THE IMPACT OF DROUGHT ON THE ASSOCIATION BETWEEN SURFACE WATER AND HERBIVORE DISTRIBUTION IN THE LAIKIPIA-SAMBURU ECOSYSTEM

EDSON ASPON MWIJAGE
March, 2016

SUPERVISORS:
Dr. Tiejun Wang
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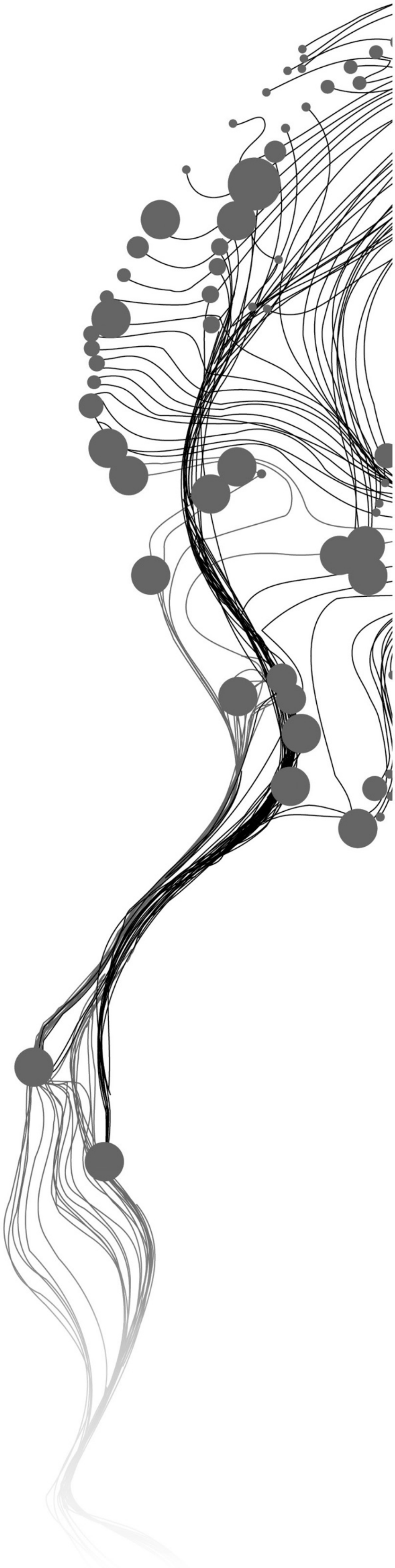

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Enschede, The Netherlands, March, 2016

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geo-information for Natural Resources Management

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ABSTRACT

It is commonly known that water is the major determinant of herbivore distribution. Using distance to water as an explanatory variable, the herbivore-water relationship in drought condition and non-drought condition can be measured by looking at the significant change in slope coefficients. Hence, this study was built on the hypothesis that herbivores will increase more close to water in drought condition compared to non-drought condition. The study applied remote sensing technique to identify and map surface water during drought condition and non-drought condition. There was a significant difference in surface water availability between drought and non-drought condition and the ecosystem lost more than 50% of its water during the drought condition.

This study observed the relationship between water and herbivores for individual species. Then species were grouped according to their water dependence and feeding behaviour to examine in to detail their relationship to water. This is because grazers are strong water dependants species and browsers are water independent species. The result showed that there was no significant difference in water dependence between browsers and grazers. The species which were significant related to water are only Giraffe, Eland and Common zebra. This relationship were observed during non-drought condition.

To our knowledge, this is the first study to examine the herbivore-water relationship during the drought and non-drought conditions in the Laikipia-Samburu ecosystem. In addition to that, this study have managed to show the spatial characteristics of surface water bodies during drought condition and non-drought condition in the Laikipia-Samburu ecosystem. These information obtained from this study are useful for decision making and management of wildlife in the Laikipia-Samburu ecosystem.

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Immeasurable appreciation and deepest thanks for the study and support are extended to the following persons who have spent time with in making this study possible.

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I would like to thanks my dear friends, advisors, classmates and ITC Natural Resources Department for cooperation and support during my academic life. My life has been so impressive and easy through their advice, support, encouragement and friendship. I have learned a lot from them and will be difficult for me to forget their tenderness.

Last but not least, I give more than thanks to my beloved family members for their financial support and inspiration to my life. Without their dedication of love to me, I would not have pursued my thesis in a credible University "University of Twente".

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1. INTRODUCTION

1.1. Background

1.1.1. Climate change and drought

Global climate change is worldwide known as a threat to species survival and integrity of ecosystems (Hulme, 2005; Erwin, 2009). The impact of climate change on wildlife is already notable at local, regional and global levels (Erwin, 2009). Previous studies have shown that climate change will lead to an increased climate variability including more frequent droughts and floods in many areas of the world (Chamaillé-Jammes *et al.*, 2007; Kioko, 2013). This may affect the distribution and number of the wildlife population due to the variation of environmental conditions specifically water and food. It is known that the geographic range of wildlife is widely determined by the presence of environmental conditions suitable for them to survive (Seabrook *et al.*, 2011). Changes in environmental conditions, such as climate variability and loss of habitats due to climate change impacts can affect wildlife distributions, mortality rate and consequently its abundance either temporally or permanent (Kioko, 2013).

Drought is defined as a prolonged and abnormal moisture deficiency (Palmer, 1965). The impact of drought in African savannah ecosystems manifest itself as stress on the surface water availability. Severe droughts have dried up sources of water such as rivers, lakes, ponds and streams (Western, 1975). For example, the drying of lake Banzena in Mali (Figure 1) and river Ewaso Ng'iro in the Laikipia-Samburu ecosystem in the year 2009 (Kioko, 2013) are notable impacts of drought that have caused high mortality rate of wildlife due to lack of drinking water and forage.

Figure 1: (a) Elephant drinking water in the Lake Banzena in Mali, and (b) young elephant carcass on the dried water source in Mali. Photographed by Jason McManus.

1.1.2. Herbivore-water relationship in Africa savannah ecosystem

Water is vital to herbivore survival, and change in its abundance and distribution can potentially have devastating implication, particularly on water dependent herbivores (Smit *et al.*, 2007; Western, 1975). Herbivore movement and spatial distributions in savannah ecosystem are mutually affected by water requirements and capability of moving to water (Western 1975; Shannon *et al.*, 2009). Water requirement scale with body size (small, medium and large) and feeding style (grazer, browser and mixed grazer and browser) and some species are independent of water (du Toit, 2002; Brown, 2006; Ogutu *et al.*, 2010). For example, browsers or mixed feeders are very likely to be water independent because they obtained the bulk of their water from forage (Du Toit 1999; Brown, 2006). Herbivores spend time looking for water and their capability to move far distance to follow water differ according to their body size (Cumming, 2003; de Boer *et al.*, 2010).

The distribution of surface water may vary seasonally and this variation may affect herbivore distributions. In savannah ecosystem water collects numerous in surface depressions during wet period and these sources dry up and become saline due to evaporation making them unsuitable or nonexistent during the dry season (Gereta, 1999). Therefore, herbivores respond to variations in water availability by adjusting their use of landscapes through time.

Previous studies found that herbivore distributions are influenced by the location of water sources, particularly in dry period (De Leeuw *et al.*, 2001; Western, 1975). Shortage of water during dry period cause herbivores to migrate towards areas with water availability, leading to rangeland degradation in areas close to water sources (De Beer *et al.*, 2006). This is due concentration and overgrazing that occur closer to water sources. Therefore, water development is usually used to improve animal distribution and grazing impacts close to water sources during drought. Example, it was observed that areas that previously received little use by most herbivores due to lack of water in Kruger National Park, became available due to borehole development (Walker, 1975). These evidence reveal the potentiality of water on herbivores distribution.

Watering frequency may vary seasonally, for example Grazers may be independent of water in the wet season and dependent in the dry season. Wildebeest, zebra, and impala water twice as often in the dry season as in the wet season (Ludwig *et al.*, 1996; Michael, 2008). Therefore, wide knowledge on the relationship between herbivores and water, particularly during drought condition, is needed for sustainable wildlife management in savannah ecosystem where severe droughts are major challenges.

The influence of water on herbivore distribution can be easily modelled by combining a distance to water map with a function describing decreasing probability of use with increasing distance to water (De Leeuw *et al.*, 2001). Shortage of water and forage during drought period repel herbivore to shift from one area to another looking for water. For instance, a study in Amboseli National Park in Kenya found that during dry season 99% of herbivores biomass aggregate within 15 km close to water sources but scatter more widely in wet season due to increased forage and ephemeral water bodies (Western, 1975). Therefore, distance to water can be a good explanatory variable for studying the change in herbivore-water relationship in drought condition and non-drought condition.

The relationship between herbivores and water can be affected by various landscape characteristics. For example, livestock and forage depletion near water in drought period can create a drive, repelling the herbivores away from water bodies (Andrew, 1988). In northern Kenya livestock uses of water sources during the day causes Grevy's zebra (*Equus grevyi*) to shift the times they visit water points to the night (de Leeuw *et al.*, 2001). However, herbivores may also be randomly distributed from water points for species that are weakly water dependant such as browsers (Ogutu *et al.*, 2010).

In this study, a large number of herbivores are expected to aggregate near the water points and decrease monotonically from water sources during the drought period. This assumption is expected to occur for the majority of species including non-water dependence species such as browsers because they get the bulk of water from forage and when there is a shortage of forage they look for water sources to drink (du Toit 2002; Brown 2006).

Small herbivores are restricted by food quality and large herbivores are restricted by food abundance (Gereta, 1998). The depletion of forage near water due to regular grazing during drought condition will force both small and large herbivores to travel further from water to satisfy their forage quantity and quality requirements (Gereta, 1998). However, large species can move greater distances than smaller ones and hence should peak in size further from water than small species.

1.1.3. Drought in the Laikipia -Samburu ecosystem

The Laikipia-Samburu ecosystem supports large herds of elephant (*Loxodonta africana*)
Grevy's zebra (*Equus grevyi*), gerenuk (*Litocranius walleri*) and reticulated giraffe (*Giraffa camelopardalis reticulata*). The ecosystem is made up of two counties (Laikipia and Samburu). Laikipia holds the second greatest wildlife abundance in Kenya after the Masai Mara National Reserve (Frank, 1998; Frank *et al.* 2005; Georgiadis *et al.* 2007).

In 2009, the Laikipia-Samburu ecosystem experienced a severe drought that affected large mammals and livestock. This drought was part of the impacts of climate change to Kenya (Figure 2). Most elephants died (n=338) during the drought due to lack of forage and water. The drought affected animals particularly the new born, younger animals as well as adults who could not access these resources. For example, for the first time in history, the river Ewaso ng'iro that provides water in the dry season and wet season in the ecosystem dried up completely (Augustine *et al.*, 2011, Kioko, 2013,). This resulted in to the death of many wildlife (Kioko, 2013) (Figure 3). Despite of severe droughts, herbivore-water relationship has not yet been studied in this ecosystem.

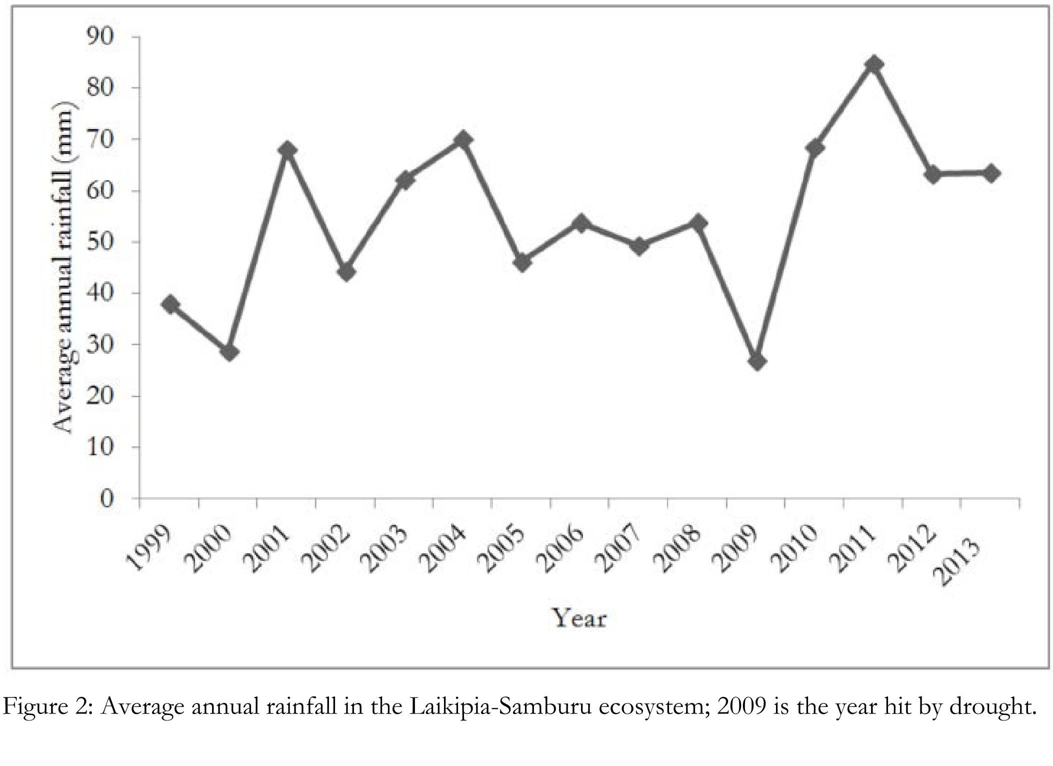

Figure 2: Average annual rainfall in the Laikipia-Samburu ecosystem; 2009 is the year hit by drought.

Figure 3: A water buck carcass in the Ewaso River. Photographed by Alison Clausen.

