EFFECTS OF DROUGHT ON THE RELATIONSHIPS BETWEEN HERBIVORES AND VEGETATION TYPES IN THE LAIKIPIA-SAMBURU ECOSYSTEM

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ABSTRACT

Climate change in Africa is expected to lead to a higher occurrence of severe droughts in semi-arid and arid ecosystems. To understand how vegetation and herbivores populations react to such events is crucial for addressing future challenges for ecosystem management and conservation. This study aims to investigate impacts of the 2009 drought on vegetation productivity and spatial distribution of the herbivores in the Laikipia-Samburu ecosystem in Kenya.

Mapping ecosystem vegetation and assessment of its productivity is an important aspect of ecosystem management. This study mapped the vegetation of Laikipia-Samburu ecosystem using multi-season Landsat 8 images and topography data. Consequently, estimated its vegetation productivity before, during and after 2009 drought using time series MODIS NDVI. Then linked vegetation data to herbivores abundance using a 2km by 2km grid that was adopted from the herbivores count survey method.

The study results indicate that vegetation productivity during drought had influence on the population dynamics of herbivores in the Laikipia-Samburu ecosystem. The status of herbivores in the year 2008 and 2012 was assessed in Laikipia-Samburu ecosystem to determine the impacts of the drought on their populations. There was a rapid decline in the population of most animals, especially the grazers. The study indicate that the vegetation type that was strongly affected by drought, species associated to that vegetation types was also affected. This was shown by the decline of medium grazers, which was associated to the decline in vegetation productivity in grassland and mixed woodland they feed on, which was affected by the 2009 drought.

Keywords: Laikipia-Samburu ecosystem, Climate change, Drought, Herbivores abundance, Vegetation types, Vegetation productivity

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1. INTRODUCTION

1.2 Background

1.2.1 Climate change, drought and biodiversity conservation

Climate change is one of the pressing issues of our time due to temperature effects and atmospheric CO_2 concentration rise (Bartholomeus et al., 2012). This may result in prolonged dry periods and more intensive rainfall in different parts of the world (Solomon et al., 2007). For example, higher solar radiations on the equator-facing slopes relative to polar-facing slopes which results in higher evaporative demand, consequently, drier soils (Gutiérrez-Jurado et al., 2006). As a consequence of this dry conditions the vegetation may become more xeric on the equator facing surfaces (Bennie et al., 2008), leading to low aboveground biomass and plant cover (Reddy et al., 2004). This areas may become more patchy than on the polar facing surfaces. Climate change impacts are significant on physiology, phenology and distribution of species , animal life cycle, migraton of bird and animals, wild animals' habitat as well as coral reefs habitat (Thakur & Phulara, 2009). Impacts of climate change can also affect preservation of wild animals and plants in protected areas and biodiversity hotspots (Thakur & Phulara, 2009). Therefore, Climate change is expected to be one of the major drivers of species extinctions in the 21st century (Foden et al., 2008). The distribution and abundance of some species may increase, others may reduce or reach a point of extinction (Midgley et.al., 2003; Garcia et.al., 2012; Huntley et.al., 2012).

These climatic changes are observed and predicted to change the natural environment, among others changing the rainfall patterns, leading to long drought periods in some regions (Breshears et al., 2005). Drought is a period of prolonged lack of precipitation that cause a serious hydrological imbalance (Solomon et al., 2007). Droughts are more frequent and more severe in many parts of the world because of increasing global temperatures. Air temperatures have increased during the past 100 years in Africa (Nicholson et.al., 2013), leading to change in rainfall patterns that worsens the impact of the drought. Examples include the severe drought in Kenya in 2009 (Zwaagstra et al., 2010; Kioko, 2013). Kenya usually expects short rains in October, November and December, but there was less rain from December 2008 and the long rains of February to April 2009 were severely depleted (Kioko, 2013). The change in hydrological cycle due to global warming can affect river run-off , accelerate water-related hazards, and consequently affect agriculture, vegetation, biodiversity and health (Thakur & Phulara, 2009). It may also cause desertification on savanna ecosystem, for example in African savanna (Smith, 2015). Temperature fluctuations and changes in rainfall patterns, which are new challenges to biodiversity conservation, are the main reason for habitat change (Thakur & Phulara, 2009). Rainfall variability is an important feature of semi-arid climates, and is likely to increase in many regions of the world (Batisani & Yarnal, 2010).

The multiple components of climate change (i.e., temperature, rainfall, extreme events, CO2 concentration and ocean dynamic) are predicted to affect all the levels of biodiversity, from organism to biome levels (Bellard et al., 2012). It may decrease genetic diversity of populations due to directional selection and rapid migration, which could affect ecosystem functioning and resilience (Meyers & Bull, 2002). The increases in the frequency, duration, or severity of drought and heat stress are associated with climate change. It could fundamentally alter the composition, structure, and biogeography of forests in many regions (Allen et al., 2010).

1.2.2 Vegetation and Herbivores

Climate change trend can cause variations in vegetation compositional state (Onyango, 2015) and this may have implications on ecological systems and wildlife species distribution (Mundia & Murayama, 2009). One of the main use of ecosystem is to provide forage for both grazing wildlife and livestock. Vegetation production is determined by the amount and timing of rainfall, soil type, temperature and fire (Yeganeh et al., 2012). Droughts are one of the significant component of such climatic variability, and can have a devastating impact on animal populations (Young, 1994; Foley et al., 2008). Through processes such as recurrent reductions in population numbers and the consequent genetic effects caused by demographic bottlenecks (Young, 1994), droughts also have the potential to lead populations and entire species to extinction.

Droughts are frequently reoccuring and are expected to become more frequent in most arid and semi-arid ecosystems (Easterling et al., 2000). Some parts of semi-arid and arid lands are the mostly affected and suffers massive loss of vegetation cover and severe land degradation. For example, drought episodes are known to recur in Kenya over a cyclic pattern and consequently, where soils are left with severely inadequate moisture to sustain plant growth (Toepfer et al., 2000). Thus prolonged, severe drought can have an impact on the dynamics of animal populations, particularly in semi-arid and arid environments where herbivores populations are strongly limited by resource availability. This climatic changes influence vegetation species to shift their distribution along temperature or rainfall gradients and consequently changes herbivores habitat suitability. To understand how animal populations react to such hydric stress, it is crucial to address future challenges in wildlife management and conservation (Garel et al., 2004), especially in drought sensitive areas (Saltz et al., 2006). Drought can vary in severity, for example, the 2009 drought in Kenya which severely affected Samburu national reserve. The reserve massively lost vegetation cover and severely degraded by end of September 2009 (Kioko, 2013). Therefore, lack of forage during drought might have been one of the causes of death of a number of herbivores in the reserve.

Rainfall determines vegetation growth and hence it may affect the distribution and abundance of herbivores (Coe et al., 1976; Owen-Smith, 1990). It is observed that decline in population of African savanna ungulates is caused by summer rainfall reductions which could result in their local extinction if regional climate change trends are sustained (Ogutu & Owen-Smith, 2003). The dynamic equilibrium that exists between regional climate and vegetation could alter if either component changes (Shukla et al., 1990). Local impacts on vegetation can have effects on biodiversity, because changes in vegetation life form and composition, led by drought, may affect habitat suitability for many species.

Grazing distribution is an important component of the foraging ecology of herbivores. Recognising the differences in foraging behaviours, that occur along spatial and temporal scales, is critical for understanding the mechanisms that result in grazing distribution patterns (Bailey & Provenza, 2007). Abiotic factors (topography, water availability and weather) and biotic factors (forage quantity and quality) affect the distribution of herbivores. Vegetation availability is a measure of the actual available amount of vegetation to the animal. The relationship between species distribution patterns and environmental factors vary spatially (Bailey et.al., 2008). Herbivores usually move in groups (Figure 1), do not randomly distribute as they display spatial grazing distribution patterns. They are selective when foraging based on biomass availability (Baumont et.al., 2000) with their distribution and density matching the vegetation distribution (Skidmore et.al., 2008).

Figure 1 : Herbivores groups in Lewa Wildlife conservancy (source: Google Earth images)

In response to climatic conditions, herbivores may move up or down elevation zones to take advantage of the variability in plant phenology. Migrations of herbivores from one region to another may be due to lack of forage or water (Senft et al., 1987) which allows them to survive in spite of the variability in weather and climatic patterns (Boone et al., 2006).

Differences in the physiological response of plant species to drought determine different levels of resistance and resilience to water deficits (Chaves et al., 2003) and ultimately influence vegetation adaptation to drought, differentiating those that slow growth (Pasho et al., 2011) or reduce greenness (Ji & Peters, 2003), those that lead to loss of biomass (Ciais et al., 2005), and those that result in plant mortality (Allen et al., 2010) (Adams et al., 2009). The response to water deficit among vegetation types is a crucial issue underlying geographic patterns of vegetation and a central concept to understanding the structure and dynamic of terrestrial ecosystems (Knapp & Smith, 2001). Nevertheless, the way by which the temporal variability of drought determines vegetation activity across the world biomes remains largely unknown because vegetation types have different characteristic response times (Pasho et al., 2011) and vulnerability to drought (McDowell et al., 2008). Most studies have considered the response of vegetation to climate by means of the simple anomaly of precipitation with respect to the average conditions (Vicente-Serrano et al., 2013). Such approach neglects the role of temperature and the drought time-scale at which the response of vegetation is highest which both are essential to identify the response to climate variability and to understand the sensitivity of vegetation to drought (Vicente-Serrano et al., 2013).

The importance of summarizing variability in population abundances is ubiquitous throughout evolutionary ecology, particularly in comparing population dynamics and evaluating extinction risk. Previous studies considering multiple species assemblages of large herbivores in African savannas have generally shown that herbivore populations are variably influenced by rainfall, with grazers being more negatively affected than browsers following droughts (Ogutu & Owen-Smith, 2003). Rapid and large-scale shifts in ecosystem structure and function can result from mortality of forest and woodland plants in response to extreme climate events (McDowell et al., 2008).

1.2.3 Remote sensing of vegetation and its productivity

Relationships between species distribution and remote sensing derived variables, if known, can be used to predict the distribution of species over large areas (Debinski & Humphrey, 1997). Remote sensing is the primary tool for the synoptic analysis of habitats at a landscape scale. It allows researchers to address questions such as what elements are present, what spatial arrangements these elements have and what are their temporal dynamics (Quattrochi & Pelletier, 1991). Application of remote sensing in ecology can widen the understanding of vegetation dynamics and reduce costs for surveying large and remote areas. Remote sensing can be used as a tool for assessing the past and future biodiversity consequences of climate change and primary productivity.

Land cover classification is the basis for many environmental applications (Zhu & Woodcock, 2014). Remote sensing data with high temporal and spatial resolution and relatively low cost has become a reliable data source for land cover classification. However, such data sets can be affected by cloud cover, which can affects image selection.

Variation in topography and rainfall are one of the factors which determines the heterogeneity of savanna structure and function on different scales (Frost et al., 1986). Savanna ecosystem can be located in complex terrain. The landscape creates spatial niches for different types of vegetation through the effects of aspect, slope and curvature on the water and energy balance at the soil surface (Gutiérrez-Jurado et al., 2006) Therefore, spatial variation in slope and aspect is a key determinant of vegetation pattern, species distribution and ecosystem processes (Bennie et al., 2008). The slope and aspect strongly affects the amount of solar radiation intercepted by vegetated surface. Solar radiation determines the exposure of vegetation to photosynthetically active and ultra-violet wavelengths (Bennie et al., 2008).

Effective use of multiple features of remotely sensed data and selection of suitable classification method are especially significant for improving classification accuracy (Lu & Weng, 2007).To improve classification accuracy, spectral data can be combined with ancillary data (topographic data). This data can then be used as additional attribute information during classification process which will improve interpretability of image information and have influences in animal distribution as relief affects vegetation, eventually affecting their spatial distribution. Previous studies by (Lu & Weng, 2007; Varga et al., 2014) and (Ricchetti, 2000) have shown that topography data can improve classification accuracy. The Shuttle Radar Topography Mission (SRTM) data provides a high quality surface model which is widely utilized in many studies in geography (Gorokhovich & Voustianiouk, 2006) and estimate vegetation height across the landscape (Hofton et al., 2006). The use of SRTM can therefore improve the vegetation and land cover detection, and in some cases it can modify the absolute accuracy (Higgins et al., 2012).

Various indices that characterize drought as experienced by vegetation exist. Aboveground biomass has been related to mean annual precipitation (Sala et al., 2012), mean precipitation deficit (Ciaiset al.,2005) and others have related vegetation to radiation (Kirkpatrick & Nunez, 1980). Therefore, we need to predict possible vegetation responses to increased drought conditions. Differences in vegetation characteristics on surfaces with different slope and aspect, with different solar radiation determines the spatial variability in vegetation characteristics due to spatially variable drought conditions (Bartholomeus et al., 2012). Solar radiation is a key determinant of vegetation characteristics, not only at large spatial scales but also at local scales where slope and aspect may vary (Bennie et al., 2008).

Remote sensing offers reliable techniques for monitoring, assessing and estimating vegetation productivity over time. Satellite imagery data have been proved to be a very useful tool for estimating grass production (Biro et al., 2013). Previous studies have shown that vegetation indices derived from remotely sensed data are correlated to vegetation production in the ecosystem (Yeganeh, Khajedein, Amiri, & Shariff, 2012). Different vegetation indices such as Normalized Difference Vegetation Index (NDVI), Soil Adjusted

Vegetation Index (SAVI) and Ratio Vegetation Index (RVI) have been used in the above said studies to show the relationship between grazers' distribution and vegetation production. Correlation of vegetation production and vegetation indices have shown that vegetation productivity vary from time to time (Yeganeh et al., 2012) depending on different climate factors. The variations in vegetation productivity can be mapped and explained through hyper-temporal remote sensing image data collected over an area for different growing seasons.

