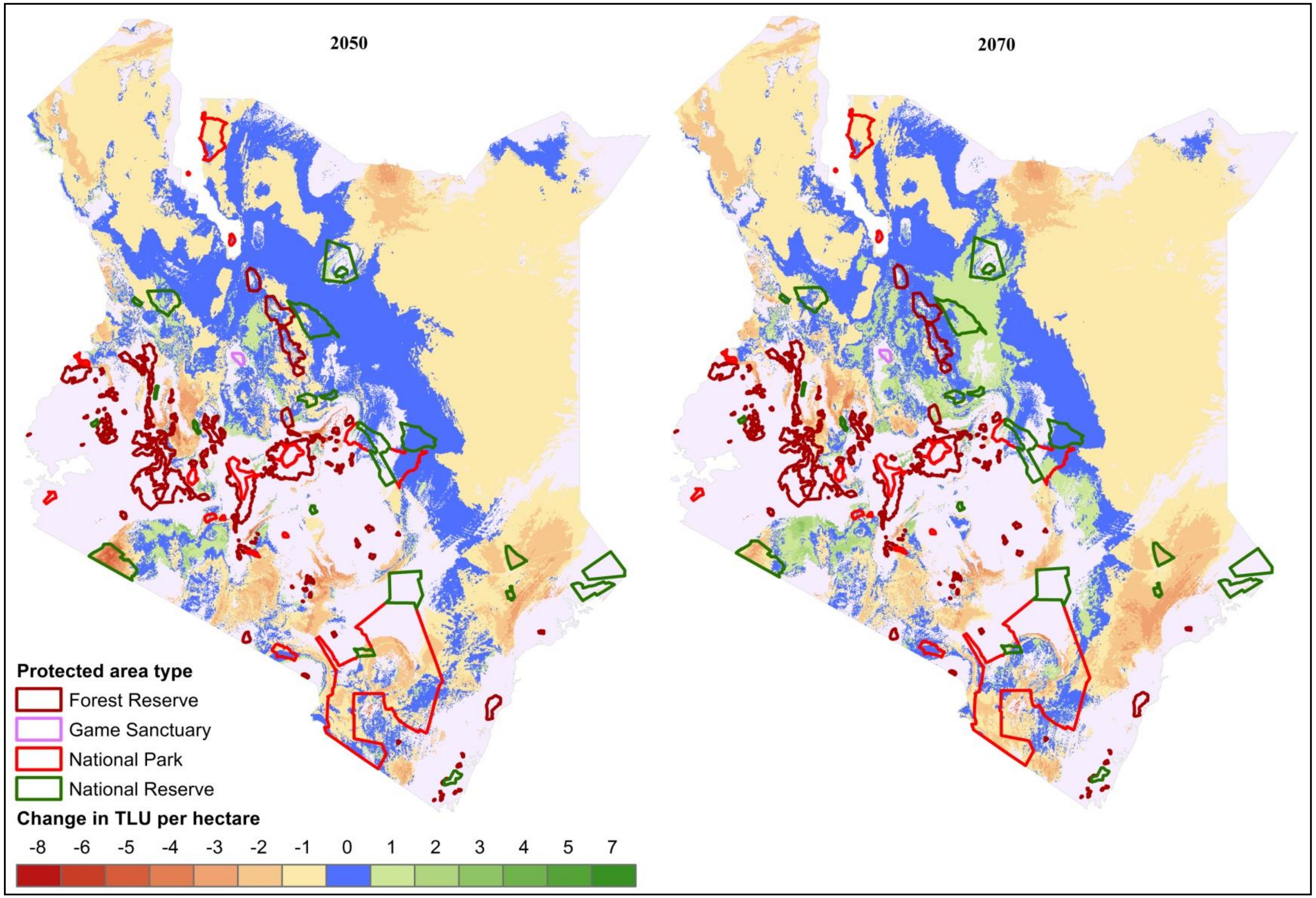
Yours faithfully,

Charles K. Kigen

Reviewed policies and legislations

Policy/Legislation	Strong (No. of respondents)	Weak (No. of respondents)	Level of implementation
The National Livestock Policy (2008)			
Agricultural Sector Development Strategy (ASDS) (2010 – 2020)			
Kenya Climate Smart Agriculture Strategy (CSA) (2017 – 2026)			
The Wildlife Conservation and Management Act (2013)			
The Forest Act (2005)			
Forest Conservation and Management Act (2016)			
Tourism Act (2011)			
National Tourism Strategy (2013-2018)			
National Climate Change Action Plan (2013 – 2017)			
Climate Change Act (2016)			
The National Climate Change Response Strategy (NCCRS) (2010)			
Threshold 21 (T21) Kenya			
Kenya National Adaptation Plan (NAP) (2015 - 2030)			
East African Community Climate Change Master Plan (EACCCMP)			
The National Environment Action Plan (NEAP) (2009-2013)			
Environmental Management and Coordination Act (EMCA) (2015)			
The Economic Recovery Strategy (ERS) for Wealth and Employment Creation (2003 – 2007)			
Kenya Vision 2030			
Constitution of Kenya 2010			
The National Policy for the Sustainable Development of Northern Kenya and other Arid Lands			
The National Disaster Management Policy (2012)			

Modelled projected changes in livestock carrying capacity in Kenya arid and semiarid lands



Appendix 6: ArcMAP Accuracy Assessment Model.