

# **The Influence of Rainfall on the Distribution of Burchell's Zebra (*Equusburchelli*) in Kruger National Park, South Africa**

**By**

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the requirements of Master of Environmental Science.**

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**AUGUST 2018**

## Declaration

I, **MakhaleAndani**, hereby declare that the dissertation of title: “The Influence of Rainfall on the Distribution of Burchell’s Zebra (*Equusburchelli*) in Kruger National Park, South Africa” was submitted by me in the Department of Geography and Geo-information Sciences at the University of Venda for the Master of Environmental Sciences (MENVSC). It has not been previously submitted for a degree at this or any other university, nevertheless, it is my own work in design and execution and that all referenced material contained therein have been duly acknowledged.

Signature.....

Date.....

## Abstract

Many South African nature reserves, like the Kruger National Park (KNP) suffer from monthly below average rainfall that puts pressure in the diversity of wildlife animals in the park. Very little attention has been given to the behaviour of zebra population during period of low rainfall in KNP. Hence, this thesis seeks to examine the role of rainfall in the distribution of burchell's zebra population from 1983 to 2012. Previous work has failed to explain the abundance of zebras in areas of low rainfall resulting from a long period of no rainfall in the area. Readily available data on rainfall and zebra population distribution was acquired from the KNP. The semi-logarithmic model was also proposed to estimate the probability of rainfall in the Kruger National Park. Three periods of low rainfall period were estimated from the graph and the years were further used to make comparison of how zebra behaves during periods when rainfall is low, medium or highest. GIS tools (spline and kernel) were used to analyse the trend between the years of zebras in relation to rainfall availability in Kruger National Park and a map was created with these tools. The study was based on a hypothesis that there exist a relationship between rainfall and the zebra population. The study advances our understanding of what determines the movement of burchell's zebra in the park. The findings from the research show that the impact of rainfall on zebra distribution is more complex than previously assumed. The findings based on mapping were able to indicate that rainfall variability does not influence the distribution of zebra, rather more zebras were found in areas with sparse vegetation and avoid dense vegetation as much as possible.

Key words: zebra, rainfall, vegetation

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## List of acronyms used

AVHRR- Advanced conditions Very High Resolution Radiometer

ENSO- El Nino Southern Oscillation

EPA- Environmental Protection Agency

GIS- Geographical Information System

KENPRO- Kenya Projects Organisation

KNP- Kruger National Park

IDW- Inverse Distance Weighted

IPCC-Intergovernmental Panel on Climate Change

ISDR- International Strategy for Disaster Reduction

ITCZ- Inter Tropical Convergent zone

NDVI- Normalised Difference Vegetation Index

WANA-The West Asia/North Africa

WHO- World Health Organisation

WICCI- Wisconsin Initiative on Climate Change Impacts

WMO- World Meteorological Organisation

## Glossary of selected words

In this study, unless the context indicates otherwise-

**Forage**- Plant material eaten by grazing livestock.

**NDVI**- is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyse remote sensing measurements and assess whether the target being observed contains live green vegetation or not

**Population**- the number of all organisms of the same group or species, which live in a particular geographic area and have the capability of interbreeding.

**Shapefile (s)** - is a simple, nontopological format for storing the geometric location and attribute information of geographic features

**Ungulates**- any member of a diverse group of primarily large mammals that include odd-toed and even-toed ungulates.

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## CHAPTER ONE: INTRODUCTION

### 1.1. Background of the study

Climate plays a huge role in the distribution of zebra population and determines its significance in the ecosystem (Celesia *et al.*, 2009) and rainfall variability is one of the characteristics of climate. Rainfall can be considered as below or above average, while what is below average in one area might be above average in another area. For the purpose of the study, rainfall below average will be considered as low rainfall, hence resulting to drought events. Droughts are a significant component of climate variability (Duncan *et al.*, 2012), and can have devastating impacts on animal population (Young, 1994). Low rainfalls are usually associated with high temperatures in the region and thus increasing the rate of evaporation (Nicholls, 2004).