By using NDVI, it has been shown that red and near –infrared (NIR) radiances can be used to monitor photosynthetically active green biomass above the earth surface. This is due to the existence of strong absorption by chlorophylls in the red channel and presence of high reflectance by leaf scattering mechanisms in the NIR channel (Tucker, 1979). The ability to use satellite data to detect drought conditions is based on spectral manifestation of reduced photosynthetic capacity of plant canopies and comparisons can be made between years in terms of the satellite-measured estimates of photosynthetic capacity(Tucker & Choudhury, 1987).

According to Onyango, (2015), trees, high shrub and woody areas have less variations in NDVI. Variability in NDVI detected through Standard Deviation (SD) shows how vegetation in the area deviates from the mean NDVI over time. When the SD is large it means that the vegetation cover is not in a stable over that period of time.

1.3 Problem statement

For biodiversity to be conserved, understanding how species and communities are likely to change under different conditions of climate change is essential. Such understanding is important because existing conservation networks will not perform adequately if species temporal turnover is not taken into consideration. Therefore, there is a need to identify the main vegetation types (i.e., forest, mixed woodland, and grassland) in the Laikipia-Samburu ecosystem to know which vegetation is present for herbivores species and it's response to climate change (drought).

To study the interaction between herbivores and vegetation types there is a need to identify herbivores and vegetation types of the study area. A detailed vegetation mapping is an important aspect of ecology because small-scale differences in topography and meteorological conditions cause significant differences in vegetation characteristics (Bennie et al., 2008).

Spatial resolution determines the level of spatial detail that can be observed on the earth surface. To describe the presence or absence of various vegetation types in Laikipia-Samburu ecosystem high resolution mapping is considered. High resolution mapping provides an effective way to depict land cover as it produces a map as a representation of the Earth's surface that is spatially continuous and highly consistent (Sun & Schulz, 2015). Using a coarser resolution satellite imagery can be a challenge in terms of vegetation accurate discrimination. A fine spatial resolution images reduce the mixed pixel problem, by providing a greater potential to extract more detailed information on land cover structure than medium or coarse spatial resolution data. To get a good discrimination of the vegetation types, a combination of spectral and spatial classification is especially valuable for fine land cover classification systems in the areas with complex landscapes (Lu & Weng, 2007). Spectral variation within the same land cover is common in complex landscapes with the high degree of spectral heterogeneity.

It is very important to understand the scales of impact driving vegetation productivity in herbivore ecosystem. The impact in vegetation productivity may reduce forage availability and also determining foraging behaviour and hence, herbivores distribution. WallisDeVries, (1996) has clearly shown that the spatial patterns of vegetation types can affect the the distribution of herbivores. The mapped Laikipia-Samburu vegetation types have to be asssessed after 2009 drought to know the impact of drought on vegetation productivity. Vegetation types respond differently to drought based on their phenology and primary productivity. . It is necessary to know the vegetation types that are affected by drought and whether are the one important to herbivores as source of forage. Moreover, relate to herbivores, they interact with vegetation differently during foraging based on their diet preferences. This can be illustrated by using time series MODIS NDVI 250m to quantify vegetation production from October to December (short rains season) from 2008 to 2012 (before, during and after 2009 drought) and relate to vegetation types.

Body size and feeding behaviour of Laikipia-Samburu herbivores should be known because changes in vegetation composition of the available vegetation may affect the animal's foraging behaviour (Hanley, 1997). The spatial distribution of vegetation is therefore likely to be important in determining forage behaviour and hence, herbivores distribution, depending on the frequency of forage patches and their location (WallisDeVries, 1996).

1.4 Research objectives

1.4.1 General objective

The overall objective of this study is to investigate impacts of the 2009 drought on vegetation productivity and spatial distribution of the herbivores in the Laikipia-Samburu ecosystem in Kenya.

1.4.2 Specific objectives

1. To map the three main vegetation types (i.e., forest, mixed woodland, and grassland) in the Laikipia-Samburu ecosystem in 2008 and 2012 using multi-season Landsat images and ancillary topographic dataset.
2. To examine the changes of the vegetation productivity of the three main vegetation types in the Laikipia- Samburu ecosystem between 2008 and 2012 using multi-temporal MODIS NDVI data.
3. To assess the abundance of herbivores in relation to the three main vegetation types in the Laikipia-Samburu ecosystem before and after 2009 drought.

1.5 Research questions

1. Can adding topographic data significantly improve mapping accuracy of the three main vegetation types in the Laikipia-Samburu ecosystem?
2. Are there any significant differences in vegetation productivity within the three main vegetation types before, during and after 2009 drought?
3. Are there any significant variability of productivity within the three main vegetation types between 2008 and 2012 due to the 2009 drought occurred in Kenya?
4. Are there any differences in abundance of herbivore species within the three main vegetation types before and after 2009 drought?
5. Are there any differences in abundance of grazers species within the three main vegetation types between 2008 and 2012?

1.6 Research hypotheses

1. **H_o:** Adding topographic data cannot significantly improve the mapping accuracy of the three main vegetation types in the Laikipia-Samburu ecosystem.

H_a: Adding topographic data can significantly improve the mapping accuracy of the three main vegetation types in the Laikipia-Samburu ecosystem.

2. **H_0:** There is no significant difference in NDVI within each of the vegetation types between 2008 and 2012 in the Laikipia-Samburu ecosystem.

   H_a: There is a decline in NDVI within each of the vegetation types after 2009 drought in Laikipia-Samburu ecosystem.

3. **Ho:** There is no significant difference in variability of NDVI between 2008 and 2012 within the three vegetation types.

   Ha: The variation in NDVI will be higher in 2012 compared to 2008 in mixed woodland and Grassland.

4. **H_o:** There is no significant difference in herbivores abundance within the three main vegetation types after 2009 drought

   H_a: There is a decline in herbivores abundance over all the three main vegetation types after 2009 drought.

5. **H_o:** There is no significant difference in medium grazers abundance and large grazers abundance within the three main vegetation types between 2008 and 2012.

   H_a: There is a decline in medium grazers abundance and large grazers within the three vegetation types between 2008 and 2012.

1.7 Structure of thesis and research approach

Chapter 1 consists of research background, explanation of research problem, the research objectives, questions and hypotheses. It also describe general research outline. Chapter 2 introduces the study area, data preparation, pre-processing and research approaches. Chapter 3 it explains the research findings in relation to specific research questions in Chapter 1. Chapter 4 discusses the methods of the study and the relevance of the results. Chapter 5 summarises the research and recommendations for further studies.

Figure 2 below shows the overall research approach framework. The research was mainly composed of mapping the ecosystem vegetation and regression analysis between vegetation types and herbivores abundance. Firstly, vegetation types were identified by using multi-seasonal Landsat images and topographic data. In addition, I used time series NDVI to study vegetation productivity trend between 2008 and 2012 for the short rains season for the Laikipia-Samburu ecosystem. Secondly, the ecosystem was assessed based on herbivores abundance in relation to identified vegetation types and vegetation productivity in 2008 and 2012 per grid of 2km by 2km. The population estimates were compared to confirm if the population had increased or decreased after 2009 drought within the three main vegetation types.

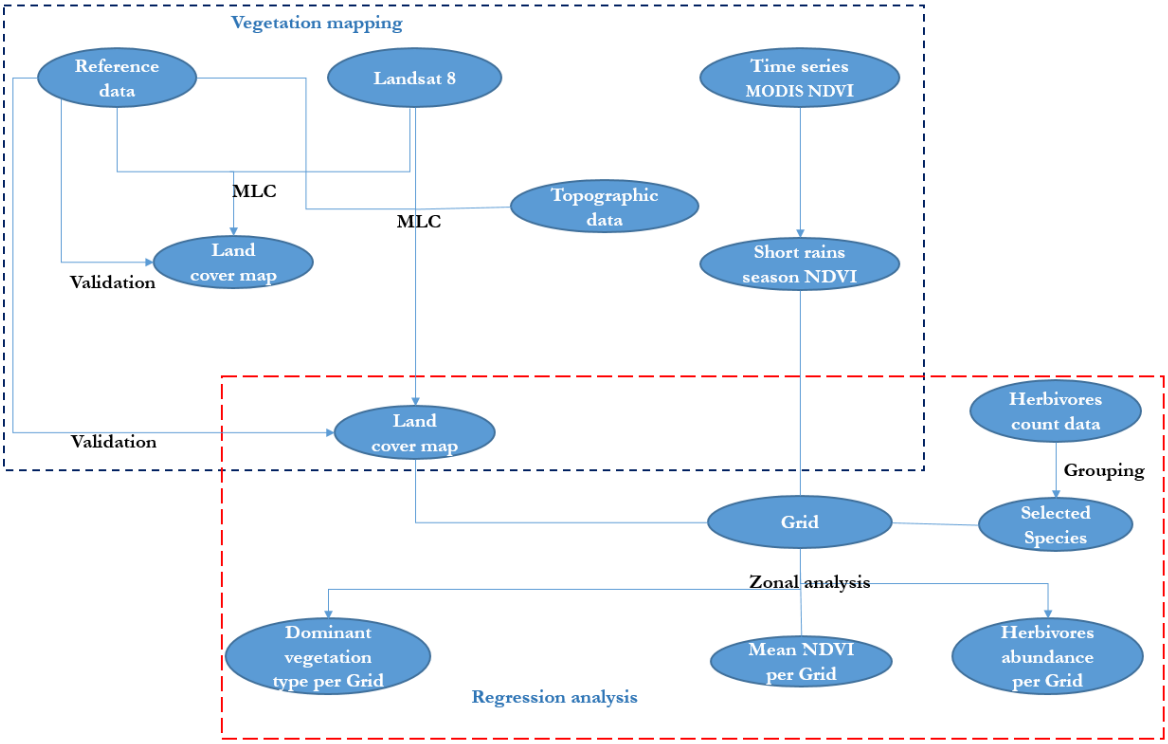

Figure 2 : Framework of the overall research approach

Lewa wildlife conservancy in Laikipia-Samburu ecosystem (Source: Google earth image)

Samburu National Reserve in Laikipia- Samburu ecosystem (Source: Google earth image)

2 MATERIALS AND METHODS

2.1 Study area

2.1.1 Geographic conditions

The study area is made of two counties, Laikipia and Samburu that are neighbouring counties on a high plateau in the rift valley province in central Kenya (Figure 3). Laikipia County (9666 km²) is adjacent to Samburu county on the north and located on the equator (36°11' - 37°24' E and 0°18' - 0°51' N). It consists of steep elevation and climatic gradient because of the presence of Mt. Kenya (5199m) to the southeast and high lands to the southwest. These uplands are drained to the north and form two perennial rivers, the Ewaso Nyiro and Ewaso Narok which continues to flow eastward through Samburu. While Samburu County covers 21 022 km² and borders the Ewaso Nyiro to the south (36°20' - 38°10' E and 0°40' - 2°50' N).

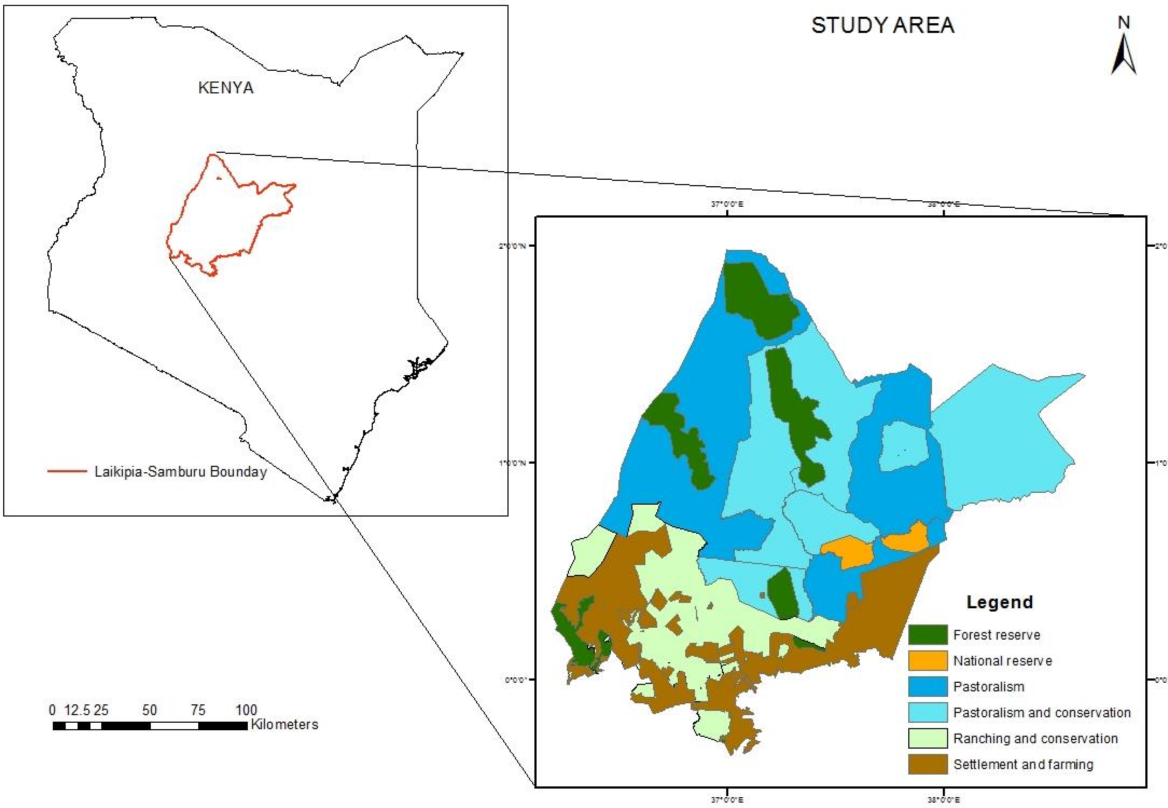

Figure 3 : Location of the study area (Laikipia-Samburu) in Kenya and its existing land use