Kenya Wildlife Survey conducted two aerial wildlife surveys in November 2008 and November 2012, respectively. In November 2008 the rainfall was relatively high while in November 2012 rainfall was relatively low (Figure 6) Therefore in this study the November 2008 was considered a non-drought condition month while the November 2012 was considered a relative drought condition month. This change in rainfall was essential in this study to examine how herbivore response to change in water availability in drought condition and non-drought condition.

1.1.4. Remote sensing of surface water

In Africa savannah ecosystem, rainfall amounts vary drastically within a season and between seasons; as such, surface water availability can completely change. The detection of changes when surface water sites are filled by rainfalls and when they are drained out is the key information for assessment of water availability and environmental conditions.

Remote sensing employs an effective means for mapping the spatial location, extent, and change of surface water bodies over time (Prigent *et al.,* 2007). In recent years, the development of remote sensing have offered new methods of surface water inundation observation. They include synthetic aperture radar (SAR), multispectral, and passive -microwave observations (Grunblatt and Atwood, 2014). Some of the high spatial resolution multispectral imagery (e.g., Landsat, SPOT, and ASTER) have been successful in detecting and delineating the water body information accurately (Jain *et al.*, 2005). However they are limited by their inability to penetrate clouds and dense vegetation cover, particularly in tropical wet seasons (Prigent *et al.*, 2007). Another disadvantage of multispectral imagery is that it is difficult to provide the routine surface water monitoring due to narrow scanning coverage and long return period between successive satellite overpasses and, therefore, cannot provide multi-temporal spatial data (Wu and Liu, 2015). However high temporal resolution multispectral data such as MODIS and AVHRR have been widely used to conduct routine inundation monitoring in large-scale but when focusing on small or regional scale their coarse spatial resolution fail to detect small water bodies.

The advantage of Scatterometers and Synthetic Aperture Radar (SAR) is that they benefit from high spatial resolution and present images with good information under many environmental conditions (Grunblatt and Atwood, 2014). For example, SAR provides a resolution of 10-50 m and this instrument can penetrate clouds hence are not contaminated by atmosphere, rain and clouds as it is to multispectral sensors. However, the main limitation of SAR imagery is poor quality of images which are destroyed by multiplicative speckle noise. Spectral noise is a common challenge that hinder many user from analysing the SAR images (Park,1999).

Water has a unique spectral signature (Tulbure and Broich, 2013). Varying degree of dissolved impurities and sub-pixel mixing with other substances in water may complicates spectral identification signature (Tulbure and Broich, 2013). Example Multispectral water indices such as the Modified Normalized Difference Water Index (MNDWI) enhances the water signature locally (Xu, 2006; Jiang *et al*., 2014). However, the thresholds for separating water differ in space and time, hindering the automation and extrapolation of models (Zhang and Wylie, 2009). Under this challenge dynamic threshold such as maximum between class variance method (Otsu method) is useful for determining the threshold for discriminating water from non-water features in the complex landscape that is characterised by many forms of water features (Li *et al*., 2013).

The opening of the Landsat archive, together with decreasing costs of computing and data storage, enables the broader study of dynamics of surface water over large, even global area. Efforts have been made to atmospherically correct Landsat images, offer a robust representation of Earth's surface over varying external conditions. Surface reflectance products provides a more precise basis for discriminating various cover types than raw or scaled radiance values and enables data fusion between measurements from Landsat and other sensors (Feng *et al.,* 2013)

Various techniques have been developed to map surface water bodies in remotely sensed imagery. Spectral indices method which uses thresholds to one or more spectral bands are simple to use but always misclassify urban areas, mountain shadows and other background noise as water bodies (Islam *et al*., 2008). Classification method, this applies supervised or unsupervised machine learning algorithm to delineate water bodies from multispectral imagery (Haibo *et al*., 2011). Expert experience or existing reference data are needed to select appropriate training samples, which prevent these methods from being applied over large areas (Hui *et al.,* 2009). Water indices methods combine two or more spectral bands using various algebraic operations to improve the difference between water bodies and non water bodies (Chen *et al., 2014*). Example of commonly used water index is Normalized Difference Water Index (NDWI). The water indices have been widely used because of their relatively high accuracy in water body mapping and their low-cost implementation (Ji *et al*., 2009, Sun *et al*., 2012)

In this study Generalized Linear Model (GLM) was used to model herbivore-water relationship during drought condition and non-drought condition in the Laikipia-Samburu ecosystem. The animal data for November 2008 and November 2012 were used as response variables and distance to water from a grid cell of 2 km by 2 km was used as explanatory variable in the model. Herbivore species considered in the analysis include four grazers (Buffalo *syncerus caffer*, Grevy's zebra *Equus burchelli*, Water buck *Kobus ellipsiprymnus*, Common zebra *Equus quagga*), three browsers (Giraffe *Giraffa camelopardalis*, Eland *Taurotragus* *oryx*, Gerenuk *Litocranius walleri*), and three mixed feeders (Elephant *Loxodonta*, Impala *Aepyceros melampus,* Grant's gazelle *Nanger granti).*

1.2. Problem statement

Water is a major determinant of large herbivore distribution in African savannah ecosystems (Coughenour, 2008). Change in water distribution have considerable potential for disrupting herbivore distributions in the ecosystems. Nowadays increasing severe droughts in African savannah ecosystem is one of the major problem affecting surface water availability and management of wildlife. For example, Kenya has experienced two worst droughts in history, the 2009 droughts and 2011 droughts. The impacts of these droughts includes drying of sources of water and deaths of wildlife due to lack of forage and drinking water. Nevertheless, information on the abundance and spatial distribution of surface water during drought condition and non-drought condition has not been studies.

Availability of surface water data with high spatial resolution in savannah ecosystem is important for wildlife management. Medium spatial resolution sensor such as MODIS shows a significant potential to study surface dynamic over large area because of their high temporal resolution sensor. However, the low spatial resolution provided by these MODIS is not appropriate to accurate delineate surface water bodies over a small-scale. Therefore, time specific water products for mapping and quantifying small and large water bodies in savannah ecosystems are not available.

Laikipia-Samburu ecosystem is one of the savannah ecosystems where the fine resolution information on the abundance and spatial distribution of surface water in drought and is not known. This study aim to map and quantify the change in surface water availability in this ecosystem using fine resolution Landsat 5 TM and Landsat OLI, and to examine how change in surface water availability affect the distribution of wildlife.

1.2.1. General objectives

To assess the impact of drought on the association between the surface water availability and herbivore distribution in the Laikipia-Samburu ecosystem.

1.2.2. Specific objectives

- To map the surface water under the non-drought condition in November 2008 and the drought condition in November 2012 in the Laikipia-Samburu ecosystem using Landsat data derived water index.
- To quantify the change of surface water areas under the drought condition and non -drought condition.
- To examine the association between the surface water availability and herbivore distribution under the non-drought condition and drought conditions.

1.3. Reseach questions

- Are there significant differences in surface water distribution patterns (i.e., patch size) between the non-drought condition in November 2008 and the drought condition in November 2012 in the Laikipia-Samburu ecosystem?
- Is there a significant relationship between distance to water and number of herbivores in drought and period?

1.4. Reseach hypotheses

- The area of surface water bodies under the drought condition are significantly smaller/lower than the situation under the non- drought condition.

- The number of herbivores increase as the distance to water decreases during drought condition.

1.5. Organisation of the thesis and reseach approach

Chapter 1 explain a general research background, explain the research problem, define the research objectives, questions and hypotheses, and describes the general outline of the research. Chapter 2 introduces the study area with respect to climate, hydrology and land use. It also explain aerial count data and the collection and pre-processing of satellite data. Chapter 3 lists and explains the research findings relevant to specific research questions stated in Chapter 1. Chapter 4 discuss the procedures taken in this study. Chapter 5 summarizes the research and makes recommendations for further in-depth studies.

2. MATERIALS AND METHODS

2.1. Study area

2.1.1. Geographic conditions

The study area was conducted in the Laikipia-Samburu ecosystem in Northern Kenya. The ecosystem covers about 33,817 km^2 , lying on and to the north of the Equator at longitude of between 36^0 and 38^0 E (Figure 4). The Laikipia highland is an area rolling low hills at an altitude of 1700 to 2000 m divided by the Ewaso Ng'iro river (Georgiadis, 2011). Below the Laikipia escarpment, which is close to the northern boundary of district, lies Samburu. The weather in Laikipia is affected by the rain shadow of MT. Kenya, and since the plateau is at high altitude it has an unusual combination of cold and dry weather (Thouless, 1995)

Rainfall is very variable in time and space because it usually results from convective cloud formation, which produces localized showers (Thouless, 1995). The rainfall is highest on the slopes of mountain Kenya and the Aberdares, in the extreme east and the south west of the district, where annual means are in excess of 800mm. In the dryer northern parts rainfall drops to 500 mm per annum. Except in the mountains, Samburu is generally dryer and hotter than Laikipia (Georgiadis, 2011). There are two main rain seasons, the "long rains" which starts in March to May and the “short rains", which begins in November to December (Georgiadis, 2011)

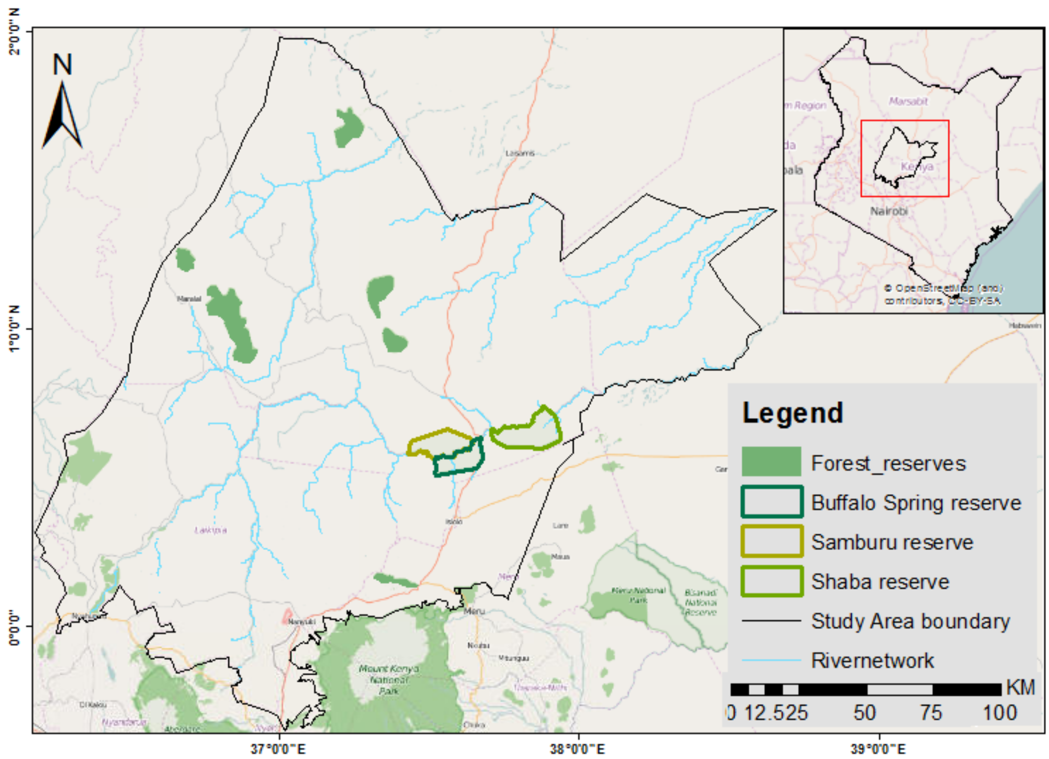

Figure 4: Location map of Laikipia-Samburu ecosystem showing drainage systems and reserves. The major rivers systems have their catchment on Mt. Kenya which is found outside the ecosystem.

2.1.2. Climate and rainfall distribution

Most of the region is typically dry savannah, hot and dry for most of the year with highly variable bimodal rainfall, 90% of which falls in April and November (Figure 5). In the drier northern extent of the study area, rainfall drop to less than 500 mm per year except in the mountains where variations may reach 120 mm per year (Georgiadis, 2011). Laikipia lies on the leeward side of Mountain Kenya and the weather is thus affected by rain shadow of the mountain (Georgiadis, 2011). During the long dry season usually lasting from late May till early October, large migrant animals congregate in the reserves due to permanent availability of water and green riverine vegetation along Ewaso Nyiro river (Barkham *et al.*, 1976).

Drinking water is everywhere during the wet season from a network of seasonal streams, a few of which persist through the dry season. Figure 6 shows the rainfall data collected in November 2008 and November 2012 respectively during aerial wildlife count.

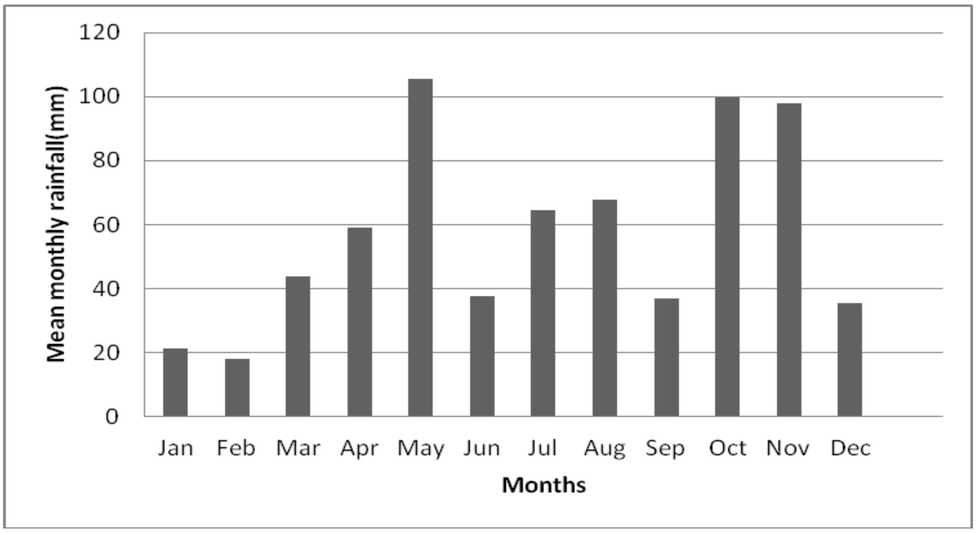

Figure 5: Mean monthly rainfall recorded at Mpala weather station from 2008 to 2012 in Kenya.