Rainfall is one of the major components in the world most specifically in the African savannahs that influences the dynamic characteristics of the ungulates such as zebras and wildebeests (Ogutu *et al.*, 2008). African herbivore abundance and community structure are primarily determined by rainfall and nutrient status of the soil and could differ from one area to the next (Fritz *et al.*, 2002). The Amboseli ecosystem in the Southern Kenya is a semi-arid savannah and is dependent on water that is highly seasonal and hence the ungulates in that area have high adaptation mechanism strategies that keep them long to the period of water season (Western, 1975). Thus it has been evident that rainfall in the form of water is a crucial parameter in determining the distribution and abundance of different communities of animals in a region.

Zebra abundance and density can be influenced by resource availability which is dependent on climate variation (Illius and O'Connor, 2000). Their population performance is often limited by plant nutritional quality (van Soest, 1994). Competition for forage resources may amongst other things be determined by the availability of rainfall (Grange and Duncan, 2006). Rainfall plays a vital role in governing population dynamics in African savannas (Ogutu *et al.*, 2008). Deciding which areas are the most important for conservation and management of ungulates requires greater understanding of the locations and spatial distribution of species

habitat (Vina *et al.*, 2008; Rushton *et al.*, 2004). Even with drought having to hit an area, the impacts differ from region to region and species to species.

## 1.2. Problem statement

Precipitation plays a vital role in the demographic profile of wildlife population in such a way that the entire population is controlled by rainfall pattern of the place. Zebras are water dependent species and, generally grazers need water at least every two days unlike browsers which get their moisture from the green leaves they consume and are less dependent on direct intake of water. During drought period in the Kruger National Park (KNP) zebra tend to migrate. As stated by Brassett (2016), large dams in the park that are usually full during summer season are apparently dry and lush and this has led to vegetation giving way to a harsh winter's landscape. Nonetheless, changes in climate particularly precipitation, impact on zebras in a variety of ways depending on the complexity of the system, including the geographical surrounding and the availability of factors that may also influence the changes (Kaeslin *et al.*, 2012). Zebras are found to occupy a common area during a period of low rainfall; the area normally becomes overgrazed leading to bare land. This is usually the result of drought and zebras cannot move to other areas because such areas lack their type of forage. Hence, too much pressure is exerted on available food resource, leading to some zebras dying from starvation. Overgrazing of grass has a negative impact on the ecosystem because it disturbs the rejuvenating of the grass, hence leading to the area becoming a bare land. This eventually leads to soil erosion once rainfall is experienced in the area. The previously experienced drought events in the KNP have significantly impacted on zebra distribution and therefore negatively impacted on the food web chain that the zebra population is part of. Zebras have been affected by the shortage of water due to limited rainfall that has been received in the park. When this happens, important biological processes such the regeneration of vegetation in the park are hampered and zebra and other animals' population composition will also change. Need therefore arises that the effects of low rainfall on zebra communities within the park be investigated further to improve the survival of other animal communities that are not drought resistant.

### **1.3. Main aim and specific objectives**

#### **1.3.1. Main aim**

To study the influence of rainfall on Zebra population for period 1983-2012

#### **1.3.2. Specific objectives**

The specific objectives are:

- To establish the relationship between annual rainfall and zebra population distribution.
- To examine how changes in normalized difference vegetation index from time to time affect zebra population.
- To map the relationship between rainfall and normalised difference vegetation index over a period of 29 years.
- To map the zebra abundance and vegetation distribution

#### **1.3.3. Research hypothesis**

- Null hypothesis ( $H_0$ ): There is no relationship between rainfall and zebra population abundances.
- Alternative hypothesis ( $H_1$ ): There is a relationship between zebra population abundances and rainfall.