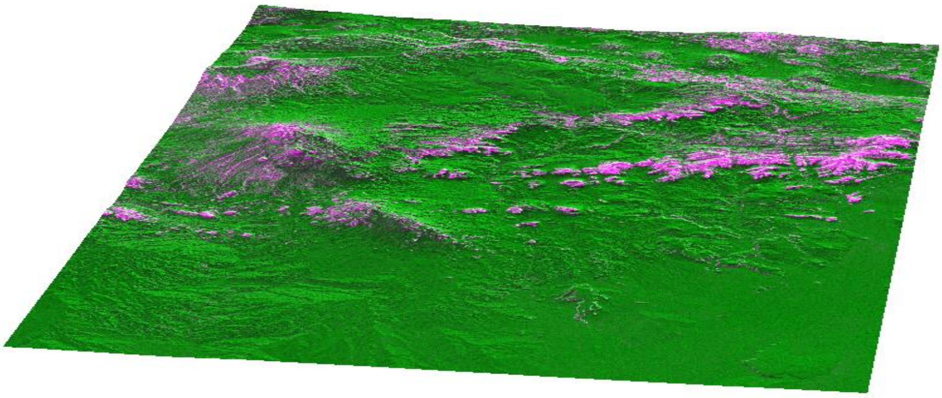

Figure 4: Three-dimensional map of the Laikipia-Samburu ecosystem showing topographic condition

The area is a typical dry savanna, hot and dry with highly variable bimodal rainfall which falls in April and November (Barkham et.al., 1976). Annual rainfall ranges from 400mm to 750mm in Laikipia and 250mm to 500mm in Samburu. Annual average temperatures ranging from 16°C to 26°C and 24°C to 33°C, respectively (Georgiadis et.al., 2007). The rainfall in Laikipia Samburu ecosystem varies along steep gradient, from 750mm in the Southern part of the plateau near Mt Kenya to 300mm in the lower northern part. This variation in altitude and rainfall has contributed to variation in land uses. Rainfall increases at higher elevations in the south and is weakly bimodal (Georgiadis et al., 2007). There was severe drought in 2009 in Kenya because of less rain from December 2008 and the long rains of February to April 2009 were severely depleted (Kioko, 2013). The study focus on year 2008, 2009 and 2012, whereby 2008 and 2012 are years of animal survey data that are non-drought years while 2009 is a drought year. Figure 5 shows annual rainfall trend in Laikipia-Samburu ecosystem from 1999 to 2014.

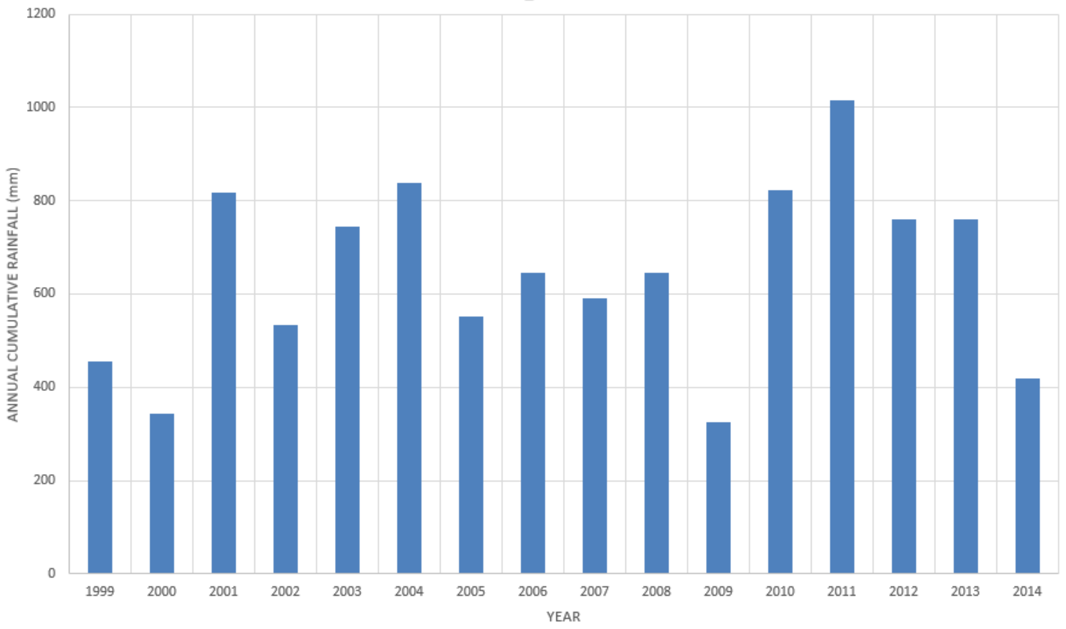

Figure 5: Annual cumulative rainfall in Laikipia-Samburu ecosystem (Mpala rainfall data from 1999 – 2014.

Laikipia-Samburu ecosystem is a home for many wild ungulate species such as Grevy's zebra (*Equus grevyi*), Grant's gazelle (*Nanger granti*), and reticulated giraffe (*Giraffa Camelopardalis reticulata*). Laikipia has the greatest wildlife abundance in Kenya after the Masai Mara National Reserve (Georgiadis et.al., 2007). Both wildlife and nomadic pastoral farmers use the same landscape in this ecosystem. Livestock production stands as the main livelihood for pastoralists and commercial ranchers (Campbell et.al., 2009) in Laikipia-Samburu ecosystem.

2.1.2 Vegetation cover and descriptions

The Laikipia-Samburu ecosystem is characterized by a number of habitat structures ranging from open grasslands to closed woody or bushy vegetation with varying amounts and composition of grass cover and grass species respectively (John et al., 2008). The Laikipia-Samburu climatic gradient is associated with land cover and land use changes, from alpine woodlands through protected montane rain forests, intensively cultivated moist zone, to relatively dry savanna grass and bushlands at low elevations (*https://www.expertafrica.com/kenya/Laikipia*). Laikipia County compose of agricultural and vegetation complexes through forest plantations, different bush land, grassland, dry forest and various marshy wetlands in the upland. While Samburu County is characterised by rangelands of wood savannah and open grassland. Therefore, the area is scrubby and open bush dominating most of the reserve areas with the fringing riverine forest of acacias, figs and palms extending from 50m to 200m from the river Ewaso Nyiro margins (*https://www.expertafrica.com/kenya/samburu-national-reserve*).

This Savanna is characterized by grasses and small or dispersed trees (scattered trees and shrubs) that do not form a closed canopy. Laikipia-Samburu ecosystem vegetation distinguishing features are as follows;

(1) Forest is usually dense and homogenous canopy of vegetation
(2) Mixed-woodland usually with low vegetation cover and partly clear areas, with some parts containing a mixture of trees, shrubs, grass and bare soil (Figure 6).
(3) Arable land is mainly paddy fields and minor areas of shrubs and trees
(4) Grassland is mainly grass and some few shrubs (Figure 7)

Figure 6: Mixed woodland (Source: Google earth image)

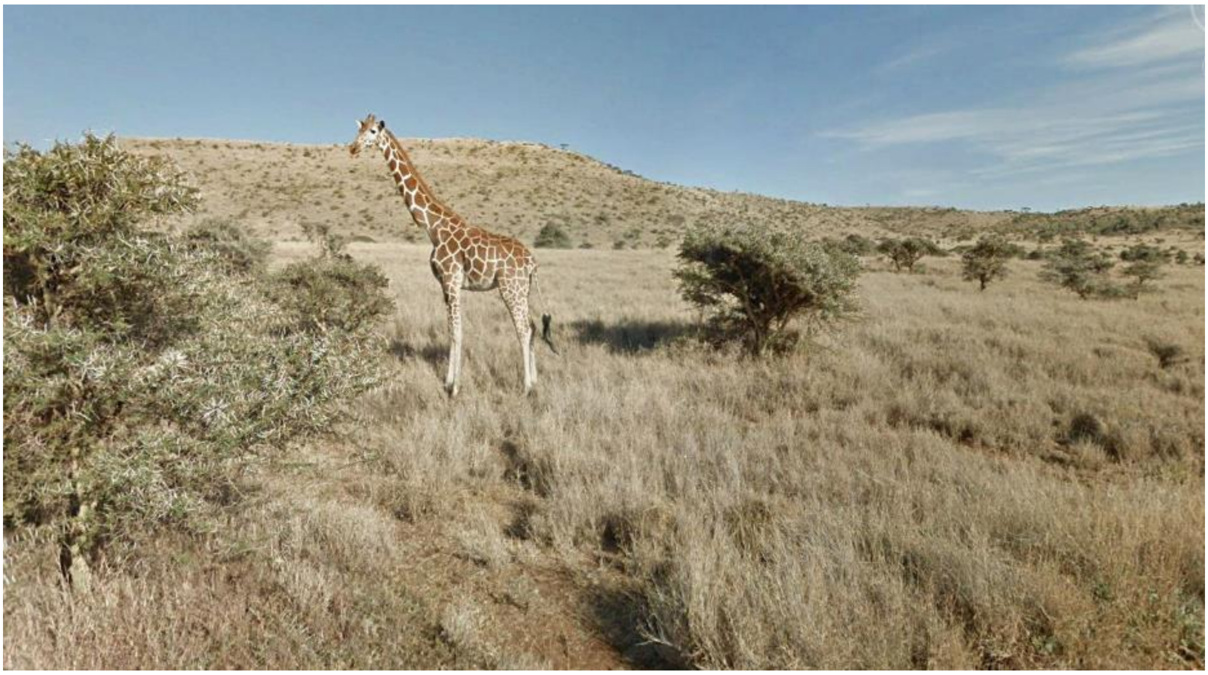

Figure 7 Grassland in Lewa wildlife conservancy (Source: Google earth image)

2.2 Data preparation and pre-processing

2.2.1 Animal data

- Count data

Animal count data was sourced from Kenya Wildlife Service (KWS). KWS carried out total aerial count surveys for large herbivores in November 2008 and November 2012, respectively. These aerial surveys were done following the method described by Douglas-Hamilton et al. (1994, 1997). They used 10 aircrafts in 2008 while 13 aircrafts were used in 2012 for surveys. Observations were saved using Global Position System (GPS) as waypoints with the geographical location referenced and used for species distribution maps (Litoroh et.al., 2010; Ngene et al., 2013). Data filtration was done to eliminate repetition of counts along block boundaries before analysis (Litoroh et al., 2010). Few photographs were taken as pilots circled complex herds for counting (Ngene et al., 2013).The ecosystem was surveyed using flight lines interval varying between one and two kilometres based on the visibility and terrain, but constant in direction and observed interval for each block when possible. In the Northern part of the area, the flight lines had wider spacing and these flight paths had various length to block delineations and topography. The census data is in point form represent herbivores heads per location (static data). The survey covered wildlife species, livestock and elephant carcasses. The focus of the survey was on large herbivores counting. Table 1 below shows the animal species both for 2008 and 2012 count surveys

Table 1: List of herbivorous animals identified during the aerial count surveys in 2008 and 2012

Species codes	**Species name**	**Scientific name**	**Average body mass** (Kg)	**Class**
BF	African buffalo	*Syncerus caffer*	590	Large grazer
DD	Guenther's dik dik	*Madoqua guentheri*	4	Small browser
DK	Ader's Duiker	*Cephalophus adersi*	9	Small browser
EL	African Elephant	*Loxotonta africana*	4000	Mixed feeder

ED	Common Eland	*Taurotragus oryx*	650	Large Mixed feeder
GR	Giraffe	*Giraffa camelopardalis*	1600	Large browser
GG	Grant's Gazelle	*Gazella granti*	65	Small Mixed feeder
GK	Greater Kudu	*Tragelaphus strepsiceros*	230	Medium browser
GN	Gerenuk	*Litocranius walleri*	44	Small browser
TG	Thompson Gazelle	*Gazella thomsonii*	25	Small Mixed feeder
IM	Impala	*Aepyceros melampus*	80	Medium Mixed feeder
LK	Lesser Kudu	*Tragelaphus imberbis*	75	Small browser
OX	Oryx	*Oryx gazella*	175	Medium grazer
WRH	White Rhinoceros	*Ceratotherium simum*	1850	Large browser
WB	Common Waterbuck	*Kobus ellipsiprymnus*	240	Medium grazer
WH	Common Warthog	*Phacochoerus africanus*	105	Medium-mixed feeder
RH	Black Rhinoceros	*Diceros bicornis*	1060	Large Browser
HP	Common Hippo	*Hippopotamus amphibius*	1500	Large grazer
ZB	Burchell's Zebra	*Equus burchellii*	280	Medium Grazer
GZ/ ZG	Grey's Zebra	*Equus grevyi*	400	Large grazer
KG	Red Hartebeest	*Alcelaphus buselaphus*	135	Medium grazer
BB	Bushbuck	*Tragelaphus scriptus*	72	Small Browser

Note: The classification of animal body size is based on Silva and Downing (1995); Owen-smith (1988)

- Animal species selection and grouping

Animal species selection and grouping was processed from animal count data. Population estimates reliability from aerial censuses is affected by counting errors and biases (Jolly, 2015). Due to vegetation cover, animal numbers are underestimated especially in thick and dense vegetation that cause visibility problems. Colour contrast between vegetation cover and animals can also have an influence on the number of animals counted (Dublin et al., 1990). Counting errors can be caused by misidentification especially with similar animals like Grant and Thomson's gazelles (Ottichilo et al., 2000). This may lead to increase in variance of survey statistics (de Leeuw, 1998). For further analysis, species such as Rhinoceros and Hippopotamus were excluded because they are the critically endangered species and only found in fenced areas. Other species like Guenther's dik dik and Ader's Duiker were also excluded because of underestimated numbers due to visibility during aerial counting as the surveys targeted large herbivores. Common warthog was excluded because of their visibility problems as they are found in thick and dense vegetation, their numbers were underestimated. Therefore, species selection and grouping was done to reduce errors. Animal species were grouped based on feeding behaviour and body size. Animal species were clustered into browsers, mixed feeders and grazers (Table 2). Browsers have a diet based around leaves for example the giraffe while grazers like buffalo; depend on the grass for their nutrition. However, in time of drought when grasses cover is poor the distinction between the two can become blurred because herbivores will eat any nutritious plant (http://www.krugerpark.co.za/Kruger_National_Park_Wildlife-travel/explore-kruger-park-grazers-and-browsers.html).