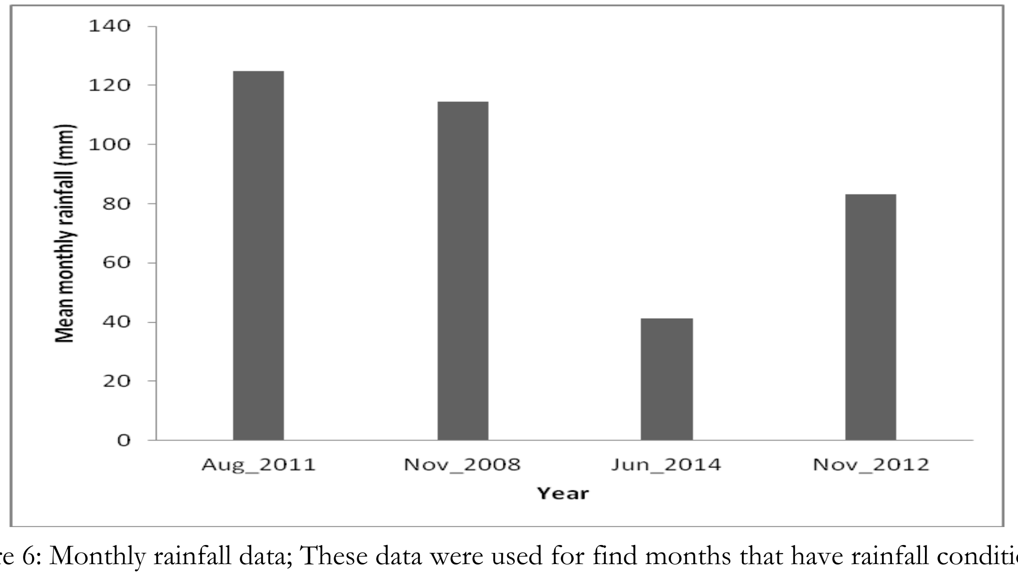

Figure 6: Monthly rainfall data; These data were used for find months that have rainfall condition relative comparable to the time of aerial wildlife count in November 2008 and November 2012.

2.1.3. Hydrology

Most of Laikipia District drains northwards through the Ewaso Ngiro, which has perennial tributaries originating from Mt Kenya and Aberdares Range. There are many dams and water tanks, fed from boreholes, on ranches. The Ewaso Ngiro river is the only natural permanent watercourse in low land areas of Samburu (Figure 7), other major water courses are seasonal, although water can be found by digging in the sandy river beds (Figure 8). There are few dams, and the many sources of water are temporary pools formed after the rains. Some of these, particularly rock pools, remain for a while in to the dry season (Thouless, 1995).

Figure 7: River Ewaso Ng'iro. Photographed by Saran Vaid.

2.1.4. Land use

Farming and settlements areas were not included in the analysis for this study these areas are separated from the rest of landscape by a fence and hence blocking the wildlife from accessing the settlement areas freely. The ecosystem comprises of six major land uses; ranches, settlements and farms, national reserves, community pastoral areas and community conservation (Ihwagi *et al.*, 2015). Community conservancies are occupied by nomadic pastoral communities, and in habited by both wildlife and livestock. National reserves are owned by the government and are managed for wildlife conservation and forest reserves. All land uses except settlements areas provide habitats for wildlife to graze and drink in this ecosystem (Ihwagi *et al.*, 2015)

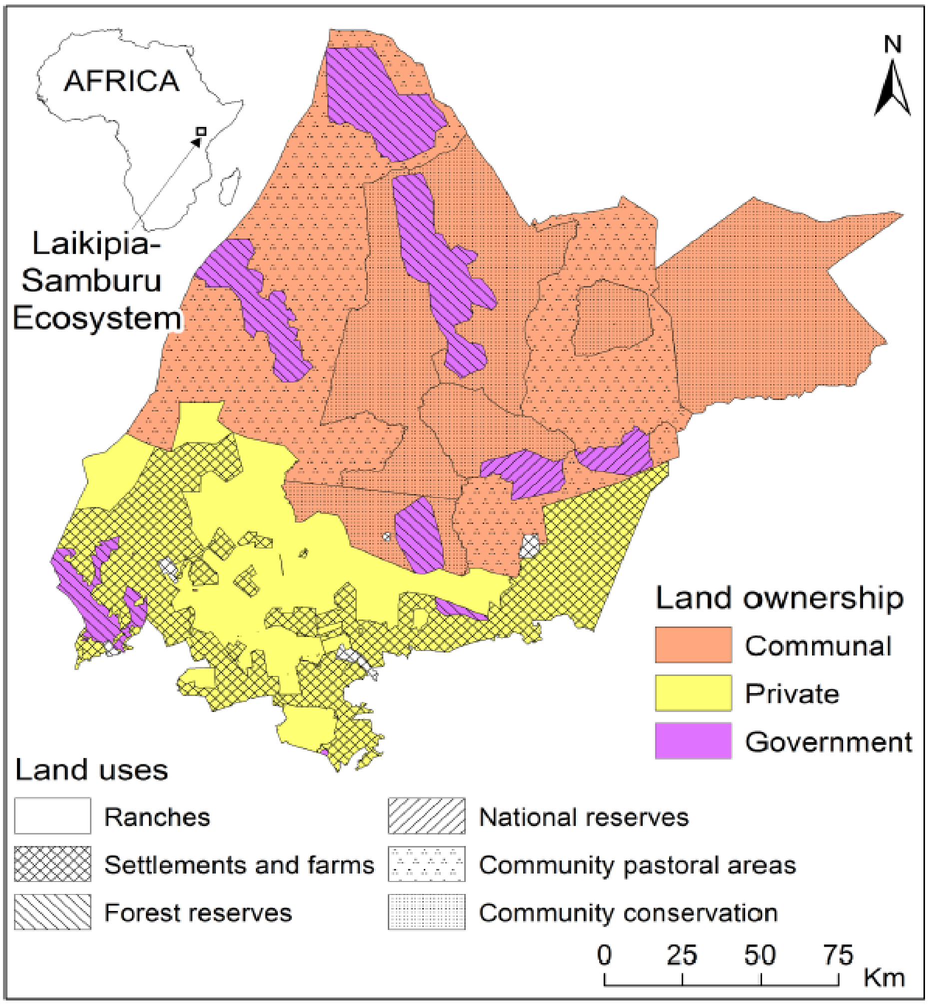

Figure 8: Land use in the Laikipia-Samburu ecosystem: Source: Ihwagi *et al.,* 2015.

2.1.5. Animal survey data

Total aerial wildlife counts in this study were carried out in November 2008 and November 2012 respectively by Kenya wildlife survey (KWS) using standard total aerial count, strip transect methodology, over almost all of the Laikipia-Samburu ecosystem (Georgiadis, 2011). The month of November 2008 was mostly wet while in 2012 was typically dry. Aerial survey is usually conducted using aircraft that flies at a speed of about 80 miles per hour at about 200 ft to 300 ft above ground (Douglas-Hamilton, 1996). A total of 13 aircrafts were employed during the count operation. The total aerial count for wildlife in 2008 and 2012 was conducted according the method described by Douglas-Hamilton (1996). The distance between the flight lines was set at one or two kilometers depending on visibility, to make sure all the ground was scanned and all the wildlife were enumerated (Douglas-Hamilton, 1996). The location and herd size of herbivore species were recorded in number per each block. The large herbivore were the focus of the aerial survey, however, small herbivore were counted wherever they were found (Douglas-Hamilton, 1996). Observations of wildlife were recorded as points shape file based on their geographic position. The double counts were cross-checked with field notes and rectified accordingly. The count data were referenced in the World Geodetic System (WGS84) datum.

2.1.6. Animal species selection and grouping

Information of count data were obtained from the count report of 2008 and 2012 from KWS (Ngene *et al.*, 2013). The count reports describe how species data were organised. All species were plotted in ArcGIS in order to visualize their distributions and extent where they occur (Figure 11 and 12). Species which were counted in November 2008 and November 2012 total aerial survey were considered for comparison purpose. Table 1 shows a list of animals selected for this study. These species were then grouped according to their body size and feeding behaviours.

Table 1 The common and scientific names, weight, feeding type, body size and water dependence of ten species.

Species name	Scientific name	Feeding type	Mean Weight (kg)	Water dependence	Body size
Buffalo	*Syncerus caffer*	Grazer	450 [c]	strong[b]	large
Grevy's zebra	*Equus grevyi*	Grazer	200 [c]	strong[b]	medium
Giraffe	*Giraffa camelopardalis*	Browser	1250 [c]	independent[b]	large
Elephant	*Loxodonta africana*	Mixed feeder	1400 [c]	strong[b]	large
Eland	*Taurotragus oryx*	Browser	350 [c]	independent[b]	large
Impala	*Aepyceros melampus*	Mixed feeder	40 [c]	weak[a]	small
Common zebra	*Equus quagga*	Grazer	200 [c]	strong[b]	medium
Gerenuk	*Litocranius walleri*	Browser	52 [c]	independent[b]	small
Grant's gazelle	*Nanger granti*	Mixed feeder	50 [c]	independent[b]	small
Waterbuck	*Kobus ellipsiprymnus*	Grazer	160 [c]	strong[b]	medium

[a] de Leeuw *et al* (2001)

[b] Western (1975)

[c] Ogutu (2014)

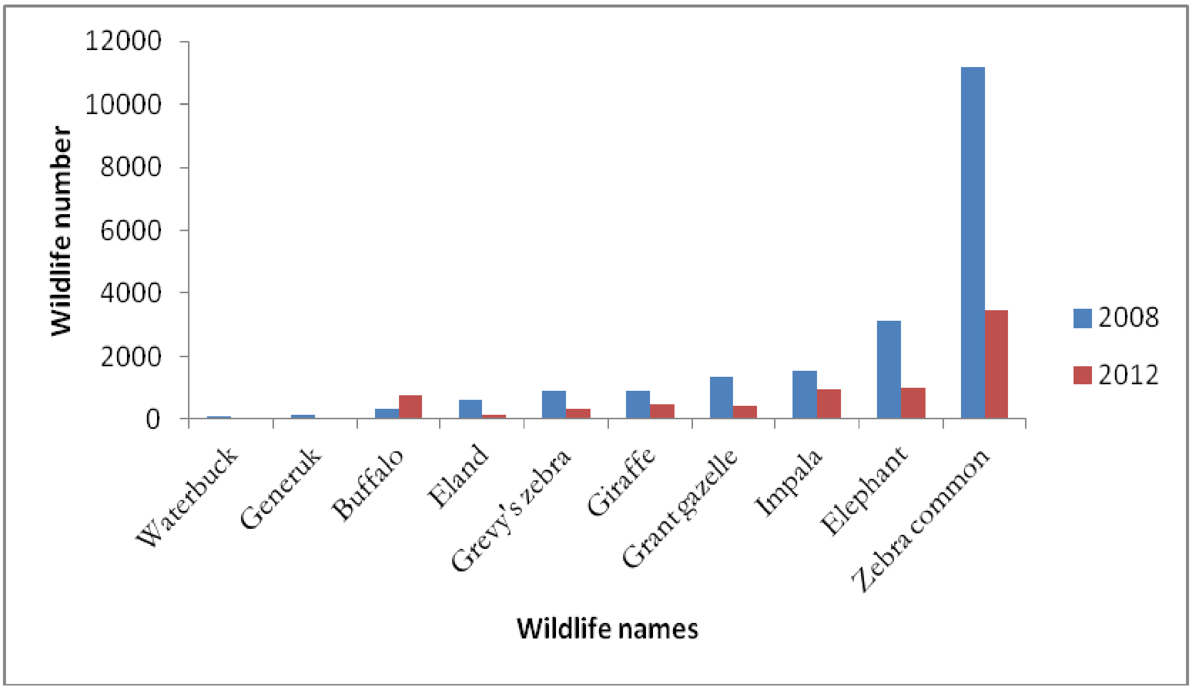

Figure 9: Number of animals counted in the study area in 2008 and 2012, respectively.