### **1.4. Delimitation and description of the study area**

#### **1.4.1. Delimitation of the study area**

The purpose of this study was to further investigate the trend of zebra survival in the period of low rainfall mostly referred to as the drought period. Amongst other communities of animals in the Kruger National Park, zebras were likely to be of interest since they are drought resistant but are water-dependent. Kruger National Park is one of the conservation areas in South Africa that harbours a greater population of zebra and they are able to interact with other different populations. There are limited studies conducted aiming at protecting wild animals as a whole, but the focus dwells on a specific population such as the Rhino or Elephants and how they respond to drought events.

#### **1.4.2. Description of the study area**

Kruger National Park was formally introduced as a conservation area in the year 1926 (Pienaar, 1990; Kruger National Park, 2008). Amongst all, it is one of the largest game reserves in Africa occupying a large space and comprised of a variety of animal and plant species. It covers approximately 19,485 km<sup>2</sup> of the Limpopo and Mpumalanga provinces in the north east South Africa (*Birkett et al.*, 2012) and resembles has an elongated shape. On the eastern part of the reserve it is bordered by private and government nature reserves and some communities. Wildlife animals in the park mostly occupy all habitats, but zebras tend to avoid the far south west habitat because the area is characterised by sour bushveld, thorn thicket near rivers and the bushwillow woodland (Smuts, 1975). Figure 1 is a map showing the study area of Kruger National Park (KNP).

#### **1.5. Characteristics of the study area**

##### **1.5.1. Climate and temperature**

The KNP experiences two seasons, dry season that occurs between May to September and wet season occurs between October to April of the following year (Zambatis and Biggs, 1995). Dry seasons are associated with winter months and are usually warm and mild. During mid-winters, average maximum temperature is approximately 23°C with minimum average of 6°C. There is occasional rainfall during this season and humidity is low, therefore water becomes scarce in the park leading to animals being attracted to permanent water sources. Wet seasons are associated with summer months (October to April). Temperatures often range above 40°C with the maximum mid-summer average temperature of 30°C and minimum average temperature of 19°C. Summers appear uncomfortably hot with high humidity and rainfall is associated with storms in the afternoons (Van Wilgen and Richardson, 2012).