In addition, grazers were further grouped according their body size (Medium and large grazers) (Table 3). Species that were not covered by both years were excluded for further analysis like Bushbuck.

Table 2 : Species grouped based on their feeding behaviour (browsers and Mixed Feeders)

Browsers	**Mixed Feeders**
Giraffe	Common Eland
Kudu	Grant's gazelle
Gerenuk	Thomson gazelle
	Impala
	Elephant

Table 3 : Species grouped based on their body size

Large grazers	**Medium grazers**
African buffalo	Oryx
Grevy's zebra	Common waterbuck
	Burchell's zebra
	Red hartebeest

2.2.2 Satellite image collection and pre-processing

Atmospheric condition is always a challenge in satellite data. Frequent cloudy conditions in the Laikipia-Samburu regions was an obstacle for capturing high quality optical sensor data. However, a medium resolution images (30m Landsat 8) was preferred because this images had less cloud cover on the study area and are free. A 250m resolution time series MODIS NDVI was considered for providing a greater potential to extract more detailed information on vegetation productivity than a coarser spatial resolution data (500m or 1km). The NDVI data was estimated from the MODIS sensors because of its high temporal resolution with a wide range of wavelengths make it to be rich in information and reliable while Landsat data provide spatial detailed information to be used for land cover and land change studies.

- Landsat 8 data

Landsat 8 satellite images of 30m spatial resolution between 23rd May 2013 and 5th January 2015, was downloaded from the United States Geological Survey (http://glovis.usgs.gov/). These images are from path/row: 169/59 and path/row: 168/60. Considering the cloud cover (<10% cloud cover), 8 images were selected for further analysis. These images are already corrected to surface reflectance. The 8 images covered both dry and wet season as shown in Table 4. Spectral bands (1-7) were layer stacked and images were mosaicked into single raster using ENVI software. The Landsat 8 satellite image data was in WGS 84 projection. The images spatial extent was reduced to the area of study boundary through Subsetting in ENVI software. Then the subset images were used for land cover classification based on the training reference data collected from digital globe images in Google pro. Table 4 below shows list of Landsat 8 images for this study.

Table 4: List of Landsat 8 images used for land cover classification in this study

Acquisition date	Season	Source
5th January 2015	Dry	USGS
8th June 2013	Wet	USGS
3rd February 2014	Dry	USGS
23rd May 2013	Wet	USGS
25th January 2014	Dry	USGS
24th December 2013	Wet	USGS
25th January 2014	Dry	USGS
30th May 2013	Wet	USGS

- MODIS NDVI

Five years (2008 -2012) time series of 16 day composite MODIS 250m Normalized Difference Vegetation Index (NDVI) terra sensor data (MOD13Q1) were downloaded from NASA Land Processes Distributed Archive Center (LPDAAC), via USGS MODIS Reprojection Tool Web Interface (http://mrtweb.cr.usgs.gov). NDVI is based on the following equation;

NDVI= (nir-red)/ (nir+red)…………………….. Equation 1

Where **red** and **nir** are the surface reflectance values of the fisrt and second spectral bands of MODIS respectively.

Each time series consists of 23 composite dimensions. One tile (h21v08) of the MODIS data were aquired for the study area. For each composite, NDVI information was extracted. The NDVI images were stacked into mega file of short rains seasons months (October, November and December). These months were selected based on the time of herbivores surveys (November). This mega image was then projected from Sinusoidal to Universal Transverse Mercator projection zone 37N. And the images were then clipped through subset to the study area. The above processes were done in ENVI software.

To reduce pontential noise of clouds and outliers (Figure 8) but also keeping high fidelity of the data, the imgaes were cleaned and smoothed (Figure 9) using an modified version of adaptive Savitzky-Golay filter (ASAVGOL) (Beltran-Abaunza, 2009) in ENVI-IDL "NRS- Timeseries ". Seasonal mean (October, November and December) and standard deviation (October, November and December) of the cleaned data were computed in ENVI IDL for use in the analysis. Then zonal statistics were generated in arcGIS based on a 2 km by 2 km grid for use in the analsis (Zonal calculations). The data is necessary for this study for simulation of forage availability and forage variability (Pettorelli et al., 2005).

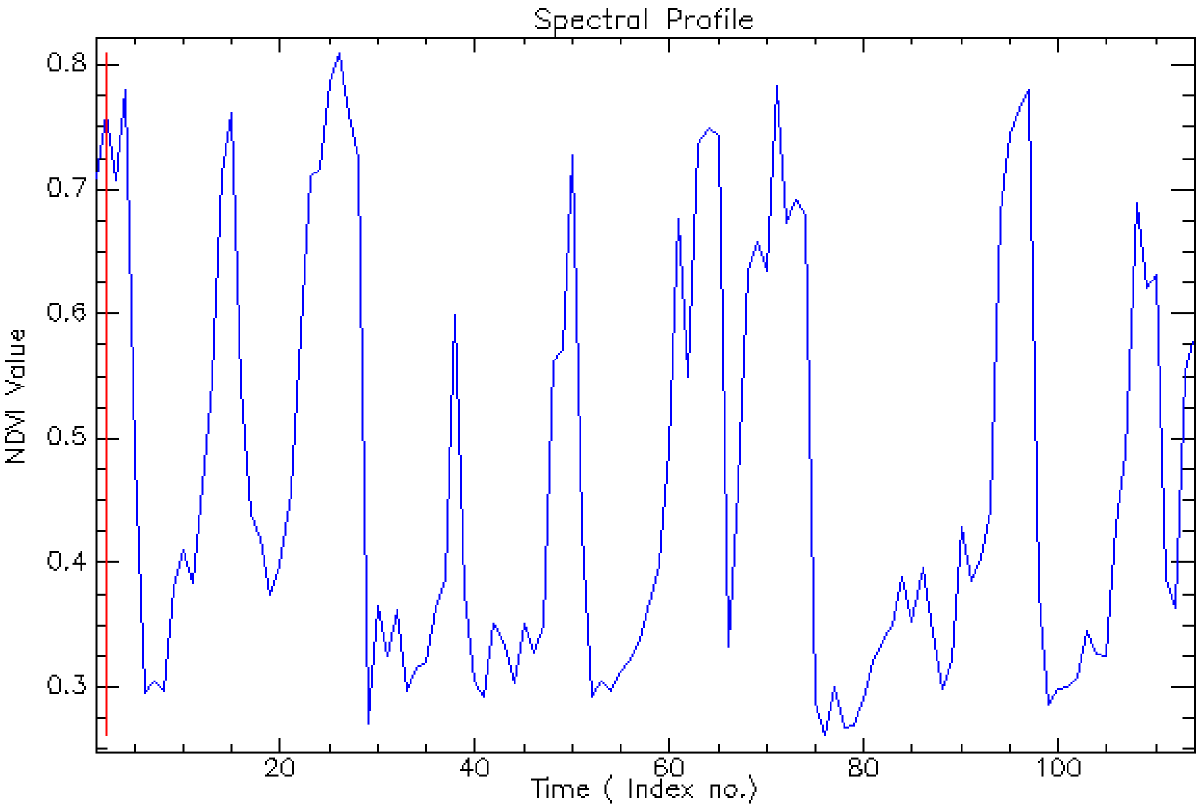

Figure 8: These are five years NDVI values plots of the original data in TIMESAT

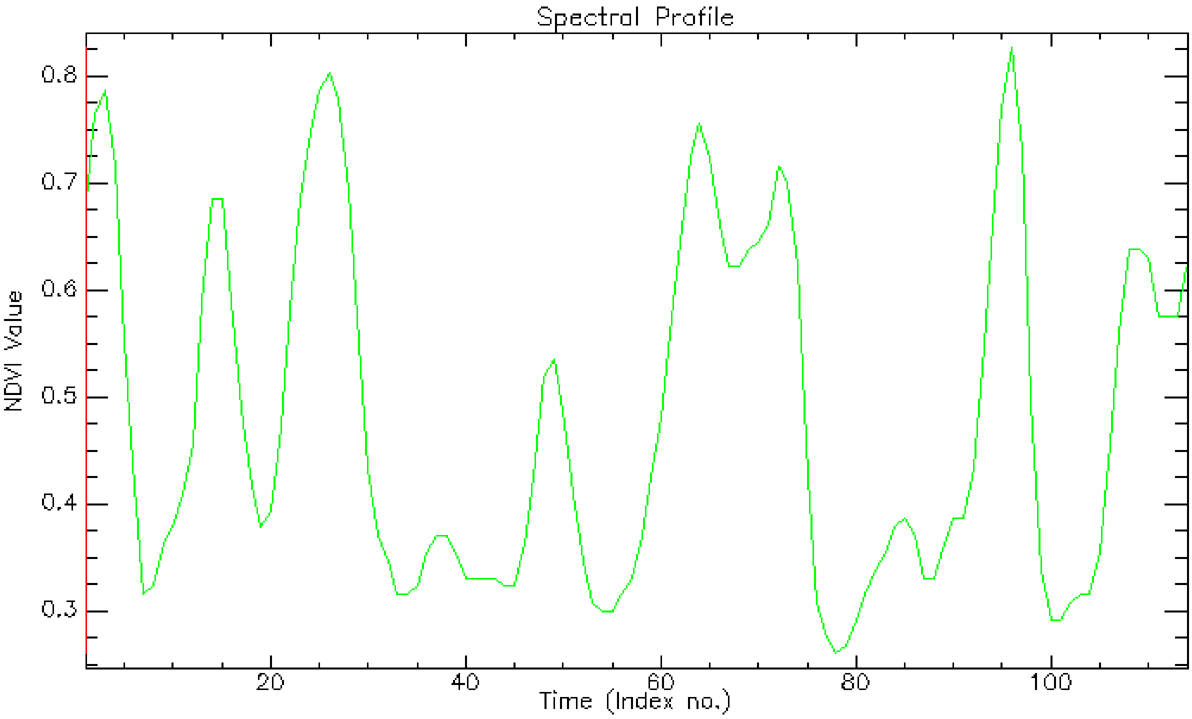

Figure 9 : These are five years plots of Smoothed data in TIMESAT

- Digital Evaluation Model (DEM)

The NASA Shuttle Radar Topography Mission (SRTM) DEM 30 m resolution was also downloaded from LP DAAC at projection of WGS 84. It was used to generate slope and aspect gradient of the study area, using topographic modelling in ENVI software. Using slope (degrees) (Figure 11) and aspect (degree) (Figure 11) as topo model parameters respectively. Both slope and aspect images was then combined with wet and dry season images by layer stacking in ENVI software for land cover classification.

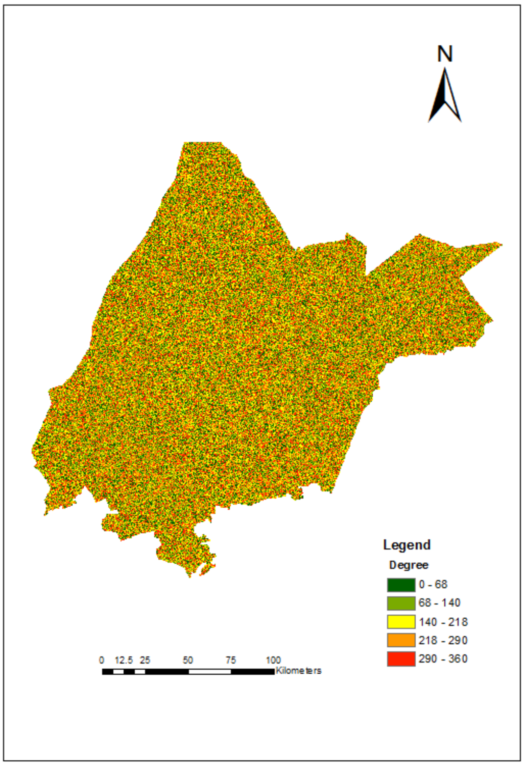

Figure 10 : Aspect map of the study area

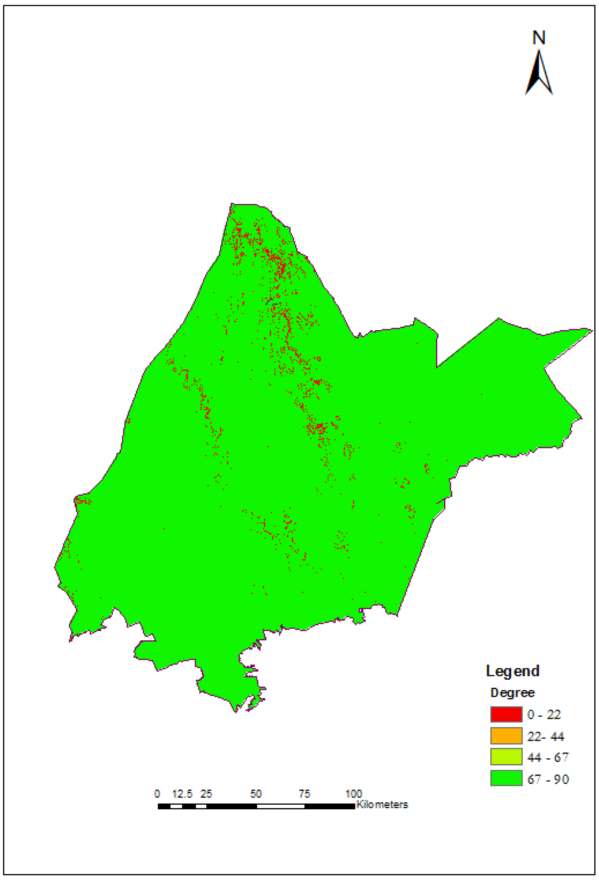

Figure 11: Slope map of the study area

2.3 Vegetation mapping

Selected remotely sensed data and image processing and classification approaches, might affect the success of a classification (Lu & Weng, 2007). Remote-sensing classification is a complex process and requires consideration of many factors. The major steps of image classification include determination of suitable classification system, selection of training samples, feature extraction, selection of suitable classification approaches, post classification processing, and accuracy assessment (Li et al., 2015). Distinguishing Savanna vegetation using satellite data is a challenge, mainly due to high structural and functional heterogeneity (Mishra & Crews, 2014). Vegetation in savanna ecosystem has large reflectance variation and cloud-free images is limited in wet season as compared to dry season. Therefore combining and classifying images for different dates, season or year as multi-temporal can improve land cover classification accuracy. Information from different seasons helps to discriminate between vegetation types based on information available at different times of the year. Hence, multi-season images were used for optimal vegetation discrimination.