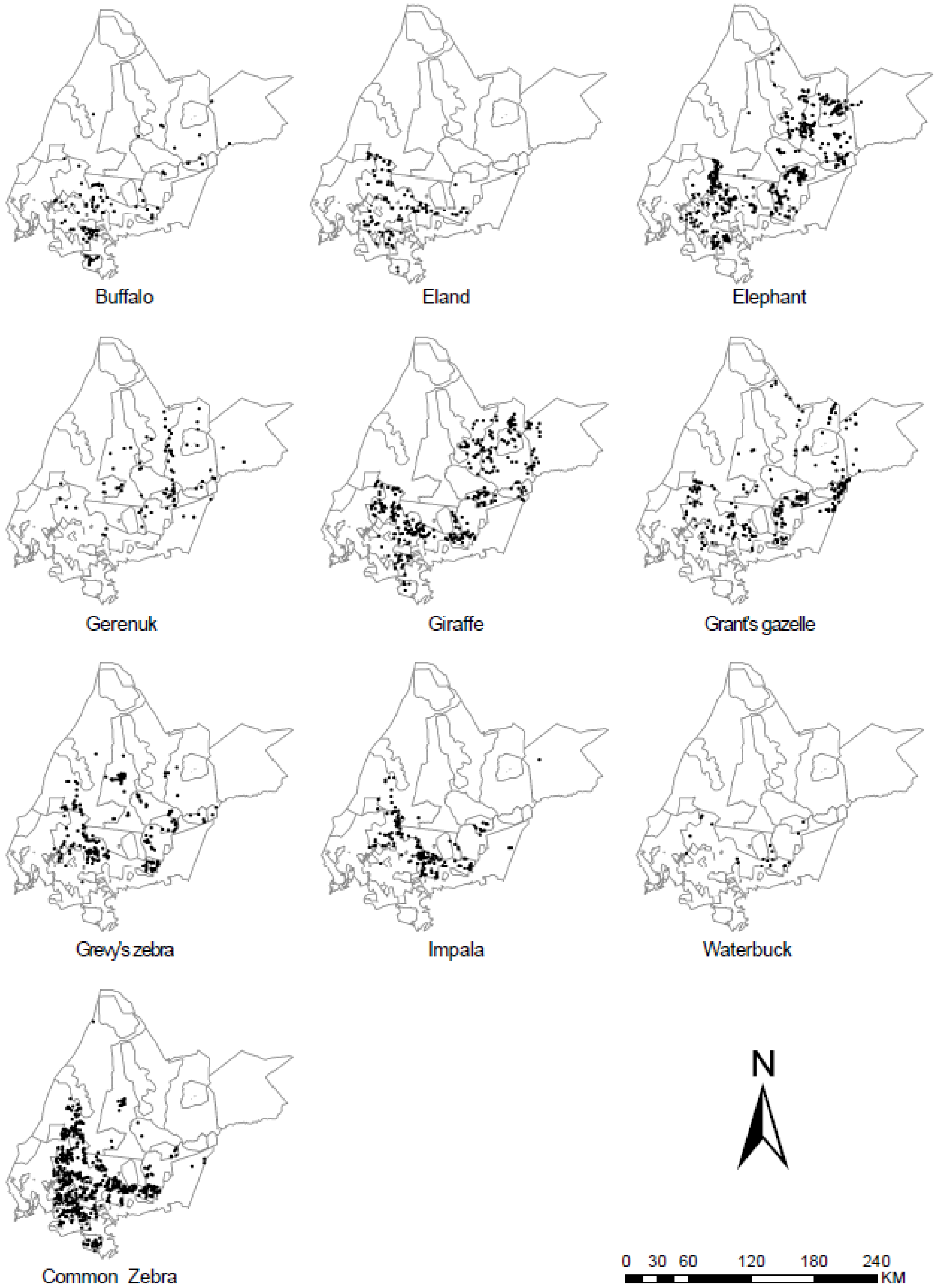

Figure 10: The distribution of Buffalo, Eland, Elephant, Gerenuk, Giraffe, Grant's gazelle, Grevy's zebra, Impala, Waterbuck and Common zebra in Laikipia-Samburu in 2008.

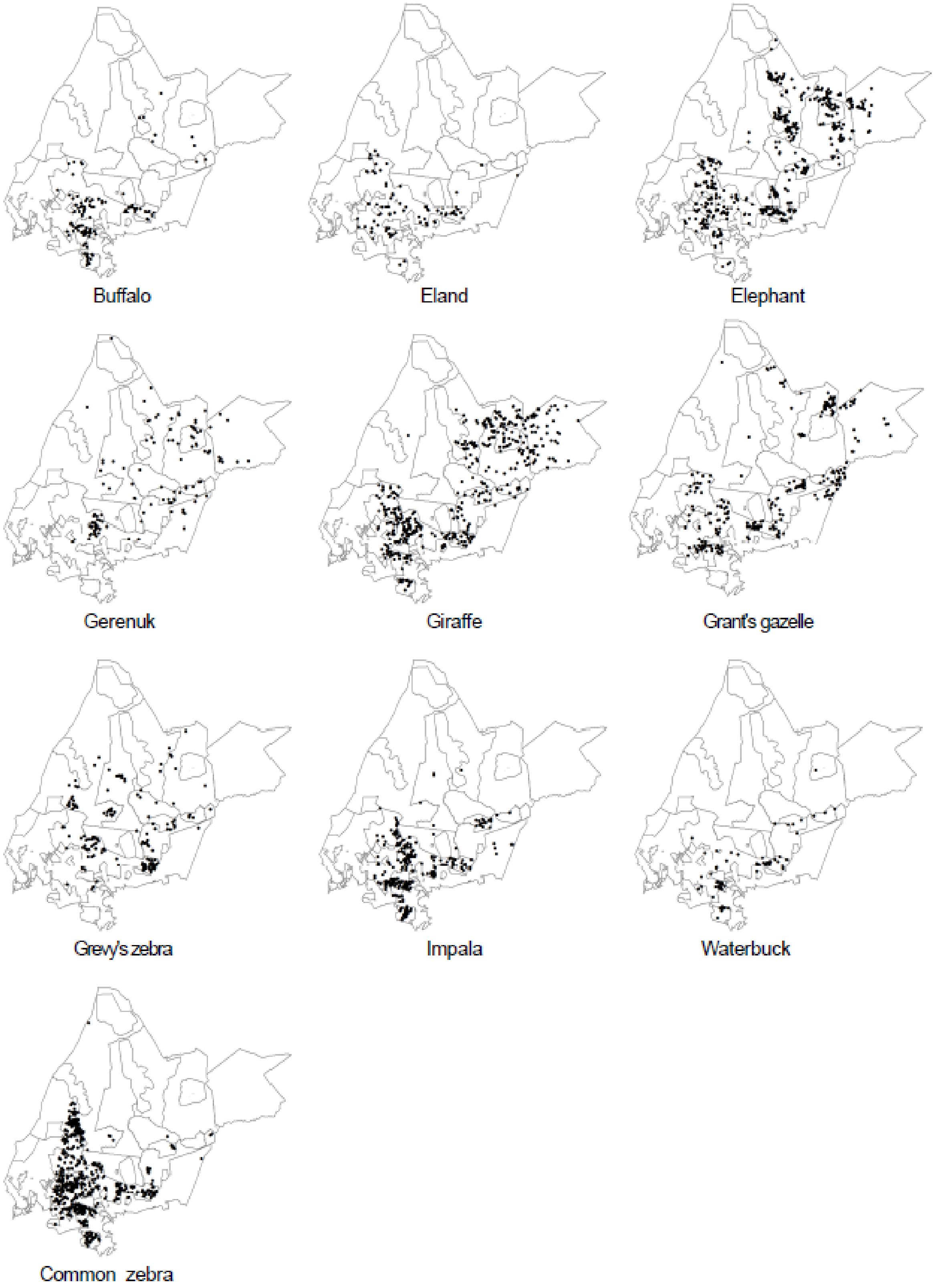

Figure 11: The distribution of Buffalo, Eland, Elephant, Gerenuk, Giraffe, Grant's gazelle, Grevy's zebra, Impala, Waterbuck and Common zebra in Laikipia-Samburu in 2012.

2.1.7. Satellite image collection and pre-processing

The effectiveness of multispectral remote sensing images for water mapping is often limited by the presence of cloud and cloud shadow. Cloud free images are often selected over cloudy images in water remote sensing applications (Huang *et al.*, 2010). However, cloud-free images are not always available.

In this study, cloud-free images were not available in November 2008 and November 2012 during aerial count.. Relative comparable Landsat images which were partly cloudy were obtained in August 2011 and Jun 2014 to represent the missing images (Figure 6). Landsat images acquired in August 2011 replaced November 2008 and were used to map water in non-drought condition. Landsat images obtained in June 2014 replaced November 2012 to map surface water during drought condition.

Two TM images were acquired on 22 August, 2011 (path/row 59/168 and 60/168) and two Landsat OLI images were acquired on 27 June, 2014 (path/row 59/168 and 60/168) . The Landsat TM and Landsat OLI data have six bands with similar spectral ranges (blue: 0.450 μm, green: 0.520-0.600 μm, red: 0.630-0.690 μm, NIR: 0.750-0.900 μm, SWIR: 1.550-1.750 μm and 2.080-2.350 μm) (Table 2). The sensors have an overpass frequency of 16 days. Images used are level-1 surface reflectance data of USGS. The images are referenced in the World Geodetic System (WGS84) datum. They are in GeoTiff format and are projected in Universal Transverse Mercator system (UTM) Zone 37 North.

Table 2 Satellite data used in the present study

Satellite	Sensor	Path/Row	Date of acquisition	Resolution(m)	Wavelength(μm)
Landsat-5	TM	59/168 60/168	22-Aug-2011	30	Band 1:0.45-0.52 Band 2:0.52-0.60 Band 3: 0.63-0.69 Band 4: 0.76-0.90 Band 5: 1.55-1.75 Band 7: 2.08-2.35
Landsat-8	OLI	59/168 60/168	27-Jun-2014	30	Band 1:0.435-0.451 Band 2:0.452-0.512 Band 3: 0.533-0.590 Band 4: 0.636-0.673 Band 5: 0.851-0.879 Band 6: 1.566-1.651 Band 7: 2.107-2.294 Band 9: 1.363-1.384

2.1.8. Cloud and cloud shadow masking procedures

Brightness effects of clouds and darkening effect of cloud shadows can be confused with water bodies if they are not screened (Zhu *et al.*, 2012). In this study clouds and cloud shadows were masked form Landsat OLI images which were partly cloudy (Figure 13), then Landsat TM and Landsat OLI were made comparable in order to make comparison in surface water availability under drought condition and non-drought condition. This was achieved by applying the same masking used for OLI image to TM images as well. Then, Landsat bands for each scene were stacked and two scenes were mosaicked to cover the study area (Figure 13).

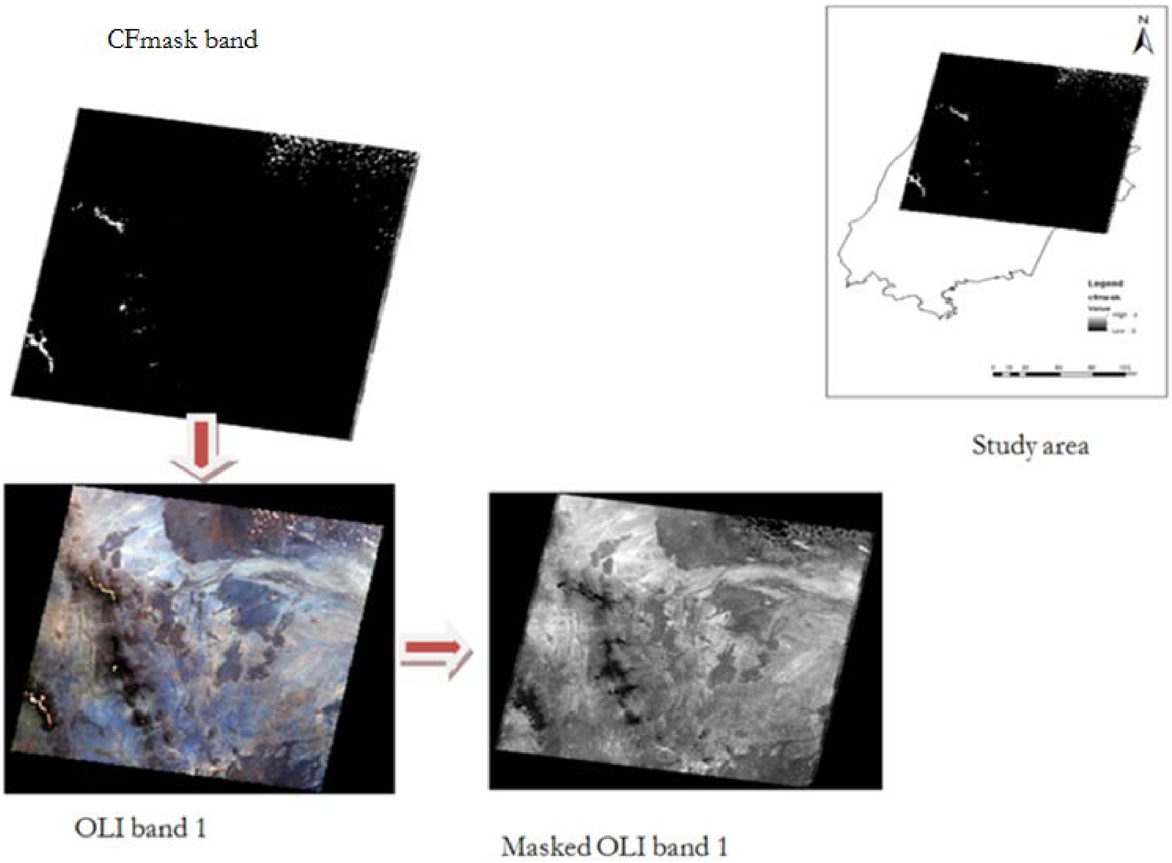

Figure 12: Sample image showing cloud and cloud shadow removal using the cloud and cloud shadow mask.

2.2. Mapping of surface water bodies

2.2.1. Use of spectral index for extracting water features

In order to delineate surface water in the Laikipia-Samburu ecosystem, the MNDWI was chosen as a spectral processing parameter to enhance surface water. The MNDWI calculation produce a grey scale image where water is bright. MNDWI was developed from NDWI (McFeeters 1996) using MIR band instead of NIR band to enhance water bodies from satellite data. (Li *et al*., 2013). MNDWI was used in this study because it has been successiful in different water body classification techniques (Jiang *et al*., 2014; Li *et al*., 2013).They are defined in the following equations:

NDWI= (Green-NIR)/(Green+NIR) Equation 1

MNDWI=(Green-MIR)/(Green+MIR) Equation 2

The values of grey scale image range from -1 to +1. According to Xu (2006), values greater than zero are assumed to represent water while values less than zero or equal to zero are assumed to be non-water. MNDWI were calculated from Landsat TM and OLI images using Equation (2) in ERDAS Imagine.