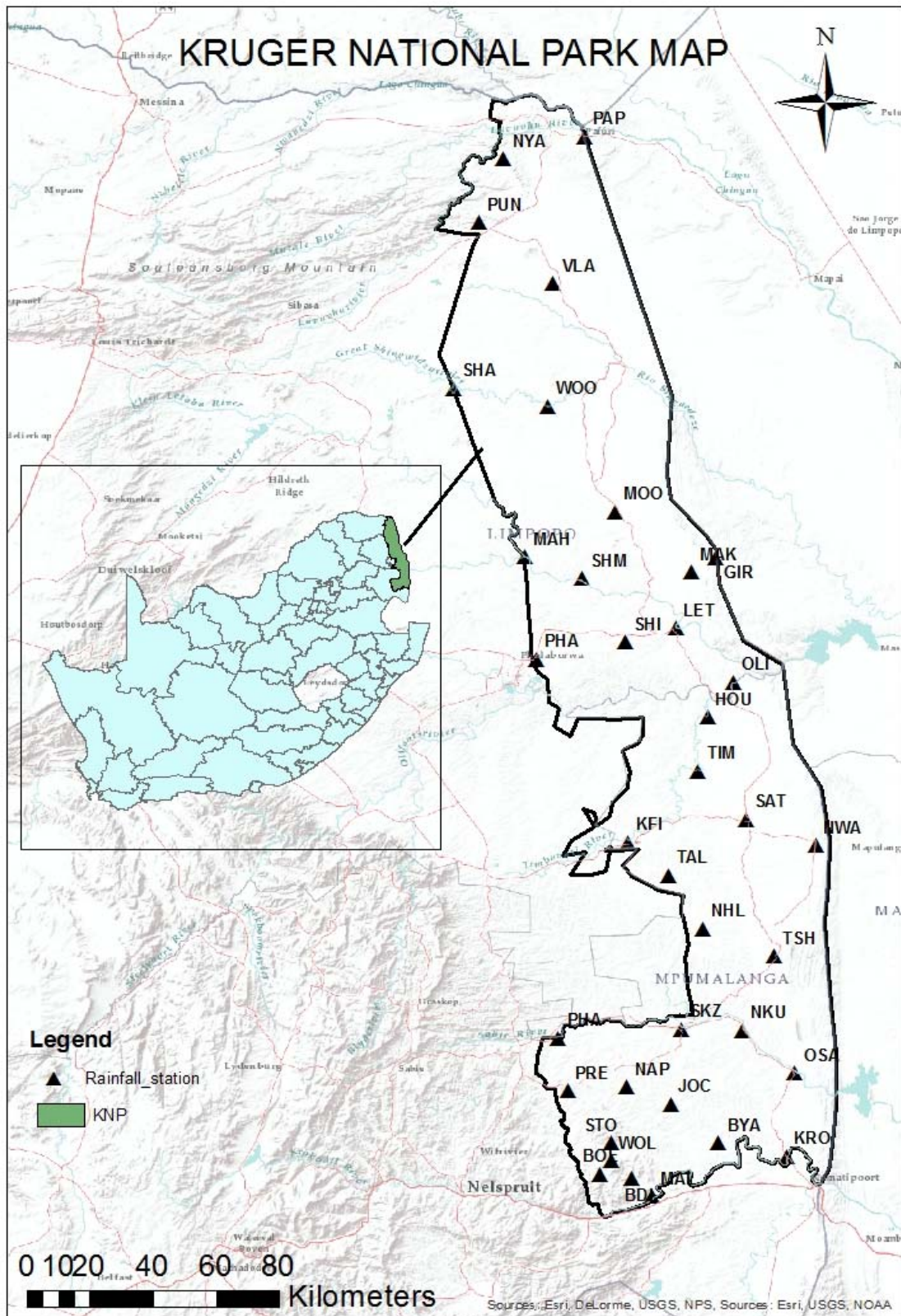


Figure 1.1: Locality map of the Study area

### **1.5.2. Rainfall distribution**

Rainy season occurs from October to April and is accompanied by thunderstorms (Zambatis and Biggs, 1995). Average annual rainfall ranges from a maximum of approximately 750mm in the south west to 350mm in the north of the park (South African National Parks, 2008). Rainfall in the region is particularly influenced by the presence of the inter tropical convergent zone (ITCZ) as it moves south of Vhembe District (Kabanda, 2004). During the wet season, zebras would migrate in large numbers leading to the area experiencing high rainfall in search for large amount of grass.

### **1.5.3. The physical environment**

The topography of KNP ranges from arid to semi-arid with sediments that are as old as 3.5 billion years (Schutte, 1986). Goudplaats and Makhutswi gneisses are two common rocks in the park and are very old, (Schutte, 1986). The geology, topography, soil and fire patterns in KNP range from regional to local factors. Its geology is comprised of the western half and the eastern clayed basaltic and rhyolitic half (South African National Parks, 2008). Basaltic areas have higher grass production than the granitic, leading to more frequent burning (Grant and van der Walt, 2000).

### **1.5.4. Land use**

According to Nekhavhambe (2012), amongst any other thing, KNP main land use is to act as a conserving area, protecting the natural area and its wildlife population. However, KNP area is characterised by a variety of land uses. These include activities like small scale farming, limited commercial farming and grazing by large stocks and other wildlife grazers within the improved rural areas and communal conservation areas (South African National Parks, 2008). Separately, the other part of the park is used for private conservation, game farming, cattle farming, high profiled crop farming and tourism purposes.