Classification results of spectral data can be improved by taking into account other object attributes such as topographic data. This study will evaluate the effectiveness of using topographic data to improve the interpretability of image information, and classification of spectral data for vegetation types. A sufficient number of training samples and their representativeness are critical for image classifications (Chen & Stow, 2002). The landscape of the study area is complex and heterogeneous therefore selecting sufficient training samples becomes difficult. However, three main vegetation are considered while scrubland was treated as part of grassland and mixed woodland because it not easy to differentiate it from grassland and mixed woodland, using satellite images.

- Sample selection

The existing vegetation map for Kenya was download from International Livestock Research Institute (ILRI) GIS Portal. It was used as a reference data, these data was collected by German Agency for Technical Cooperation (GTZ) in collaboration with Kenya Ministry of Agriculture, livestock development and Marketing in 1994. Department of Resource Surveys and Remote Sensing (DRSRS) converted these data into a GIS database in 1994 (*http://data.ilri.org/geoportal/catalog/main/home.page*). This dataset portrays vegetation at a scale of 1:500,000. Then we reduced the spatial extent to the region of interest by using the study area boundary.

Using Analysis tools for ArcGIS 10.3.1 software 450 random samples were generated. Random selection eliminates sampling biases and corresponding criticisms encountered when samples are selected non-random. The sample points were transferred to google earth pro to overlay with digital globe images (high-resolution images) (2006 to 2010 images) to identify the study area classes. The digital globe images with clouds cover of < 10% were selected for sample selection. Then manual classification (visualisation) was done based on high-resolution data. To identify and distinguish land cover classes within the study area. Sample points that fall on areas covered by clouds were also eliminated. To ensure sample representation of each land cover class, each sample location must be at the central point of the homogenous land cover representing the dominant land cover type. Then from this dataset, a portion was selected to train the classification (60%) and another random portion for the validation.

Collection strategies such as single pixel, may be used , but they would influence classification results, especially for classification with fine spatial resolution image data (Chen & Stow, 2002). Therefore, selection of training points, samples must consider the spatial resolution of the remote sensing data being used and the complexity of landscape in the study area. Three dominant vegetation types (mixed woodland, grassland and forest) were identified using high-resolution Digital globe images in Google earth pro. A total number of 400 samples were considered (60% training and 40% validation) for further analysis.

2.3.1 Classification with maximum likelihood classifier

Landsat 8 satellite images were used to classify land cover of Laikipia-Samburu ecosystem into three main vegetation types according to Table 5 below. Supervised classification method was used by applying maximum likelihood classifier (MLC) that is based on parametric density distribution model. MCL was used because of its advantages over other classification techniques such as feasible assimilations, logical interpretations and simple realizations. MLC has been widely applied in remote sensing and it is based on assumptions that the training samples are normally distributed in spectrum space. Classification was done to categorise image pixels into classes by providing training data and using MLC in ENVI software. Majority filter was applied to smooth the classification. Therefore, it changed the spurious pixels within single class to that class. Smooth Kernel size 3 by 3 pixels was used, centre pixel in the kernel was replaced with the class value that the majority of the pixels in the kernel has.

Table 5: Reference data for land cover classification

CLASS	**Training Pixels**	**Testing pixels**	**TOTAL**
Arable land	53	31	84
Forest	50	30	80
Mixed woodland	53	31	84
Grassland	54	30	84
Others	54	30	84
Total	264	152	416

The same classification procedure was followed for classifying Landsat 8 satellite images combined with topography data (Slope and aspects). Trying to improve the mapping accuracy of the three main vegetation types in the ecosystem.

2.3.2 Accuracy assessment

The accuracy of the classification was assessed using 152 testing samples (40% of total samples) chosen with the stratified random method to represent different area land cover classes with the probability of selection within classes (Congalton, 1991). In any land-cover mapping procedures, it is essential to evaluate the performance of the designed classification method and it gives a chance to experts to have a degree of confidence to the results. This study adopted the commonly used accuracy assessment method in remote sensing, confusion matrix/error matrix. It shows the proportions of correctly classified (overall accuracy) and misclassified pixels in a table matrix. Overall accuracy and kappa statistics are used as quality measures. They are a consequence of producer and user accuracies. The user's and producer's accuracies varied, the user's accuracy and producer's accuracy for forest were relatively stable and higher than those of grassland and mixed woodland (Table 6 & 7). After adding topography data, grassland user's accuracy had a higher increase than other vegetation classes (13.43%). This may suggest that grassland can be better discriminated when considering topographical data. Grassland class also caused most error as compared to other vegetation classes (Table 6 & 7). However, this misclassification may lead to misinterpretation on spatial herbivores abundance interaction with vegetation types. Kappa statistics is useful in evaluating different remote sensing methods because it accounts for the degree of accuracy that can be attained when labels are assigned at random. According to, Cohen, (1960) Kappa coefficient ranges from 0 to 1 and higher value shows better performance. These was done for both the first classification (Landsat 8 images without topographic data) and second classification (Landsat 8 images combined with topographic data).

Table 6: Confusion matrix derived measures of classification accuracy for Landsat 8 multi-season images classification

Classified data	Reference data					
	Forest	Arable land	Mixed woodland	Grassland	Others	Total
Forest	28	0	0	0	1	29
Arable land	0	30	2	4	5	41
Mixed woodland	2	0	24	4	3	33
Grassland	0	1	5	22	0	28
Others	0	0	0	0	21	21
Total	30	31	31	30	30	152

Producer's acc. (%)	93.33	96.77	77.42	73.33	70.00	
User's acc. (%)	96.55	73.17	72.73	78.57	100	
Overall acc. (%) =82.2						
Kappa coefficient = 0.78						

Table 7 : Confusion matrix derived measures of classification for Landsat 8 multi-season images combined with topography data classification

Classified data	Reference data					
	Forest	Arable land	Mixed woodland	Grassland	Others	Total
Forest	29	0	0	0	0	29
Arable land	0	29	2	3	2	36
Mixed woodland	0	0	29	3	3	35
Grassland	0	1	0	23	1	25
Others	1	1	0	1	24	27
Total	30	31	31	30	30	152
Producer's acc. (%)	96.67	93.55	93.55	76.67	80.00	
User's acc. (%)	100	80.56	82.86	92.00	88.89	
Overall acc. (%) =88.2						
Kappa Coefficient = 0.85						

2.4 Determining the relationship between herbivores and vegetation

Herbivores abundance was defined by using a 2 km by 2 km grid that was adopted based on the size of flights lines intervals, which were used during 2008 and 2012 total aerial count surveys. The flights lines intervals varied between one and two kilometres based on the visibility and terrain, but constant in direction and observed interval for each block when possible. Therefore, the finer resolutions was resampled to coarser resolution of two kilometres to adopt same resolution scale. Herbivores species data is in point form representing more than one animals therefore as per representation of a 2 km by 2km grid.

The land cover map (30m resolution data) was downscaled to 250m resolution, to have a similar resolution as the NDVI maps. This was done using data management toolbox in ArcGIS 10.3.1 software. Resampling is necessary when one raster is at a finer resolution than the other, therefore, the finer resolution raster (Landsat 30m) is resampled to the same resolution of the coarser one (MODIS 250m), making all the raster datasets the same resolution. Using a 2km by 2km grid a dominant vegetation cover was assigned per grid as a representative of vegetation type for that grid. Zonal calculations were also done to extract mean NDVI per grid and NDVI standard deviation per grid.

Therefore, vegetation and animal data was linked using this 2km by 2km grid. Within a grid, dominant vegetation cover, mean NDVI (before, during and after drought), NDVI standard deviation (SD) (before, during and after 2009 drought) and herbivores abundance were generated for further analysis (Figure 12). It is advisedly to use dominant cover and mean NDVI (short rains season NDVI) for the location (per grid) because animals data are in point form as a representation of the whole grid. In addition, a mean NDVI per grid was calculated to represent that location. Mean NDVI was used as a representation of a grid to match the animal data.

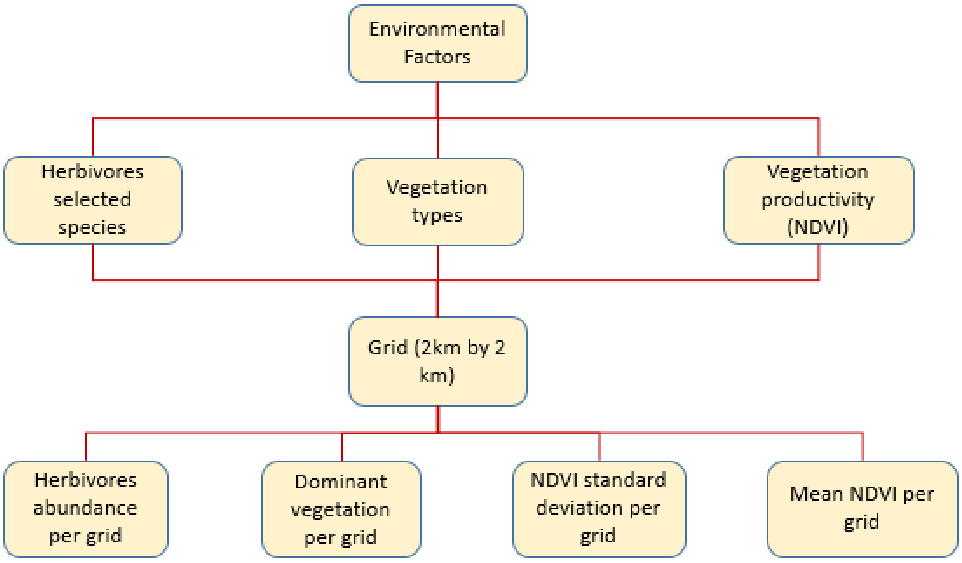

Figure 12 : Structure of environmental factors used in assessment of herbivores abundance and vegetation in the Laikipia-Samburu ecosystem

2.5 Statistical analyses

- Assessment of the normality of data

Assessment of the normality of data is a prerequisite for many statistical tests because normal data is an underlying parametric testing. The graphically and numerically methods are used in assessing normality. The approach can rely on statistical tests or visual inspection. Statistical tests have the advantage of making an objective judgement of normality, but sometimes cannot be sensitive enough at low sample sizes or overly sensitive to large sample sizes. Graphical interpretation allow good judgement to assess normality in situations when tests might be over or under sensitive, but graphical methods do lack objectivity.

For this study, to determine normality graphically we used the output of a normal Q-Q plot. If the data are normally distributed, the points will be close to the diagonal line. If the data points stray from the line in an obvious non-linear fashion, the data are not normally distributed. This was applied for both vegetation productivity and herbivores data normality assessment using SPSS Statistics.

As presented by the Figures below (14, 15 and 16) of Normal Q-Q plots, the vegetation productivity data is not normally distributed, the data points for both years are deviating from Normal way.

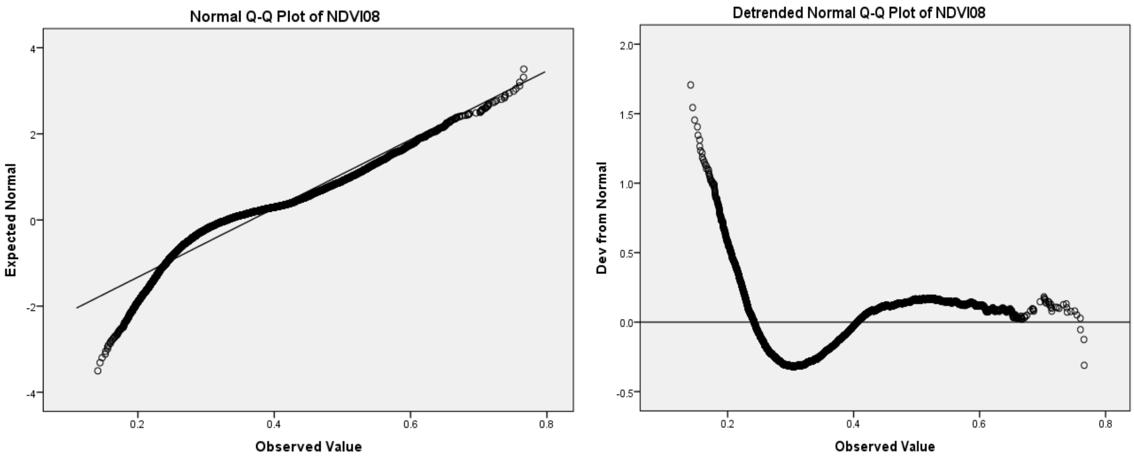

Figure 13 : Shows how vegetation productivity values in 2008 are expected to look like in a normal way (left side) and how they deviate from normal way (right side).