The benefit of Xu's MNDWI model is that not only enhances the spectral signals of water by contrasting the reflectance between different wavelengths, but also suppress out most of the noise components that are common in different wavelength regions such as sensor calibration and changing radiation conditions caused by illumination, soil, topography, and atmospheric conditions (Jiang *et al.*, 2012, Li *et al.*, 2013).

2.2.2. Image thresholding segmentation

Threshold is very important in extracting water bodies from the background. There are several techniques that can be used for image threshold segmentation.This includes histogram shape-based methods (Glasbey, 1993 and Ramesh *et al.*, 1995), clustering-based methods (Otsu, 1979), entropy-based methods (Li and Tam, 1998). In this study the commonly thresholding method of Otsu method (Sezgin and Sankur, 2004) was employed to partition water bodies from MNDWI. Otsu method gives a satisfactory results when the number of pixels in each class are close to each other (Chen and Leung, 2004). Since the number of pixels in water area being close to each other, Otsu method was preferred in this study.

Threshold selection is a key step in defining Xu's MNDWI. The threshold values for Xu's MNDWI were set to zero (McFeeters, 2013), however, dynamic or variable thresholds are needed when different regions or different phases of remote sensing data are used to detect water body information (Li et *al.*, 2013).
The maximum between -class variance method (the Otsu method) is one such dynamic threshold method (Li *et al.*, 2013).

The Otsu method pick the threshold by using the rule of maximum between-class variance of the background features and water body features (Li *et al.*, 2013). When part of a water body feature is mistakenly classified as a background or part of a background is wrongly classified as a water body, the variance between class decreases (Li *et al.*, 2013, Smith *et al.*, 1979). The grater the variance, the more different the background features and the water body features. Hence maximizing the variance between water body features and background features minimize the probability of misclassification. (Li *et al.*, 2013)
The obtained threshold (0.4) was used to classify the MNDWI map in to water and non water classes.
The classification were based on MNDWI values. MNDWI from 0.4 and above were classified as water features and values below 0.4 were classified as non water features.

2.2.3. Accuracy assessment

Accuracy assessment in this study were performed using reference data collected from false colour composite and high resolution Google Earth images. According to literature, the reference dataset are used to assess the accuracy of the water mapping result (Ji *et al.*, 2009). These data can be some small images subsets in space which are accurate or relatively accurate compared with the mapping data (Ji *et al.*, 2009).

Ground truth for accuracy assessment were obtained from False Colour Composite (FCC) Landsat-5 TM (RGB-543) and Landsat-8 OLI (RGB-742). Combination of TM band 4, 3 and 5; and OLI band 7,4 and 2 displaced in false colour composite (Red, Green, Blue) enhance surface water bodies. Employing these band combinations water and non water bodies were enhanced (Figure 13a and 13b). The high-resolution Google images and few known water points were used as additional reference dataset to collect ground truth points from False Colour Composite.

Rahman and Saha (2008) recommended that the sample size should take at least 30 samples for each category for achievement of an accuracy assessment of 90%. In this study, points were randomly generated in a stratified random format to define approximately 80 samples for water bodies and
80 samples non water samples. Samples were collected from (FCC) of TM and OLI images. The points collected were overlaid on the MNDWI images and MNDWI values were extracted from each point. A

cross tabulation was performed in SPSS to compare MNDWI values and validation points. The agreement of ground truth data and MNDWI values were assessed using Kappa coefficient.

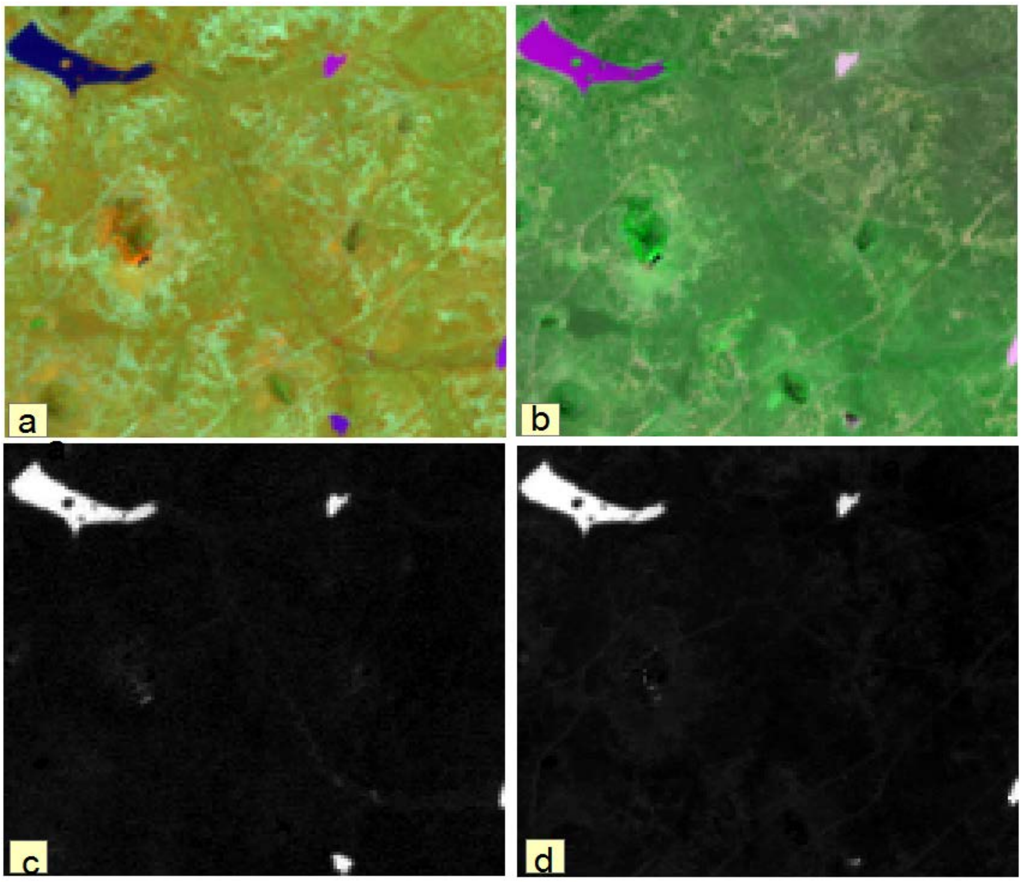

Figure 13: Example of the enhanced water bodies from false colour images.(a) TM false colour composite (b) OLI False Colour Composite (c) TM MNDWI (d) OLI MNDWI. False colour images were used to collect ground truth for validation.

2.3. Re-sampling of animal survey data and the calculation of distance to water bodies

A two by two kilometer grid was prepared using ArcGIS fishnet tool and overlaid on the extent of the study area. This resolution was chosen because the interval between the flight lines during aerial count varied between a maximum of two kilometres (Georgiadis, 2011).The distance from the centre of each grid cell to the nearest water sources was calculated in ArcGIS software and was used as an explanatory variable (Figure 14 and Figure 15). The number of herbivore per each grid cell were used as the response variable for all the analysis. The minimum distance was set to 5km and the maximum distance was set to 25km assuming that herbivores will not stay far away from the water above that distance, and if for animals found far from the selected distance, will be considered as water independent. The combination of water data and species with the grid fishnet of 2 by 2 km were done in GIS using spatial join and union tool. Statistical analysis were performed in R programme.

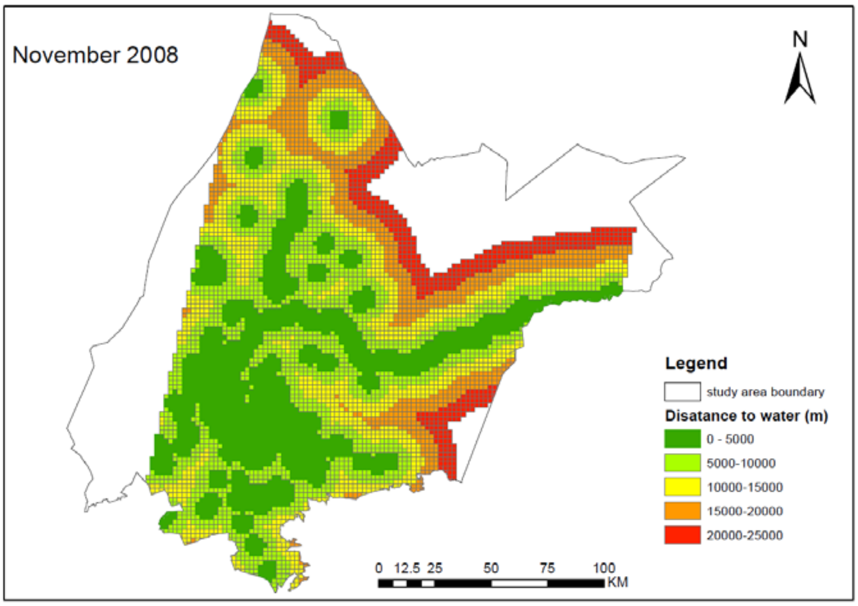

Figure 14: The distribution of distance from the centre of each 2 x 2 km grid cell to the nearest water point in Laikipia-Samburu ecosystem in November 2008.

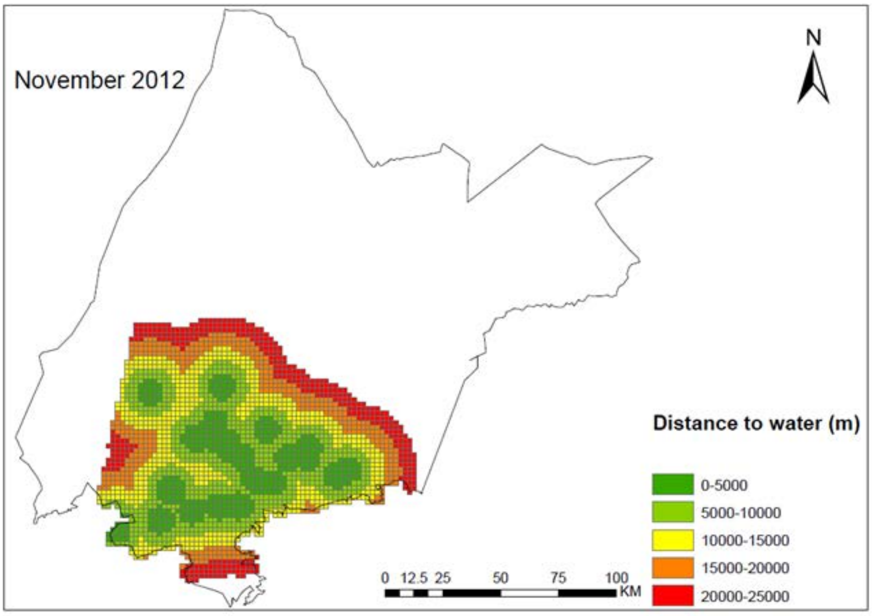

Figure 15: The distribution of distance from the centre of each 2 x 2 km grid cell to the nearest water point in Laikipia-Samburu ecosystem in November 2012.

2.4. Statistical analysis

2.4.1. Quantifying the distribution patterns of surface water bodies

The number and area of surface water bodies are naturally dynamic in space and time and most of surface water bodies in savannah ecosystem experience seasonal dynamic, with rainfall and drought, Basic knowledge of natural dynamics of surface water in space and time is needed to quantify their decline.

To enable calculation of surface water area and number of water bodies, the water pixel groups were converted to a polygons vector in ArcGIS (Feyisa *et al.,* 2014). The area and number of water bodies mapped in drought condition and non-condition were calculated using patch analyst tool in ArcGIS.To test if water distribution in drought condition and non-drought condition is significantly different, the average area of surface water bodies for the whole landscape was compared using spatial Wilcoxon rank sum test in R programming software. The Wilcoxon test in this study was used because the data were not normally distributed (*Shapiro-Wilk test:* p-value<0.05). The average distance to water during drought condition and non- drought condition was also tested.

2.4.2. Examining the relationship between animal distribution and distance to water bodies

The generalized linear regression model (GLM) was used to examine the relations between herbivore number and distance to water in this study. The herbivore number were dependant variable and distance to water were independent variables in the model. Prior fitting the regression model, variables were tested to see if they are normally distributed using Shapiro-Wilk test. Shapiro-Wilk test ($p<0.05$), showed that both herbivore distribution data and distance to water were not normally distributed. A number of transformation were done to normalize the data but still could not follow a normal distribution. All tests of statistical significance were conducted at alpha level of 0.05.

3. RESULTS

3.1. Mapping of surface water bodies from satellite remote sensing

- Image classification

In figures 16 and 17 the results of MNDWI for TM band 2 and band 5, OLI band 3 and band 6 are shown. The classification of satellite imagery using MNDWI clearly showed the water features as a result of enhancement. Water features are enhanced using white colour.