### **1.5.5. Hydrology**

Rivers are more common in the western half of the parks. Terrestrial landscape is largely dissected by the drainage channels of undulating land as the rivers cross Kruger primarily in the west-east direction. The KNP is characterised by a very low stream density on the northern part of the Park (Smit *et al.*, 2013). KNP is highly dependent on the downstream part of the Olifants River in South Africa. The Olifants River flows through KNP and Mozambique then into the Indian Ocean. As it moves through KNP, it drains it then empties into the Ocean. The other portion of the Olifants River catchment covers an area of approximately 74 500 km<sup>2</sup> and has 201 water storage dams (Gyedu-Ababio *et al.*, 2012). The Sabie and Crocodile River are the most diverse in South Africa in terms of aquatic biodiversity (Ferrira, 2012).

### **1.5.6. Vegetation**

In the park, plant life is mainly found in four main conservative areas. The common vegetation of the KNP include thorn trees and bush-willow veld, the knob thorn and Marula veld, red bush-willow and mopane veld and lastly the shrub mopane veld. The thorn trees and bush-willow velds are found along the western boundary and severe in the centre of the park along south of the Olifants river and are mostly avoided by zebras (Smuts, 1975). *Acacia* trees are commonly found along the streams. The Knob-thorn and Marula veld lie along the south of the Olifants River on the eastern part of the park. Then there is the shrub mopane veld, which occupies the entire north-eastern part of the park. The park is also characterised by shallow grassy wetlands and large alluvial deposits along the major rivers in the northern part of the park and the southern part of the park is characterised by open tree savannah (Smit *et al.*, 2013).

## **1.6. Significance of the study**

Low rainfall is one of the disturbing events in the environment; it disrupts the ecosystem and the life pattern of natural organisms. KNP has since experienced at least three (3) events of drought between 1991 and 2003 Wessels and Dwyer (2011), and these events are still expected to occur in the near future if low rainfall continues to occur in the park. African forests are commonly known to experience a

variety of climate change and yet little has been published or few studies have been conducted about the climate change threats to wildlife population (Chidumayo et al., 2011). The total average rainfall that is required for the survival of zebra species in the park has not yet been clearly stated. The focus has rather dwelled much on how rainfall influences wildlife population in general in the park. The zebra population basically occurs throughout the park, but the study aims at indicating areas of high densities within the park during low rainfall years or seasons. Therefore, it is of significance to conduct this study in order to examine the influence of rainfall on zebra abundance. Previous studies conducted in KNP were focused on the general management of the park (based on certain population such as the rhino and elephant population) instead of the entire population (South African National Parks, 2008), while there is very little knowledge about the distribution of zebra abundances during the low rainfall period and the available forage. This study aims at expanding the academic knowledge regarding the conservation of zebra population during the most devastating events such as drought. It will contribute to improving the current environmental management strategies as those being implemented together with those that have been already been implemented.

## CHAPTER TWO: LITERATURE REVIEW

### 2.1. Introduction

This chapter made use of scholarly articles, books, dissertations, conference proceedings, journals and other sources which were relevant to a particular issue on this study, area of research and provided context for the dissertation by identifying past research that were related to Kruger National Park, meteorological drought, rainfall, and zebra population. A number of studies on rainfall influence to the zebra have been done around the world, but little information has been provided on South Africa most especially the Kruger National Park. This review focuses on the influence of rainfall on zebra globally and locally and how low rainfall in a form of drought has been handled within the past years. Rainfall is one if not the common aspect that influence the occurrence of drought in an area, thus historical record of rainfall need to be compared with current rainfall patterns.

### 2.2. Climate change and its variability

Due to climate change, Gaum in the United States is likely to experience warmer temperatures and changes in rainfall that would shift or disturbs the ranges of various plants and animals within the Gaum forest (Change, 2007) and over the past 30 years it has produced numerous shifts in the distributions and abundance of species worldwide (Thomas *et al*, 2004). However, it is not always clear whether the animals and plants would be able to survive the changing nature of climate. Various studies have been able to anticipate that climate change is expected to accelerate major changes on the environment of which most have already begun. This is also expected to occur in the Arctic which will eventually affect the rest of the world through global warming and rising sea level (Assessment, 2004). As projected by Van der Linden and Mitchell (2009), by the year 2100, climate of Europe will be very different from what it is currently.