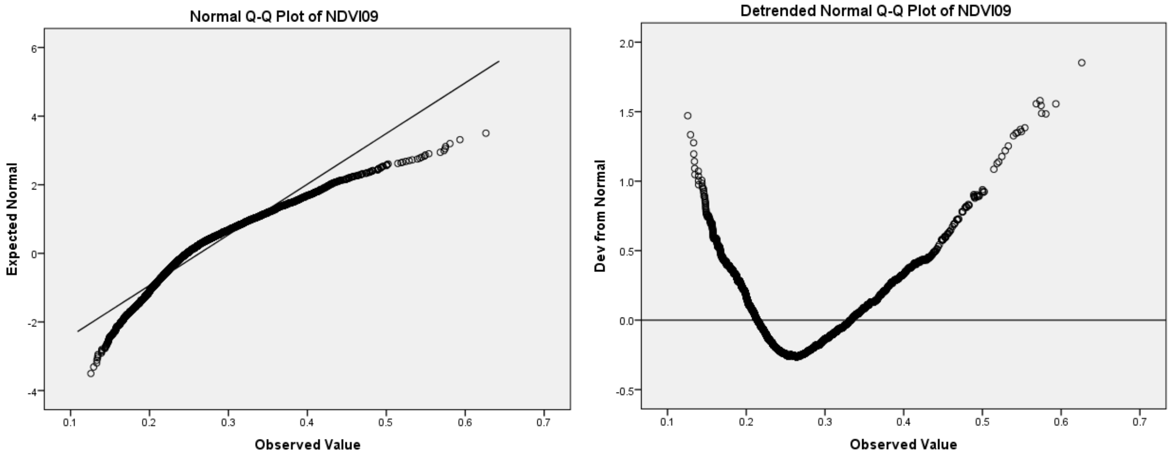

Figure 14: Shows how vegetation productivity values in 2009 are expected to be normal (left side) and how they deviate from normal way (right side).

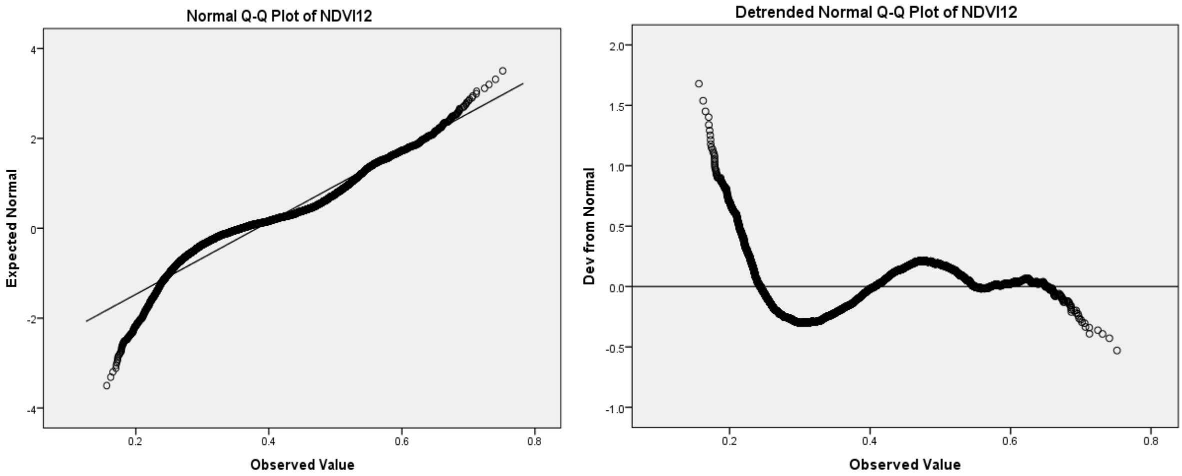

Figure 15 : Shows how vegetation productivity values in 2012 are expected to be normal (left side) and how they deviate from normal way (right side)

As presented by the Figures below (16 and 17), both 2008 and 2012 herbivore estimates are not normal distributed, both estimates deviate from normal distribution.

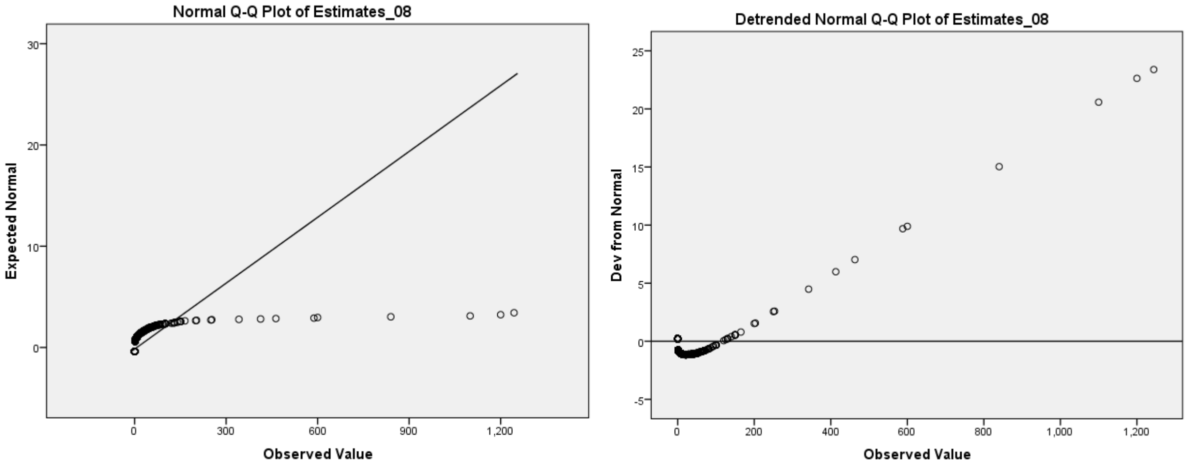

Figure 16 : Show how 2008 herbivorous estimates are expected to be distributed in a normal way (left) and how they deviate from normal distribution (right)

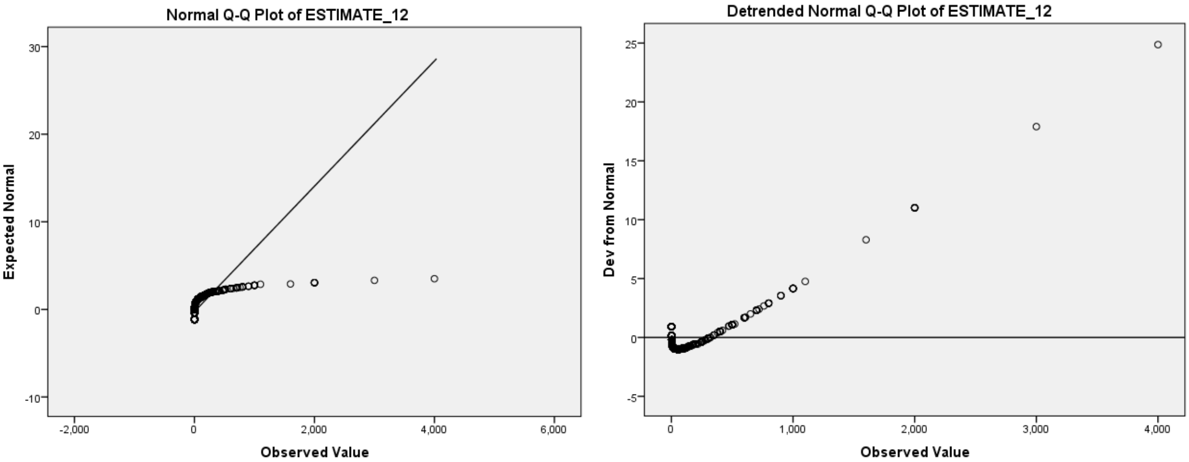

Figure 17 : Shows how herbivorous estimates are expected to be distributed in normal way (left) and how they deviate from normal distribution

Based on the above normality assessment, a non-parametric testing is considered for both vegetation and herbivores data. Figure 18 below was followed to choose a statistical test to use for further analyses.

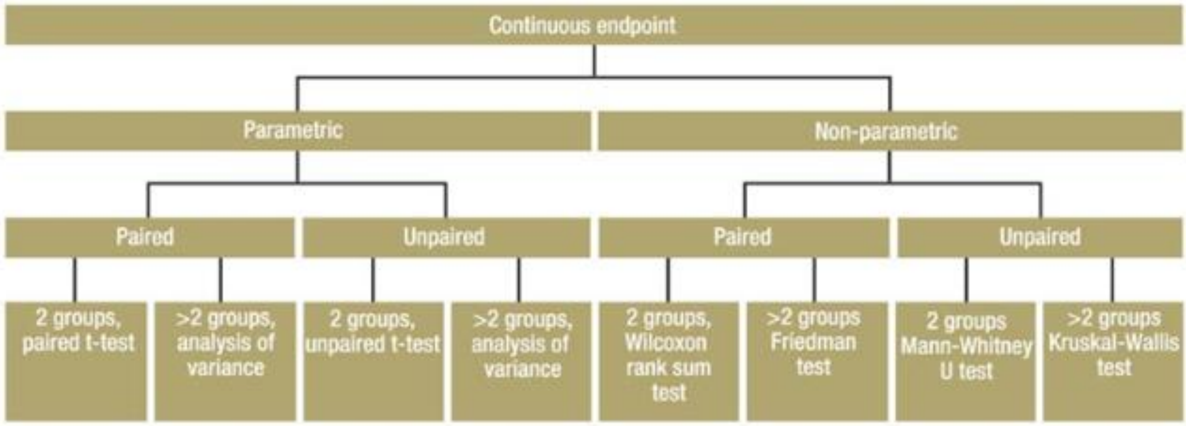

Figure 18: Algorithm for test selection for group comparison of continuous endpoint (du Prel, Röhrig, Hommel, & Blettner, 2010)

- Statistical tests

For Null hypothesis that adding topographic data cannot significantly improve the mapping accuracy of the three main vegetation types was tested using Kappa calculation and Z-test. It was used to check significance difference of the classified maps based on accuracy parameters.

The null hypothesis that the NDVI within each of the vegetation types were not different between 2008, 2009 and 2012 was tested using Friedman test to pick short-term decline in NDVI caused by drought. The test was also applied for variability of productivity within the three main vegetation types. However, it does not pinpoint which groups in particular differ from each other. Then post hoc test was applied by using a Bonferroni adjustment on the results from the Wilcoxon tests to avoid Type I error (declaring a result significant when it should not). When using the Bonferroni adjustment, the initially significance level (0.05) is divide by number of tests to run. Therefore, in this case we have a new significance level of .05/3= 0.017. This means that if the p-value is larger than 0.017, we do not have a statistically significant result. Observations were selected randomly to create a subset to get a more representative set (half of the observations), because small data set increases the risk of a type-I error (not rejecting the null hypothesis while you should) and a large dataset increases the risk of a type-II error (rejecting null hypothesis while you should). Wilcoxon Signed-rank test was conducted in R program.

To examine where the differences actually occur, Wilcoxon signed-rank tests was done separately on the different combinations of related groups. Therefore, i compared the following combinations:

1. NDVI 08 to NDVI 09
2. NDVI 08 to NDVI 12
3. NDVI 09 to NDVI 12

The Wilcoxon Signed-rank test, as a non-parametric equivalent of a paired t-test, was also used to compare the differences in population estimates before and after drought within the three main vegetation types. It was used to pick short-term decline in population estimates caused by drought. This applied at significance level of 0.05.

3 RESULTS

3.1 Vegetation mapping and accuracy assessment

Vegetation classification maps are presented in Figure 19; displaying the land cover classification with multi-season images without topographic data and figure 20; displaying land cover classification with multi-season images combined with topography data. In Figure 19, classification results obtained an overall accuracy of 82.2% and a kappa coefficient of 0.78 (Table 6). The map shown by Figure 20, After adding topography data (slope and aspect) overall accuracy raised to 88.2% and kappa Coefficient of 0.85 (Table 7). However, there is visual difference between Figure 19 and 20. This classification of land cover results is good and accurate enough to be involved in the further analyses of herbivore and vegetation interaction.

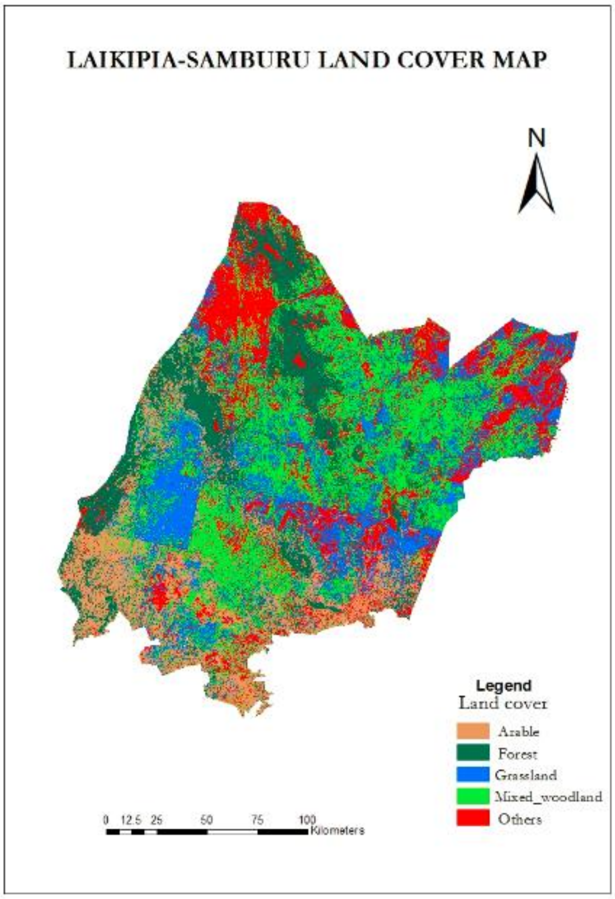

Figure 19 : Land cover map after multi-season classification without topography data

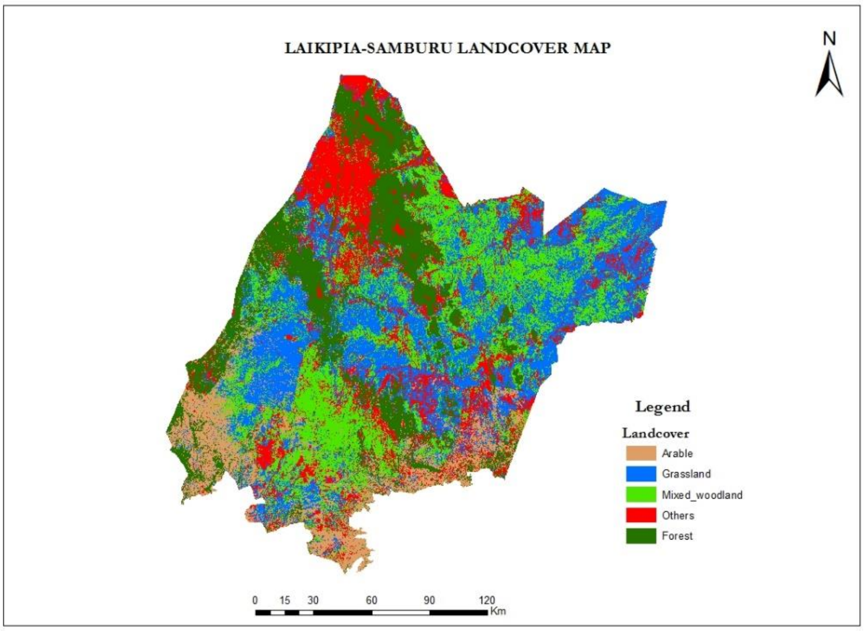

Figure 20: Land cover map after multi-season classification with topography data included

Using Z-test for kappa coefficients to test the significant difference between the two maps, results did not show any significant difference between land cover classification map generated without topographic data and the one where topography was incorporated. The calculated Z value was 1.42 which was less than t=1.96 ($\alpha = 0.05$).