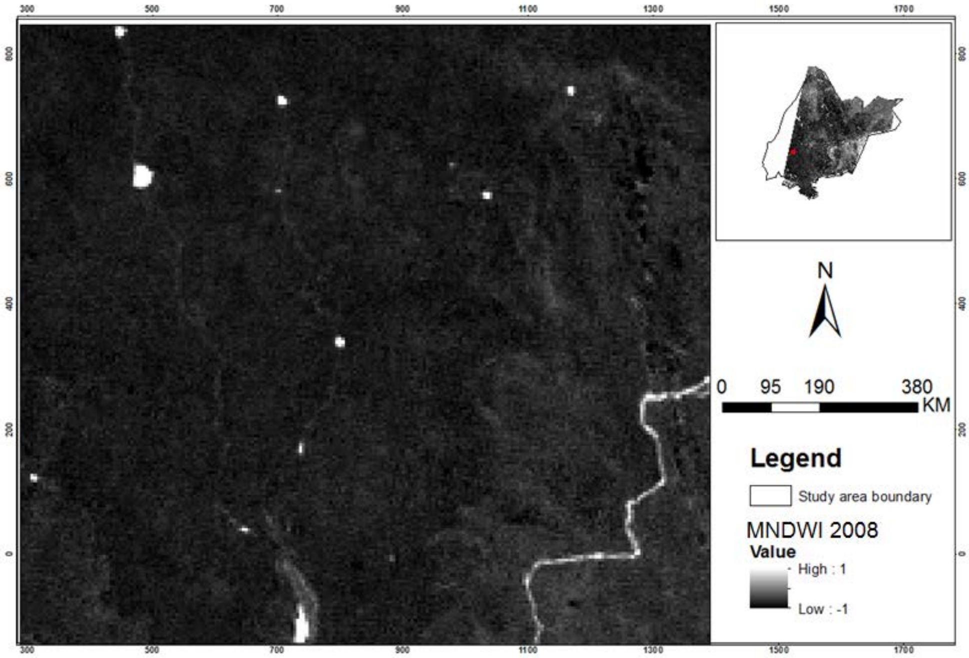

Figure 16. Water feature enhancement using MNDWI during non-drought condition.

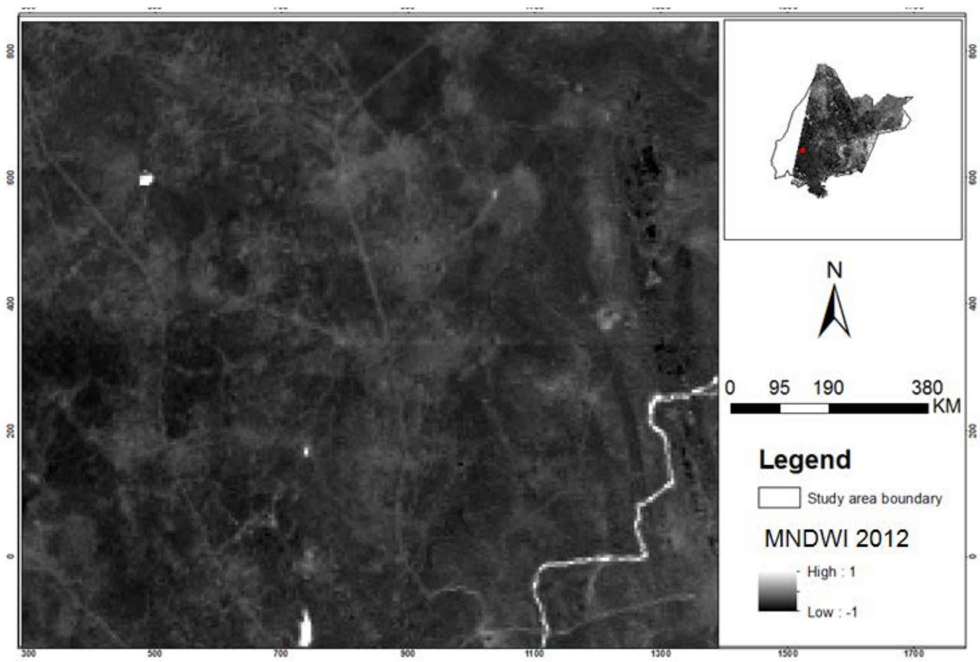

Figure 17. Water features enhancement using MNDWI during drought condition.

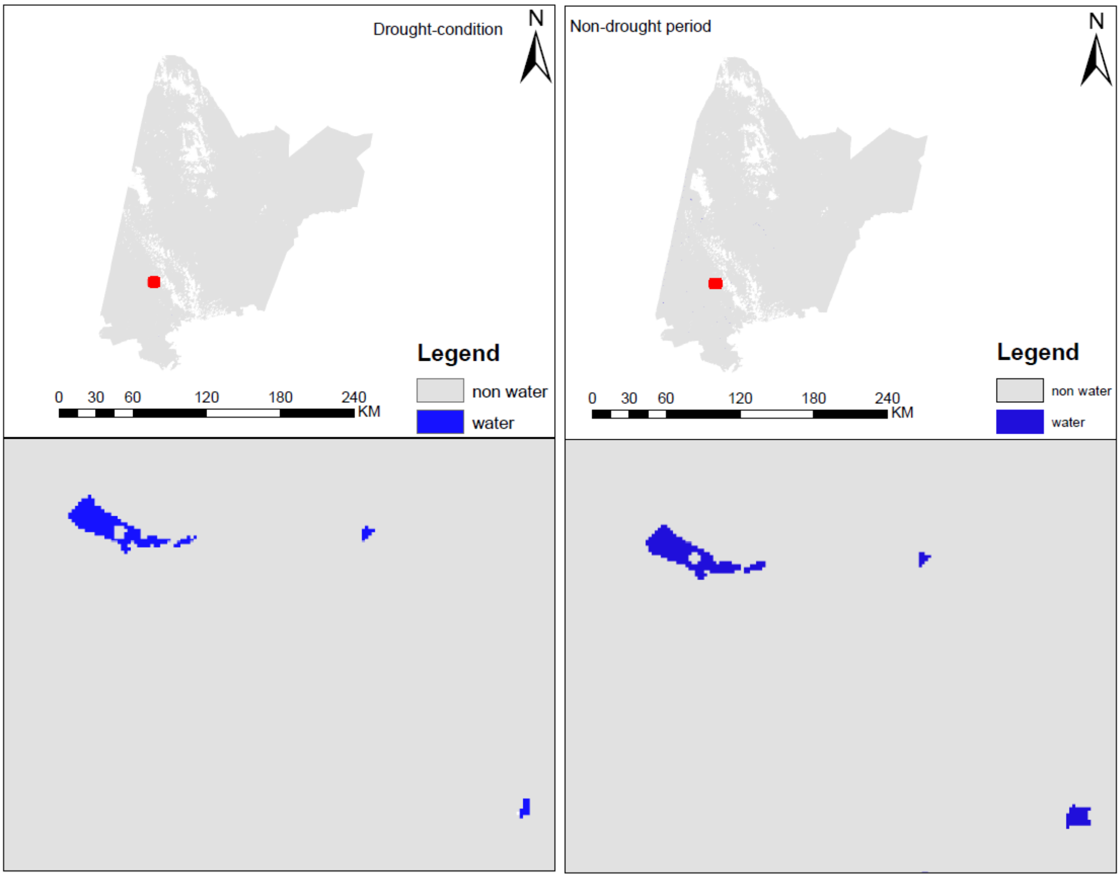

Figure 18. Classified MNDWI maps; the left image shows enhanced water in drought condition and it subset below. The right image shows enhanced water in non-drought condition and its subset below.

The result of accuracy assessment are shown in Table 3 and 4. The overall accuracy during wet period was 99% and Kappa coefficient is 0.97. The overall accuracy in drought condition was 93% and Kappa coefficient is 0.86 (Table 3).

Table 3. Summary of accuracy assessment in 2008.

Classification method	Land cover class	Threshold	User accuracy (%)	Producer accuracy (%)	Overall accuracy%	Kappa
MNDWI	Water	0.4	97.5	100	98.7	0.97
	Non water		100	100		

Table 4. Summary of accuracy assessment in 2012.

Classification method	Land cover class	Threshold	User accuracy (%)	Producer accuracy (%)	Over all accuracy%	Kappa
MNDWI	Water	0.4	86	100	93	0.86
	Non water		100	87.7		

3.2. Spatial patterns of water body distributions under drought and non-drought conditions

There was a significant difference in the average area of surface water bodies between non-drought condition and drought condition (*Wilcoxon rank sum test: W=6460*, p=0.04). Mean distance was also compared. The result shows that there was a significant difference in the mean distance to water in drought condition and non-drought condition (*Wilcoxon rank sum test: W=4344800*, p<0.005*)*.

The number of water bodies in the Laikipia-Samburu ecosystem varied from a minimum of 28 water bodies in drought condition to a maximum of 766 in non drought condition.The number of water bodies showed high variation with highest numbers water bodies in non-drought condition when there was more surface water in the ecosystem and lower numbers of water bodies in drought condition when the ecosystem was dry (Table 5). The average size of water bodies varied from 0.009 km^2 to 0.012 km^2 in non-drought condition and drought condition, respectively (Table 5). The total water area in the Laikipia-Samburu ecosyetem varied from 6.899 km^2 during drought conditon to 0.34 km^2 during non-drought condition. The total abundance of water in non-drought condition was 0.099% and 0.0023% during drought condition.

Table 5. Quantification of water bodies in the Laikipia-Samburu ecosystem

Year	Area of water bodies(km^2)	Nr.water bodies	Mean size of water body (km^2)
2008	6.899	766	0.009
2012	0.34	28	0.012

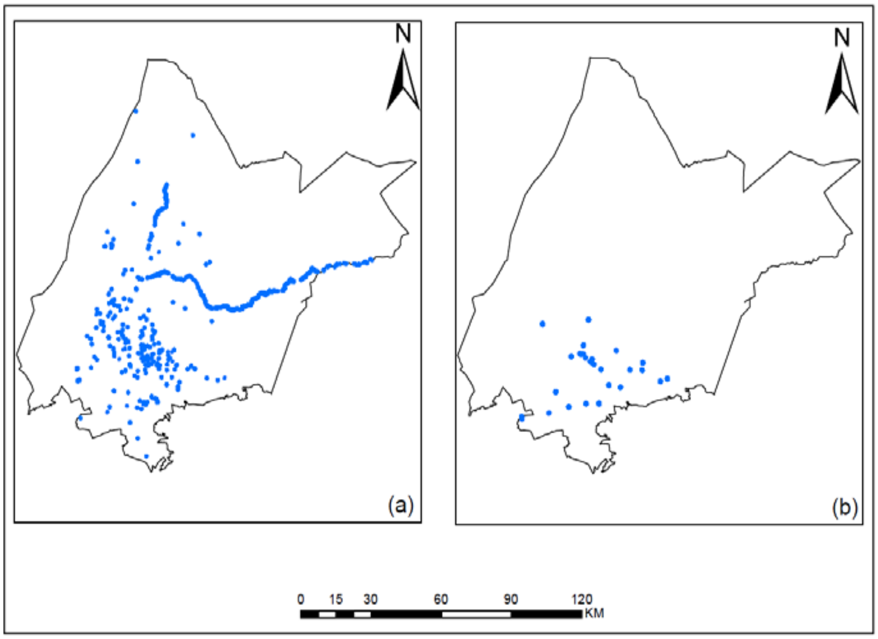

Figure 19. Distribution of water bodies in the Laikipia-Samburu (a) shows the distribution in non-drought condition and (b) shows the distribution in drought condition.

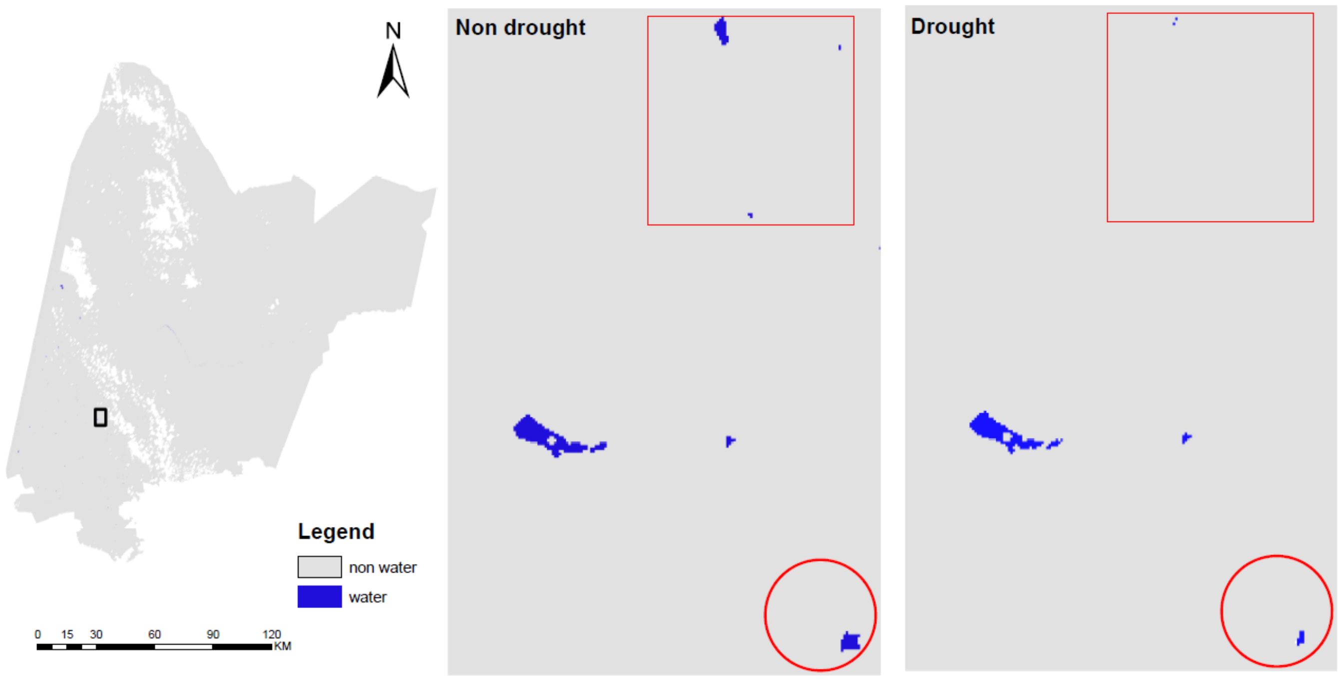

Figure 20. Difference in quantity and size of water body. The Square objects shows the change in quantity of water in non-drought condition and drought condition. The round object shows the change in size of water body in non-drought condition and drought condition.