In reference to a study conducted by the Intergovernmental Panel on Climate Change (IPCC) (2007), the rate of climate change will have various consequences that would lead to the increase in average global temperature, rise in sea levels, change in global precipitation patterns (either cause floods or droughts) ( IPCC,

2007). An increase in temperature with change in rainfall and humidity has a significant impact on zebra population (Hofmeister *et al.*, 2012). Annual average recorded temperatures have risen steadily globally in the past decades and this change is expected to occur in the future (Kaeslin *et al.*, 2012). This change is common in African countries where current models used to project climate have indicated a mean annual temperature rise of about 3-4°C across the entire continent (Kaeslin *et al.*, 2012).

It seems that very little studies were conducted in the past years on climate change because most of studies available are dated after 2000. Does this imply that before then the rate of climate change was not expected to have reached the stage to which it is at now and still expected to accelerate? The studies are also conducted by organizations and not individual scholars. It would have been probably easier if more studies on climate change were conducted in the previous years in order to understand the current situation better. Nonetheless, since the situation is already current and becoming frequent, more widespread and intense, the demand for information services on weather and climate extremes is growing (Data, 2009).

Climate change effects are likely to result in low rainfall or drought leading to the increase of overgrazing by livestock due to limited precipitation to support the survival of vegetation and the availability of water (Butler *et al.*, 2006). Droughts are endemic to features in southern Africa (Austin, 2008). Even though drought appears to be common to many, it is the least understood natural hazard and gets a chance to affect many people and wildlife animals (Erian *et al.*, 2013). Even though it happens not to be understood by many, it is now receiving popular attention because of its intensity and frequency (Kenya Projects Organization (KENPRO, 2010). Although the impacts of drought may be the same, the management of coping strategies may differ from region to region or from one population to the other just like with the zebra population (Wilhite, 2000).

### **2.3. Rainfall distribution and drought**

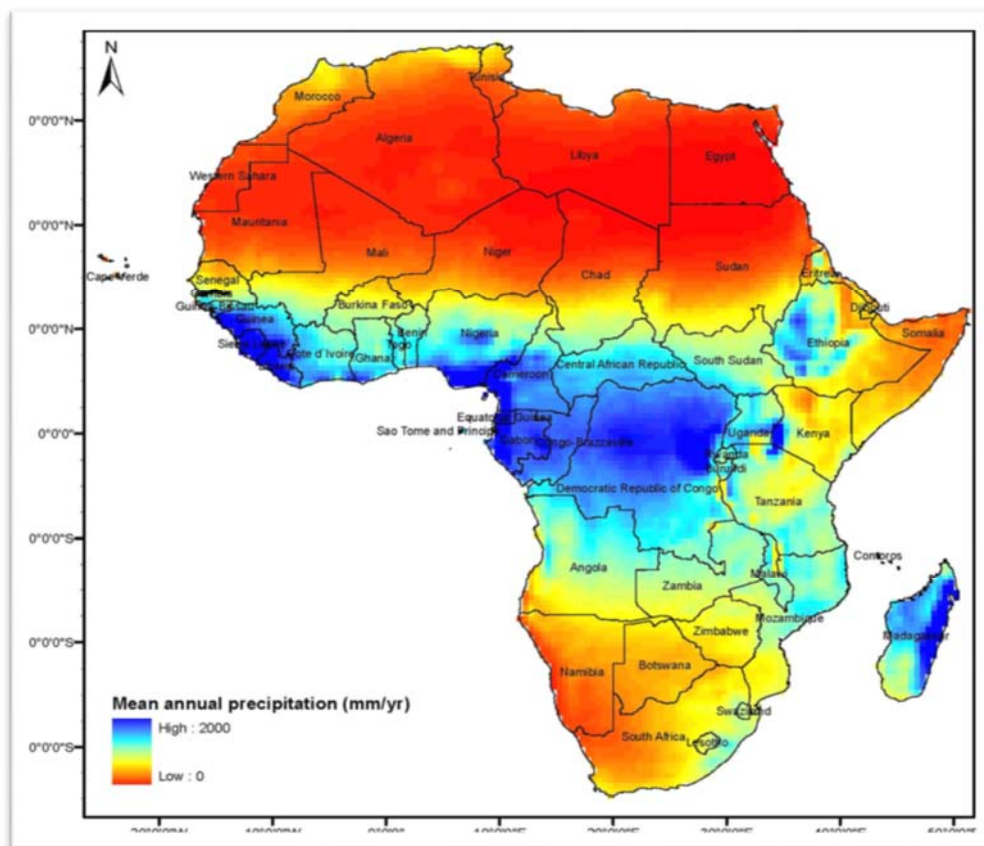
According to Davis (2010), it has been estimated that due to climate change, there will be a shift in the availability of water and it will increase water stress which leads to high demand of water by African animal population in year 2020.