3.2 Change of vegetation productivities for the three vegetation types before, during, and after the drought

To compare vegetation productivity, Friedman test was used to test if there were statistically significant differences in vegetation productivity before, during and after drought within the three vegetation types (grassland, mixed woodland and forest) and results are presented in Table 8. The result show that there is high significant difference of vegetation productivity between the three vegetation types at significance level of $p \leq 0.05$ leading to a conclusion that the mean of NDVI within each of three vegetation types before, during and after are not equal (*p* = 0.001). However, is not possible tell which group or groups are different from the other. Boxplots were constructed to visualize the change in NDVI before, during and after drought (Figure 21).

Table 8 : Table showing the significance results using Friedman Test

Test Statistics[a]

N	4339
Chi-Square	6445.549
df	2
Asymp. Sig.	0.001

a. Friedman Test

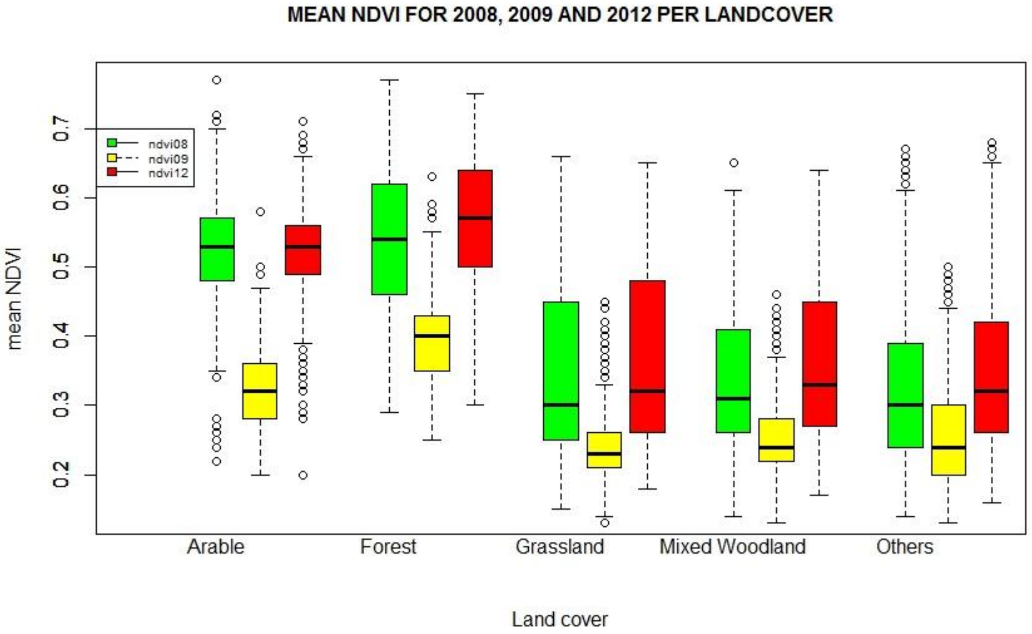

Figure 21 : Boxplots showing vegetation productivity before, during and after drought within the three main vegetation types

Since the group mean NDVI of the three vegetation types are different, a post hoc test analysis was carried out for comparisons of vegetation productivity data. The Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in significance level set at $p<0.017$. Results show that there was significant decline in vegetation productivity between 2008 and 2009 within the three vegetation types ($p < 0.001$) as presented in table 9. Significant decline was also detected in vegetation productivity between 2009 and 2012 within the three vegetation types ($p < 0.001$). However, significant change in vegetation productivity between 2008 and 2012 was not detect in grassland and mixed woodland ($p = 0.060$ and 0.028 respectively). This may suggests that grassland and mixed woodland may have recovered over time from drought, while there was also significant decline in forest productivity between the same period ($p = 0.007$). This may suggests that forest might have been recovering slower than the grassland and mixed woodland over time from drought.

Table 9 : Wilcoxon test results for mean NDVI significance difference for the three vegetation types

Vegetation types	2008NDVI and 2009NDVI	2008 NDVI and 2012 NDVI	2009 NDVI and 2012 NDVI
Grassland	$p < 0.001$	$p = 0.060$	$p < 0.001$
Mixed Woodland	$p < 0.001$	$p = 0.028$	$p < 0.001$
Forest	$p < 0.001$	$p = 0.007$	$p < 0.001$

There variability of vegetation productivity for the whole study period was tested whether there were differences in variability of NDVI within the three vegetation types also using the Friedman test. Results showed that there was a significant variation of NDVI within the three vegetation types using the standard deviation approach as presented in Table 10. The post hoc analysis with Wilcoxon signed-rank tests was then used to check the significant difference in standard deviation of the three vegetation types at significance level of 0.017. Standard deviation between 2008 and 2012. Boxplots were constructed to visualise standard deviation of vegetation productivity within the three vegetation types between 2008 and 2012. Results show that there is no significant difference between the mean NDVI standard deviation within the three vegetation types between 2008 and 2012 as presented in figure 22.

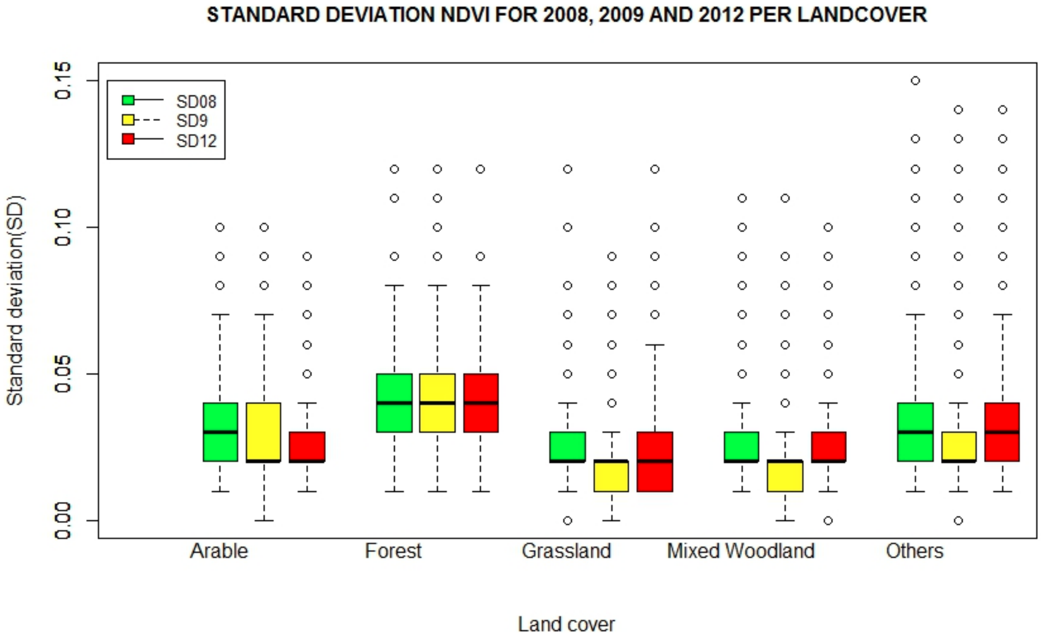

Figure 22: Boxplots of NDVI standard deviation for the three main vegetation types before, during and after drought.

The Test Statistics presented in Table 10 show the overall statistically differences in variability of NDVI between 2008 and 2012 within the three vegetation types (*p* = 0.001), but it does not shows which groups in particular differ from each other.

Table 10 : The table shows the significance results of using Friedman Test

Test Statistics[a]

N	4339
Chi-Square	7149.763
df	2
Asymp. Sig.	0.001

a. Friedman Test

The post hoc tests results are presented in table 11. The Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in significance level set at p<0.017. There was a statistically significant difference in variability of vegetation productivity within grassland and mixed woodland between 2008 and 2009 then 2009 and 2012 (*p* < 0.017). This may suggest that vegetation was not in a stable state over that period. There was no significant difference in variability within the three vegetation types between 2008 and 2012 there, suggesting that vegetation cover was in a stable state over time.

Table 11: Wilcoxon test results for significant differences in variability of mean NDVI within the three vegetation types.

Vegetation types	2008 SD and 2009 SD	2008 SD and 2012 SD	2009 SD and 2012 SD
Grassland	$p = 0.006$	$p = 0.499$	$p = 0.011$
Mixed Woodland	$p = 0.001$	$p = 0.102$	$p = 0.012$
Forest	$p = 0.095$	$p = 0.274$	$p = 0.668$

3.3 Change of herbivores abundance within the three vegetation types before and after the drought

The Null hypothesis that the herbivore estimates were not significantly different before and after 2009 drought was tested using Wilcoxon-test, to pick short-term decline in herbivore numbers, with significant level set at P-value of 0.05. A non- parametric was used because the population estimates were not normally distributed. Figure 23 shows plots of herbivore estimates within the three main vegetation types against time during the study period. Then we tested whether there was change in herbivores abundance within the three vegetation types after 2009 drought. In 2008 overall herbivores numbers within the three main vegetation types were 23 685 animals, 4 661 browser, 4 444 mixed feeders and 14 580 grazers. The number reduced to 11 741 animals within the three main vegetation types in 2012 after the 2009 drought, which can also be seen in figure 23.

The population of herbivore species consistently declined after the drought, although there was an increase of browsers and grazers in forest which increased by 12.3% and 29.8% respectively. In grassland, mixed feeders were more affected with a population decline of 66.1%, followed by grazers with 46.7% decline and browsers with a decline of 40.6%. There was a significant decline in grazers and mixed feeders ($p = 0.001$ and $p = 0.002$ respectively) in grassland as shown in Table 12, while there was no significant change in the population of Browsers ($p = 0.090$) at significance level of $p \leq 0.05$.. This suggests that the population of browsers may have remained stable over time in Grassland.

Grazers were mostly affected in mixed woodland with a decline of 70.6%, followed by mixed feeder with a decline of 46.1% and browsers with a decline of 19.3%. Grazers and mixed feeders significantly declined with p-value of 0.004 and 0.001 respectively while there was no significant change in the population of Browsers over time ($p = 0.074$) as presented in Table 12. It suggests that population of browsers may also have remained stable in mixed woodland.

There was no significant change in the populations of both groups (browsers, grazers and mixed feeders) in forest ($p > 0.05$) (Table 12). This suggests that the population of these groups may have remained stable over time. The null hypothesis, that populations of herbivores were not significantly different before and after 2009 drought was rejected and we conclude that grazers and mixed feeders significantly declined. This suggest that grazer and mixed feeder numbers may have been unstable between before and after 2009 drought.

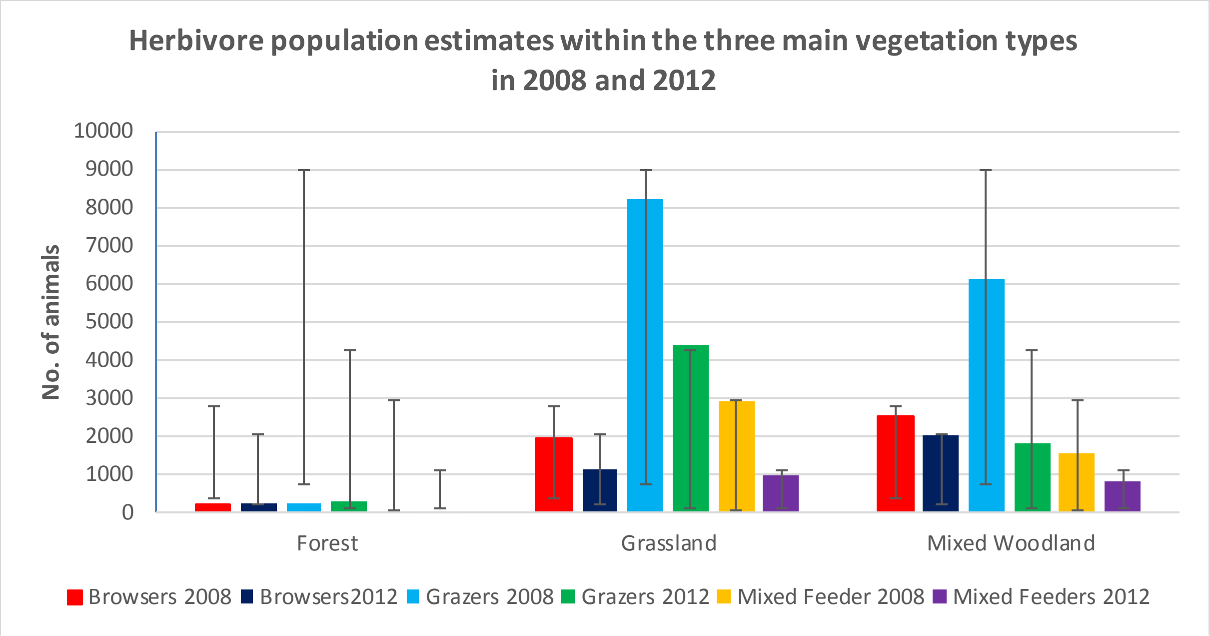

Figure 23: Herbivore estimates within three main vegetation types in 2008 and 2012

Table 12: Wilcoxon test significance differences results for herbivores estimates within the three main vegetation types before and after 2009 drought

Vegetation types	Browsers 2008 and Browser 2012	Grazers 2008 and Grazers 2012	Mixed Feeders 2008 and Mixed Feeder 2012
Grassland	$p = 0.090$	$p = 0.001$	$p = 0.002$
Mixed Woodland	$p = 0.074$	$p = 0.004$	$p < 0.001$
Forest	$p = 0.543$	$p = 0.430$	$p = 0.563$

Null hypothesis that the population estimates for medium and large grazers were not significant different before and after 2009 was tested using Wilcoxon-test, to pick short-term decline in grazers caused by 2009 drought. A non- parametric was used because the population estimates were not normally distributed. Total number of gazers were 14 580 in 2008 and decreased to 6 502 grazers in 2012 after the 2009 drought. Medium grazers were mostly affected and declined by 58.1% while larger grazers declined by 38.7% which can also be seen in figure 24. The large and medium grazers population declined in grassland and mixed woodland while in forest their population of large grazer increased by 97.8% and medium grazers declined by 50.8%.