3.3. Relationship between animal distribiution and water availability

Table 6. Shows the results of herbivore-water relationship during drought condition and non-condition. The herbivore-water relationship was different among the species.. Common zebras were significant ($p<0.05$) related to water sources during non-drought condition. There was no significant relationship observed during drought condition. The result show that the slope coefficient of Common zebra and water relationship was significant ($p<0.05$) different between drought condition and non-drought-condition. Giraffes in this study were significant ($p<0.05$) related to water sources during non-drought condition. During drought condition, there was no significant relation observed. Giraffes-water relationship was not significant different between drought condition and non- drought condition. Buffalos were significant ($p<0.05$) related to water during drought condition and not significant related to water during drought non-drought condition. There was no significant change in the Buffalos-water relationship between drought condition and non-drought condition. Gerenuk did not show any significant ($p>0.05$) relationship to water in drought condition and non-drought condition. Gerenuk and water relationship was not significant different between drought condition and non-drought condition. Elands were significant ($p<0.05$) related to water during non-drought condition and not significant related to water in drought condition. The slope test show that there was significant ($p<0.05$) change in Elands-water relationship between drought condition and non-drought condition. Impalas showed significant ($p<0.05$) relationship to water during drought condition. There was no Impala-water relationship observed during non-drought period. Impala-water relationship was significant different between drought condition and non-drought condition. Elephants, Grant's gazelle and Grevy's zebra were not related to water during both drought condition and non-drought condition. Their distribution was not significant different between drought condition and non- drought condition.

Generally, four species (Waterbuck, Grant's gazelle and Grevy's zebra) did not show any significant relation to water points. Three species (Giraffe, Eland and Common zebra) appeared to stay close to water in non-drought condition and avoid water points in drought condition. Two species (Elephant and Impala) appeared far from water points in drought condition and non-drought condition. One species (Gerenuk) were significantly associated to water during drought condition and not significant related to water in non-drought condition. One species (Buffalo) were found away from water in non-drought condition and were not significantly associated to water in drought condition.

Table 6. Statistics describing the relationship between herbivores and distance to water in drought condition and non- drought condition.

	Herbivore –water relationship			
	Slope coefficient (non-drought)	P-value (non-drought)	Slope coefficient (drought)	P-value (drought)
Giraffe	$-1.58x^{-05}$	0.00	$+8.93x^{-06}$	0.23
Eland	$-3.77x^{-05}$	0.01	$-1.24x^{-05}$	0.46
Grant's gazelle	$-6.43x^{-06}$	0.14	$+1.42x^{-05}$	0.22
Grevy's zebra	$-9.03x^{-06}$	0.35	$-4.40x^{-06}$	0.68
Common zebra	$-2.56x^{-05}$	0.00	$+3.14^{-06}$	0.19
Impala	$+3.99x^{-06}$	0.70	$+2.46^{-05}$	0.00
Buffalo	$+1.44x^{-05}$	0.03	$-1.14x^{-05}$	0.69
Elephant	$+1.05x^{-05}$	0.00	$+3.95x^{-05}$	0.00
Gerenuk	$+5.23x^{-06}$	0.68	$-8.95x^{-05}$	0.07
Waterbuck	$-3.18x^{-05}$	0.16	$+2.71x^{-05}$	0.69

Table 7. The analysis test for significance difference between the slope coefficients during non-drought condition and drought condition.

	Slope coefficient (non-drought)	Slope coefficient (drought)	P-value
Giraffe	$-1.58x^{-05}$	$+8.93x^{-06}$	0.22
Eland	$-3.77x^{-05}$	$-1.24x^{-05}$	0.01
Grant's gazelle	$-6.43x^{-06}$	$+1.42x^{-05}$	0.05
Grevy's zebra	$-9.03x^{-06}$	$-4.40x^{-06}$	0.18
Common zebra	$-2.56x^{-05}$	$+3.14^{-06}$	0.00
Impala	$+3.99x^{-06}$	$+2.46^{-05}$	0.04
Buffalo	$+1.44x^{-05}$	$-1.14x^{-05}$	0.8
Elephant	$+1.05x^{-05}$	$+3.95x^{-05}$	0.00
Gerenuk	$+5.23x^{-06}$	$-8.95x^{-05}$	0.06
Waterbuck	$-3.18x^{-05}$	$+2.71x^{-05}$	0.21

Large pure grazer and mixed grazer and browsers are strong water dependent species. In this study Buffalo and Elephant which belong to this class were analysed. The results obtained show that there was no significant association between water and large pure grazer and browsers observed during drought condition and non-drought condition (Figure 21).

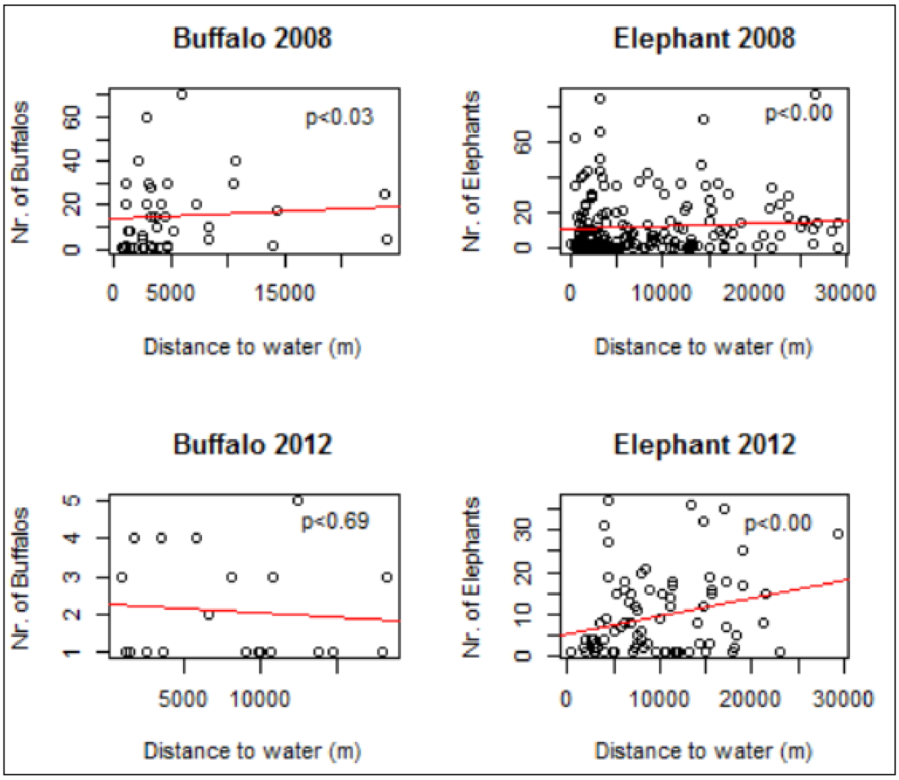

Figure 21: Distribution of large grazer and mixed grazers and browsers in relation to surface water.

Small mixed grazer and browser are strong water dependent species. In this study, Impala and Grant's gazelle which belong to this class were analysed. The result obtained demonstrate that there was no significant association between water and small mixed grazer and browser observed during drought condition and non-drought condition (Figure 22)

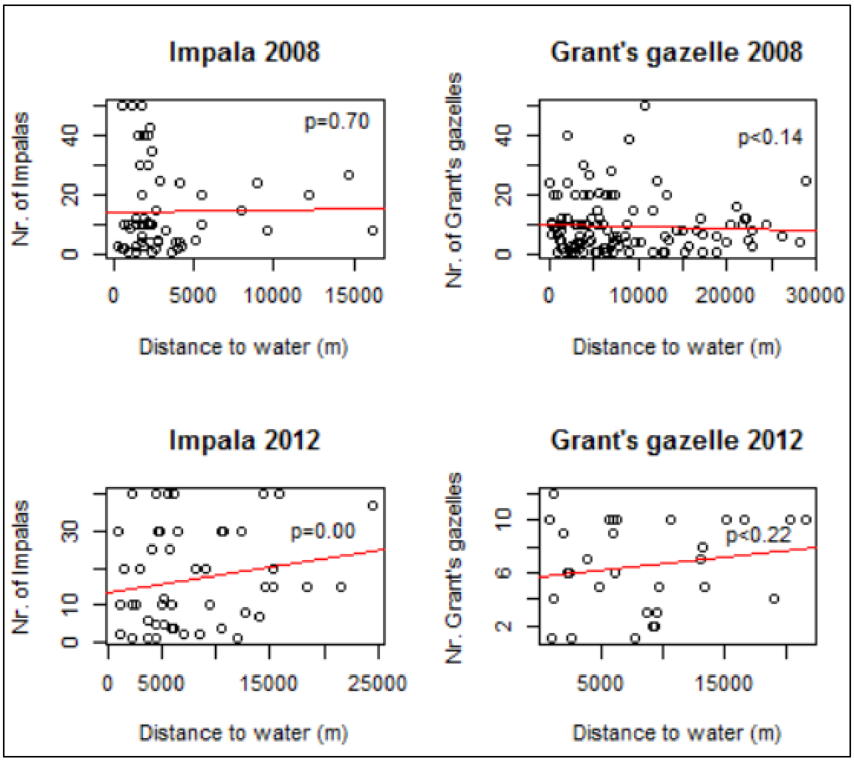

Figure 22: Distribution of Small mixed grazer and browser in relation to surface water

Large pure browser

Large pure browser are non-water dependent species. In this study Giraffe and Eland which belong to this class were analysed. The results obtained show that there was not significant association between water and large pure browser observed during drought condition. However these species showed strong significant relationship to water during non-drought condition (Figure 23).

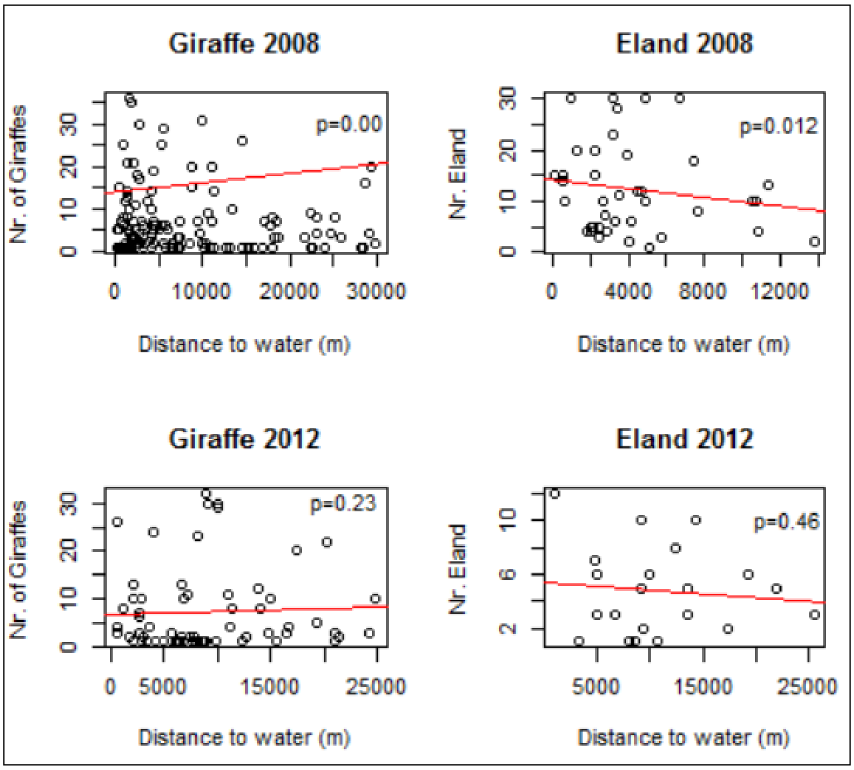

Figure 23: Distribution of large pure browser in relation to surface water.

Small pure browser

Large pure browser are non water dependent species. In this study Gerenuk which belong to this class were analysed. The result obtained show that there was no significant association between water and small pure browser observed during drought condition (Figure 24).

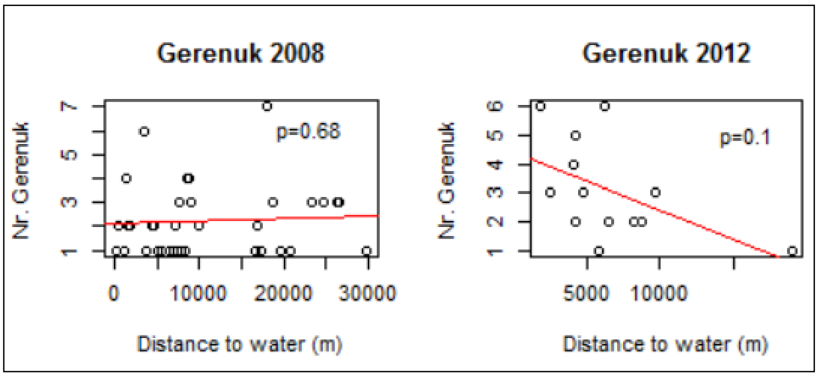

Figure 24: Distribution of small pure browser in relation to surface water.

Medium pure grazers are strong water dependent species. Waterbuck, Grevy's zebra and common zebra which belong to this class were analysed in this study. The results obtained show that there was no significant association between water and medium pure grazers species observed during drought condition. However, Common zebras show significance ($p<0.05$) relationship to water in non-drought condition (Figure 25).

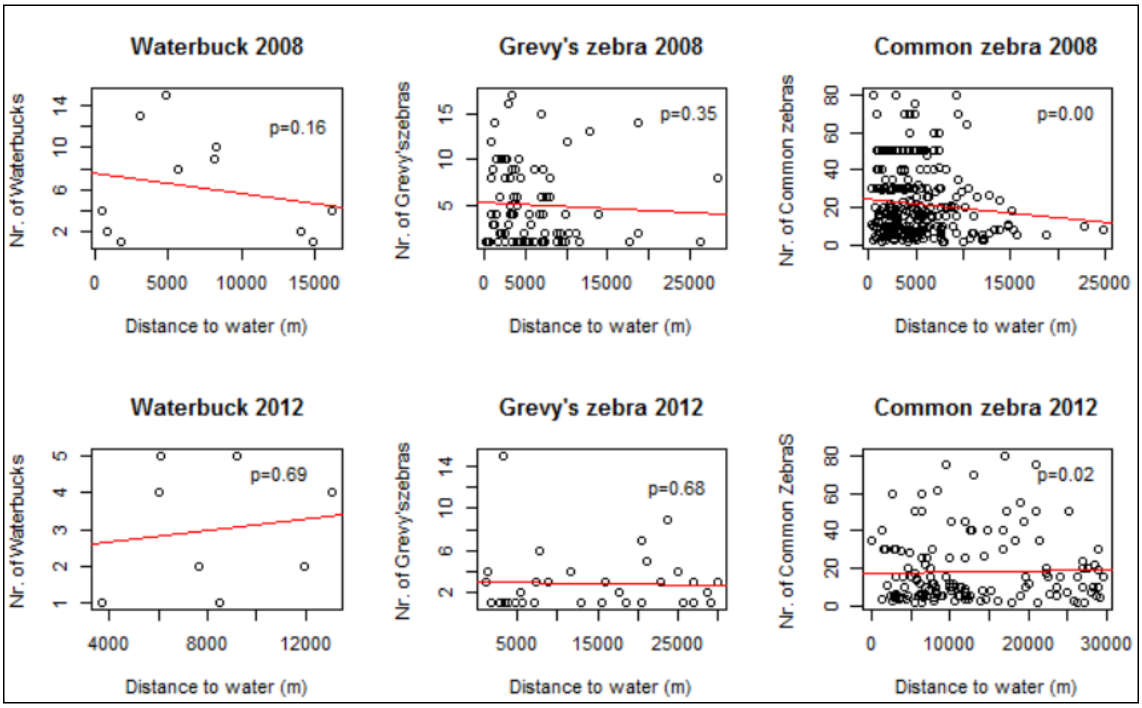

Figure 25: Distribution of medium pure grazers in relation to surface water.

4. DISCUSSION

4.1. Mapping surface water bodies using spectral indices derived from Landsat data

This study aimed to map surface water bodies during drought condition and non-drought condition. The MNDWI classification method was employed to delineate surface water in the study area. The MNDWI clearly displayed open water bodies due to enhancement process and the result of water mapping using MNDWI show that the overall accuracy during non-drought condition was 99% and Kappa coefficient is 0.97. The overall accuracy in drought condition was 93% and Kappa coefficient is 0.86 (Table 3). This indicates that that there were few misclassification in the MNDWI maps. These misclassification may be caused by some cloud and cloud shadow residuals that might have remained after performing cloud and cloud shadow masking.

One thing that may significantly affected the efficiency of MNDWI maps in using the normalised difference water index is the threshold selection (Chen and Leung, 2004). The threshold for MNDWI mapping will be influenced by the subjective decision of the user (Du *et al.*, 2014, Li *et al.*, 2013). To avoid the bias of the threshold selection, Otsu's threshold segmentation method was employed to obtain the image partition threshold in this paper. The result show that there was a decline in the extent of surface water bodies in the ecosystem during drought condition.

Furthermore the study showed the effectiveness of MNDWI method for mapping and monitoring the declining of surface water bodies in the Laikipia-Samburu ecosystem. The study suggest that carrying out similar study, using high resolution images, may give much more detailed water information in the ecosystem. However, the result may differ depending on the season as the MNDWI normally use the spectral reflectance values which is variable in space and time. Hence, it is proposed to use the satellite images captured from the same season of different years to arrive at the results (El-Asmar and Hereher, 2011; Feng *et al.*, 2015).

The disappearance of river Ewaso ng'iro during drought condition is the notable sign of drought impact in the study area.This is the main natural source of water that flows out in wet season and dry season in the Laikipia-Samburu ecosystem (Kioko, 2013). The observation in this result conform with previous studies who found the similar observation (Ericksen *et al.*, 2012; Kioko, 2013).

The data and maps produced in this study clearly revealed the spatial and temporal distribution of water bodies in the study area. This shows the effectiveness of satellite images in providing detailed information covering large geographical area. The result of mapping surface water showed the situation of water availability during drought condition and non-drought condition in the Laikipia-Samburu ecosystem. However, high resolution images such as SPOT and ASTER are proposed for further studies because high resolution images will be able to map both large and small water bodies which were not mapped by Landsat images. These sensors will provide detailed information of spatial and temporal characteristics of surface water in the Laikipia-Samburu ecosystem.

4.2. Change in water body availability under drought and non-drought conditions

In this study it was hypothesized that the abundance of water decreased significantly during drought condition. The final results agrees with the hypothesis since the abundance of water was significant ($p<0.05$) lower during drought condition compared to non-drought condition.

From the result, it was observed that, during non-drought condition the amount of water increases and become available in many parts across the ecosystem. Number of water bodies increased significantly during non-drought condition. Considering that the image used to map surface water was selected from high rainfall month, this increase in the amount of water in the ecosystem may be attributed by high rainfall. This shows that during non-drought period water is available in big part of the ecosystem and this may cause herbivores to spread evenly in many part of the ecosystem particularly browsers (Western, 1975).

During drought condition, surface water declined by more than half of water observed during the non-drought condition. Surface water were observed in few areas of the ecosystems specifically in the southern part of the ecosystem (Laikipia plateau). The result show that most water disappeared and few water sources remained reduced in size (Figure 20). The drastic declining in surface water availability in drought condition is the indicator that severe drought that occur in African savannah ecosystems affect surface water availability (Kioko, 2013). This is very challenging for ecosystem management because surface water provides many benefits for wildlife and environment.

4.3. Response of herbivores to water availability under drought and non- drought conditions

In this study, it was hypothesized that the number of herbivores increase as the distance to water decreases during drought condition. Herbivore distribution patterns always vary during drought condition because of increasing scarcity and distances between water and food resources (Ilbers, 2015; Smit and Grant, 2009). In this regard distance to water can be an important landscape characteristics to explain herbivore-water relationship during drought period (Redfern, 2002; Ogutu *et al.*, 2014, Letnic *et al.*, 2015).

If herbivores drinking requirements require regular access to surface water, water dependence species (e.g. grazers) should occur more close to water sources during drought condition. Hence the result of this study found that most water dependent species (Table 1) were not associated to water sources in drought condition. In non-drought condition only Common zebras were strong water-dependent of ten species analyzed having distribution strongly related to the proximity of water sources. The results of this analysis do not agree with findings from previous studies (Western 1975; Owen-Smith 1996); where they found grazers were more water dependent during dry period (De Leeuw *et al.*, 2001) in Northern Kenya, found similar result and he suggested that some other factors, related to distance to water, prevent these wildlife species from coming near to the water sources. In that case, other landscape characteristics related to distance to water may be the reason for this result.

The study also found that the distribution of water independent species (e.g. browsers) were not significantly related to surface water during drought condition. However, few browsers (e.g. Giraffes and Elands) showed strong relationship to water during non-drought condition. According to previous studies, browsers are not related to water particularly in non-drought condition because they obtain the bulk of water from the forage (Western 1975). In this case, the result of Giraffes and Elands do not conform with the finding observed by Western (1975) but conform with the finding investigated by De Leeuw (2001) which shows that wildlife are close to water regardless of species type.

The distribution patterns for elephant, impala and grant's gazelle, the three mixed feeders considered in this analysis, were comparatively similar in drought condition and non-drought condition. Their abundance were increasing as distance from water increased and they were not associated to water. The results of this study conform to the assumption made by Wolanski (1999), saying that small herbivores are restricted by food quality and large herbivores are restricted by food abundance. Therefore, the depletion of forage near water due to regular grazing during drought condition may compel both small and large herbivores travel further form water sources to satisfy their forage quality and quantity needs.

The distribution of herbivore in relation to water was tested by comparing the slope coefficients of their association. Herbivore-water relationship coefficients for four species common zebra, Eland, impala and elephant showed significantly ($p<0.05$) different between drought condition and non-drought condition. Six species (Giraffe, buffalo, gerenuk, water buck, Grevy's zebra and Grant's gazelle) did not show significant difference ($p>0.05$) in their distribution in relation to water. In reference to previous studies, herbivores distribution patterns usually vary during drought condition due to increasing scarcity and distance between water and food resources (Smit and Grant, 2009). Hence, the distribution of four species may have changed significantly due to water shortage, therefore, they need to travel far distance to access water.

The results obtained in this study are not amazing because it is commonly known that large herbivores respond to multiple landscape characteristics (Georgiadis 1986). Some of these characteristics can attract animals toward water and other can push away them. Though distance to water can be most important landscape characteristic influencing herbivore distribution during drought condition, other factors such as competition of resources can repel animals away from water. In this study appearing of animals away from water sources may be attributed by the following predicted factors as also observed by previous studies;

Heavy livestock grazing, savannah ecosystem is inhabited by both wildlife and pastoral societies (Ogutu *et al., 2010)*. During drought condition, food and water are limited. Livestock and wildlife compete over few resources available (De Leeuw *et al.*, 2001). Livestock may prohibit wildlife access to water sources in place herders can access, compete with and displace wildlife close to water. This situation may force herbivores to move far away from water sources to find alternative sources.

Animals may be pushed away from water sources by predators. Example, in Mara -Serengeti, it was found that riparian woodland habitats fringing most water courses were much avoided by herbivores because of elevated risks of predation. The common large ambush predator in the Mara serengeti, the Lion (*Pathera leo*) usually rests in these woodlands in the day time (Ogutu and Dublin, 2004). Avoiding zones near water where forage is low and if predation risks is high can cause herbivore-water relationship being insignificant.

Herbivores population may increase as distance from water increase due to depletion of forage around water and occurrence of vegetation abundance at the intermediate distance from water (Andrew, 1988; Kanga *et al.*, 2013). For example, Adler and Hall (2005) found forage production to increase with distance from water. This is due to overgrazing of that occur close to water sources during dry periods. Reid *et al.* 2003 found that grasses peak at intermediate distances from water and shrubs are most abundant far from water and hence attract and repel the herbivores to move away from water points. These evidences indicate the possibility of other characteristics to change the patterns of herbivore-water relationship.

The extent of aggregation close to water is influenced by the time of day when the observation are made. Drinking regularly takes place in the late morning for most of wildlife species (Ogutu *et al.*, 2014). Underlying this observation, good observation time would be done in the morning. However, wildlife counting survey in the study area was conducted from morning to evening. This may not provide enough information to study sufficiently the herbivore-water relationship. Hence based on this limitation, animal locations by proximity to water would need survey conducted over long periods of time and information on animal movements and behaviour (Ogutu *et al.*, 2014, Western, 1975).

The challenges uncounted from dataset used for this study may also be one of the factor that could also affect the hypothesis of this study. This study used the moderate high resolution. This resolution is limited to water bodies which have the size equivalent to image resolution. The small water bodies less that (30 m) were missing for the analysis. It may be possible that the missing water information had significant impact to the herbivore distribution since many arid and semi-arid rangeland characterised by small water ponds and these water ponds are potential for animals (Redfern *et al.*, 2005, Smit and Grant, 2009).

5. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study was to examine the impact of drought on the association between the surface water availability and herbivore distribution in the Laikipia-Samburu ecosystem. More specifically, the study aimed to test if there was a significant change in surface water availability during drought and non draught condition, and how herbivores respond to this change.

It is commonly known that water is the major determinant of herbivore distribution. Using distance to water as an explanatory variable, the herbivore-water relationship in drought condition and non-drought condition can be measured by looking at the significant change in slope coefficients. Hence, this study was built on the hypothesis that herbivores will increase more close to water in drought condition compared to non-drought condition. The study applied remote sensing technique to identify and map surface water during drought condition and non-drought condition. There was a significant different in surface water availability between drought and non-drought condition and the ecosystem lost more than 50% of its water during the drought condition.

This study observed the relationship between water and herbivores for individual species. Then species were grouped according to their water dependence and feeding behaviour to examine in to detail their relationship to water. This is because grazers are strong water dependants species and browsers are water independent species (Du Toit and Cumming, 1999; Western, 1975). The result showed that there was no significant difference in water dependence between browsers and grazers. The species which were significant related to water are only Giraffe, Eland and Common zebra. This relationship were observed during non-drought condtion.

To our knowledge, this is the first study to examine the herbivore-water relatioship during drought period and period in the Laikipia-Samburu ecosystem. In addition to that, this study have managed to show the spatial characteristics of surface water bodies during drought condition and non-drought condition in the Laikipia-Samburu ecosystem. These information obtained from this study are potential for decision making and management of wildlife in the Laikipia-Samburu ecosystem.

However, few limitaions were observed in this study and may have influenced the result of this study. First, Land sat used for mapping surface water was not of exact day when the animal count were conducted. Though they were relative comparable but they were not similar, this may lead to over etimation or under estimation amount of water. Second cloud masking involve removing pixel with cloud from the images. Masking may lead to small cloud residuals which may couse misclassification of water information.

Further reseach is need to study widely the spatial and temporal availability of surface water in the Laikipia-Samburu ecosystem and examine their influence on the herbivore distributions. More over this study recommend future studies to use active sensor and very high resolution images such as SAR for mapping surface water in savannah ecosystems. This recomandation is based on the fact that, savannah ecosyestem is characterised by clouds which is a challenge for passive sensors such as Landsat. Obtaining accurate surface water information will improve the herbivore-water relation understanding in African savannah ecosystem.

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