In grassland, there was significant decline in medium grazer estimates ($p = 0.001$) while there was no significant change in large grazers ($p = 0.070$) as shown in Table 13. This suggest that the population of large grazers may have remained stable in grassland over time while in mixed woodland, there was significant decline in both groups (medium grazers $p = 0.010$ and large grazers $p = 0.001$). There was no significant change in the population of both groups (medium grazers $p = 0.995$ and large grazers $p = 0.377$) in forest (Table 13). This suggest that the population of these groups may have remained stable over time. The null hypothesis, that populations of medium and large grazers were not significantly different before and after 2009 drought was rejected. We conclude that medium grazers significantly declined in both grassland and mixed woodland, while large grazers significantly decline only in mixed woodland.

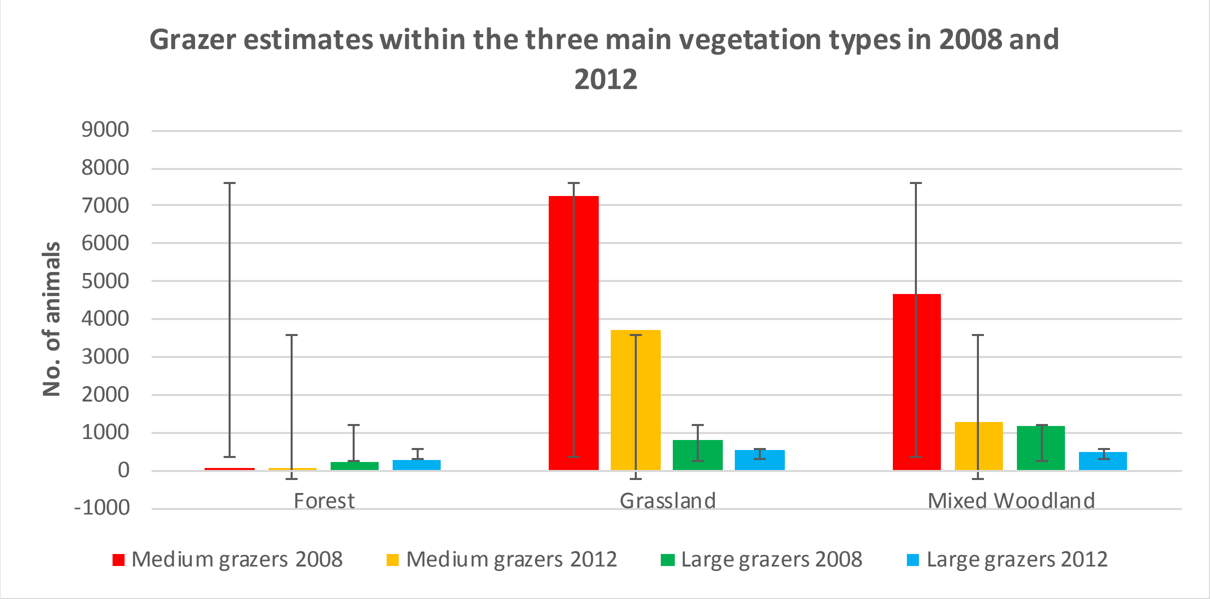

Figure 24: Medium grazer and large grazers estimate within the three main vegetation types before and after 2009 drought.

Table 13: Wilcoxon test significance difference results for Grazers estimates within three main vegetation types before and after 2009 drought

Vegetation types	Medium grazers 2008 and Medium grazers 2012	Large grazers 2008 and Large grazers 2012
Grassland	$p = 0.001$	$p = 0.070$
Mixed Woodland	$p = 0.010$	$p = 0.001$
Forest	$p = 0.995$	$p = 0.377$

4 DISCUSSION

4.1 Improved vegetation mapping accuracy with the contribution of ancillary topographic data

To understand the dynamics of Laikipia-Samburu ecosystem, information on the spatial distribution of vegetation is needed. In this study, mapping ecosystem vegetation was successfully done by using medium resolution (30m) multi-season Landsat 8 images (dry and wet season images). Land cover map of three main vegetation types was produced (grassland, forest and mixed-woodland). The overall accuracy of 82.2 % was obtained with a kappa coefficient of 0.78 (Table 6). In savanna ecosystem, land cover classification is a challenge because of land surface reflectance that shows intra annual variation due to phenology. Information from different seasons may help to discriminate between vegetation types based on available information at different times of the year. This helped to avoid confusion between grassland and others such as bare land and arable land. Phenological changes of vegetation and availability of high temporal resolution remote sensing data lead to use multi-temporal remote sensing images which has been applied in other studies like the studies by (Joshi et al., 2001) and (Chacón-Moreno, 2004).

The combination of spectral data and topography data (slope and aspects) improved mapping overall accuracy and kappa coefficient. However, it was not visually evident in figures 19 and 20. The classification results demonstrate that an increase of overall accuracy has been achieved by combining spectral data with topographical data but there was no significant difference between the two maps when using the Z-test for kappa coefficients.

Mapping ecosystem vegetation and assessment of its productivity is an important aspect of ecosystem management. This study mapped the vegetation of Laikipia-Samburu ecosystem and estimated its vegetation productivity linked it to herbivores abundance. The 2009 drought may have affected the productivity of forage in the ecosystem. The patterns of change in NDVI showed decreases in NDVI in 2009, which was due to the drought year, for three vegetation types. The three vegetation types showed recovery from the drought which is shown by the NDVI increase in 2012 (non-drought year) (Figure 21).Higher NDVI values in 2008 and 2012 may reflect greater vigour and greenness of the vegetation as compared to drought year. It is evident that there was a significant decline in vegetation productivity during drought year (2009) within the three vegetation types as shown by the P value of less than 0.017 proving the instability in three main vegetation types.

The findings also show that there is no significant difference in vegetation production variability within the three main vegetation types before and after drought as shown by the P-value of more than 0.017. However, there is significant difference in vegetation variability between non-drought years (2008 and 2012) and drought year in Grassland as shown by the P-value of less than 0.017and mixed woodland as shown by the P-value of less than 0.017 only. This shows that the ecosystem have differing resilience characteristics and response pathways of drought as shown by the forest, which resisted the drought period. This resistance of an ecosystem to disturbance and speed recovery mark ecosystem stability (Pimm, 1984). Results of this study are in line with previous studies which studies that the differences in the physiological response of plant species to drought determine different levels of resistance and resilience to water deficits (Chaves et.al., 2003; McDowell et al., 2008) and influencing the type of impact of a drought. By differentiating those that slow in growth (Pasho et.al., 2011) or reduce greenness (Ji & Peters, 2003) and those that lead to loss of biomass (Ciais et al., 2005). And also those that result in plant mortality (Allen et al., 2010; Adams et al., 2009). This NDVI decrease in 2009 shows that drought can reduce productivity and alter forage quality in grassland and mixed woodland.

4.2 Impact of drought on herbivores distribution

Impact of drought on herbivores distribution was assessed in this study. Almost all the species declined in numbers after 2009 drought in Laikipia-Samburu ecosystem. Most of the animals were located within grassland (13 037) and mixed woodland (10 187) and only 461 animals in the forest in 2008 (before drought). The few animals observed in forest may be due to underestimation as some animals may have been hiding under vegetation cover, which is thick, or dense causing visibility problems. Herbivores numbers declined to 11 741 in 2012 (after drought), with 6 516 in grassland, 4 671 in mixed woodland. However, there was an increase in the forest to 554 herbivores. This decline in herbivores numbers in Laikipia –Samburu ecosystem after drought, may have been influenced by a combination of different factors such as counting errors and biases, climatic effects, habitat changes, competition for forage resources, and poaching, among other factors.

When using Wilcoxon signed-rank tests, results show that there was a significant decline in grazers and mixed feeders in grassland as shown by the P-value of less than 0.05 while there was no significant change in the population of Browsers as shown by a P-value of more than 0.05 (Table 12). Grazers and mixed feeders also significantly declined in mixed woodland shown by a P-value of less than 0.05 while there was no significant change in browser over time in mixed woodland as shown by a P-value of more than 0.05. There was no significant changes in the populations of both groups (browsers, grazers and mixed feeders) in forest ($p > 0.05$) (Table 12). This result suggest that the 2009 drought may have been the other cause of decline in grazers and mixed feeders in mixed woodland and grassland.

There was significant decline of medium grazer while there was no significant change in large grazers in grassland (Table 13).In mixed woodland, there was significant decline in both groups (medium and large grazers). There was no significant changes in the population of both groups in forest (Table 13). Results show that medium grazers significantly declined in both grassland and mixed woodland, while large grazers significantly decline only in mixed woodland. Species that maintained high abundance through the dry phase were likewise diverse in their feeding habits. The distribution of medium grazers may have been highly influenced by forage quality than that of larger grazers.

If a vegetation type was strongly affected by drought, species associated to that vegetation types may also have been affected. This was shown by the decline of medium grazers, which can be associated to the decline in vegetation productivity in grassland and mixed woodland they feed on, which was affected by the 2009 drought.

The drought is one of the environmental factors that is highly listed as an explanatory variable for the decline of most wildlife species (Sitati et al., 2014). This caused by climate variability, particularly precipitation, which affect the production of plant material and hence, in carrying capacity of the ecosystem (Coe et al., 1976). The status of wildlife in the year 2008 and 2012 was assessed in Laikipia-Samburu ecosystem to determine the impacts of the drought on their populations. There was a rapid decline in the population of most animals, especially the grazers. Grazers are more affected by annual rainfall variability than browsers, because the herbaceous layer responds more strongly to annual precipitation than does the woody component of savanna vegetation (Rutherford, 1984). The amount of grass growth, and hence food supply to grazers, depends on the amount and distribution of rainfall.

The severe and prolonged 2009 drought affected much of East Africa had a severe impact upon Kenya. Vast areas became parched and barren; wildlife numbers decreased and died of thirst and starvation Droughts are a significant component of such climatic variability, and can have a devastating impact on animal populations (Young, 1994; Foley et al., 2008) . Through processes such as recurrent reductions in population numbers and the consequent genetic effects caused by demographic bottlenecks (Young, 1994), droughts have the potential to lead populations, and entire species, to extinction.

5 CONCLUSION AND RECOMMEDATION

5.1 Conclusion

The main objective of this study is to investigate impacts of the 2009 drought on vegetation productivity and spatial distribution of the herbivores in the Laikipia-Samburu ecosystem in Kenya. This study demonstrated a successful approach for investigation using techniques of remote sensing and geographic information system. The ecosystem environmental factors (herbivores estimates, vegetation types and vegetation productivity) were successful linked together using a 2km by 2km grid, the scale used during herbivores counting surveys. For this study, we explored three accepts corresponding to the research objectives:

a) Vegetation types, which is most important factor to herbivores as forage, thus was identified using multi-season Landsat 8 and topographic data.
b) Vegetation productivity estimations from satellite derived vegetation information from time series MODIS NDVI and compared between non-drought years and drought year.
c) Herbivores abundance and vegetation interaction was assessed before and after the 2009 drought.

- Multi-season Landsat 8 data combined with topographic data was used successfully to improve mapping accuracy of the three main vegetation types. The outcome of this study shows that there was no significant different ($Z<1.96$) between the two maps even though they was an increase in overall accuracy. We conclude that classification results demonstrate that an improvement in overall accuracy can be achieved but with no significant difference between the two maps. Therefore, integrating topographic data with multispectral data, it improves interpretation potential.

- Time series MODIS NDVI data can be used as a surrogate measure of forage availability and successful predict vegetation productivity to compare non-drought year and drought year.

- Impact of drought in herbivores abundance and vegetation interaction was successfully quantified. The rapid decline in herbivores populations can be attributed to drought that lead to competition for forage among others. Results of this study indicate that vegetation productivity during drought had influence on the population dynamics of herbivores in the Laikipia-Samburu ecosystem. The vegetation productivity during drought year shows food production for herbivores. Ecologically, drought leads to reduction in availability of forage and water resources which in turn become limiting factors to wildlife due to starvation. This was shown by decline in herbivores numbers after the 2009 drought.

Climate variability like droughts prevalence is a one of the major factors responsible for unexpected dying of large populations of animal over wide areas (Ottichilo et al., 2000). For example, in Kenya's rangelands, the 2000 severe drought caused high mortality and decline in the population of large herbivores (Kanga et al., 2013).

The expected response to the drought was a decline of the population estimate followed by a recovery thereafter. Visual inspection of data presented here show that there was recovery in vegetation productivity after 2009 drought but not certain with animal population estimates during drought year, because there was no animal estimates for drought year to quantify the impact. Hence, we conclude that our data provide evidence to support the hypothesis that the decline of herbivores was caused by the 2009 droughts based on forage availability.

5.2 Recommendation

From this research, the decline in herbivores numbers in Laikipia-Samburu ecosystem after drought may have been influenced by a combination of different factors. Therefore, is highly recommended that a further research can be carried out considering other environmental factors such as poaching, predators among other factors.

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