Drought has always been related to nutritional factors on intra-annual rainfall patterns, such as dry season rainfall (Sitati *et al.*, 2014). They are common conditions in California's climate and have been recorded as intense between period 2011 and 2014, (Hanak *et al.*, 2015) and were the driest years experienced since the year 1995. During a study by the Water Research Commission (2015), it was concluded that Texas is likely to experience drought that would last for a period of six months to a year, than it is most likely to experience average precipitation during the course of the same period. Drought is therefore a condition that is directly linked to the amount of precipitation that is received in a region from time to time. Studies were conducted in Africa specifically referencing period 1900 to 2003 in relation to rainfall distribution amongst different parts of the world (Davis, 2010) and it was estimated that rainfall variability will change overtime.

There are distinct differences in intra-annual variability of rainfall across different regions in the African continent (Masih *et al.*, 2014). Southern Africa receives most of the rainfall during October–March, whereas Sahel rainfall is concentrated during July–August summer monsoon period. The decrease in rainfall distribution has given way to the likely increase of drought within some parts of the world. It includes; the Sahel, the Mediterranean, south western Africa and some parts of the Southern Asia (Davis, 2010; Duncan, 2011). These conditions eventually lead to changes in seasons with an increase in runoff and disturbances of glacier formation in particular affected areas. Most countries in the Horn of Africa and equatorial eastern Africa receive rainfall in two seasons from/during October to December which is referred to as the short rainfall season and from/during March to May is referred to as the long rainfall season. Northwestern Africa receives most of the rainfall during October–April (Masih *et al.*, 2014). Drought monitoring is a key step in drought management (Trambauer *et al.*, 2014). Figure 2.1 indicates the African continent with rainfall depicting very high spatial and temporal variability across the continent (Masih *et al.*, 2014).

The map displays the occurrence of rainfall throughout African countries, indicating that the highest rainfall occurs in the middle of African countries and in countries along the west coast of the West Africa, with the least rainfall experienced in the

western, eastern and some part of the southern African parts such as South Africa and Namibia (Masiah *et al.*, 2014).



**Figure 2.1: Map of the Africa’s rainfall patterns. (ERA-Interim corrected with GPCP v2.1; period: 1979–2010.) (Masih *et al.*, 2014)**

South Africa experienced the driest year in the record during the year 1992. This dry period can lead to drought events. However, 1992 was not the only year when drought occurred. There were still some years prior to 1992 whereby rainfall low was experienced (1982 and 1983) (Zambatis and Biggs, 1995). Studies that have been conducted indicate that the West and Central Africa have highly experienced shortage of rainfall which led to exceptional events such as drought and impacted negatively on the key wildlife population and its habitat (Chidumayo *et al.*, 2011).

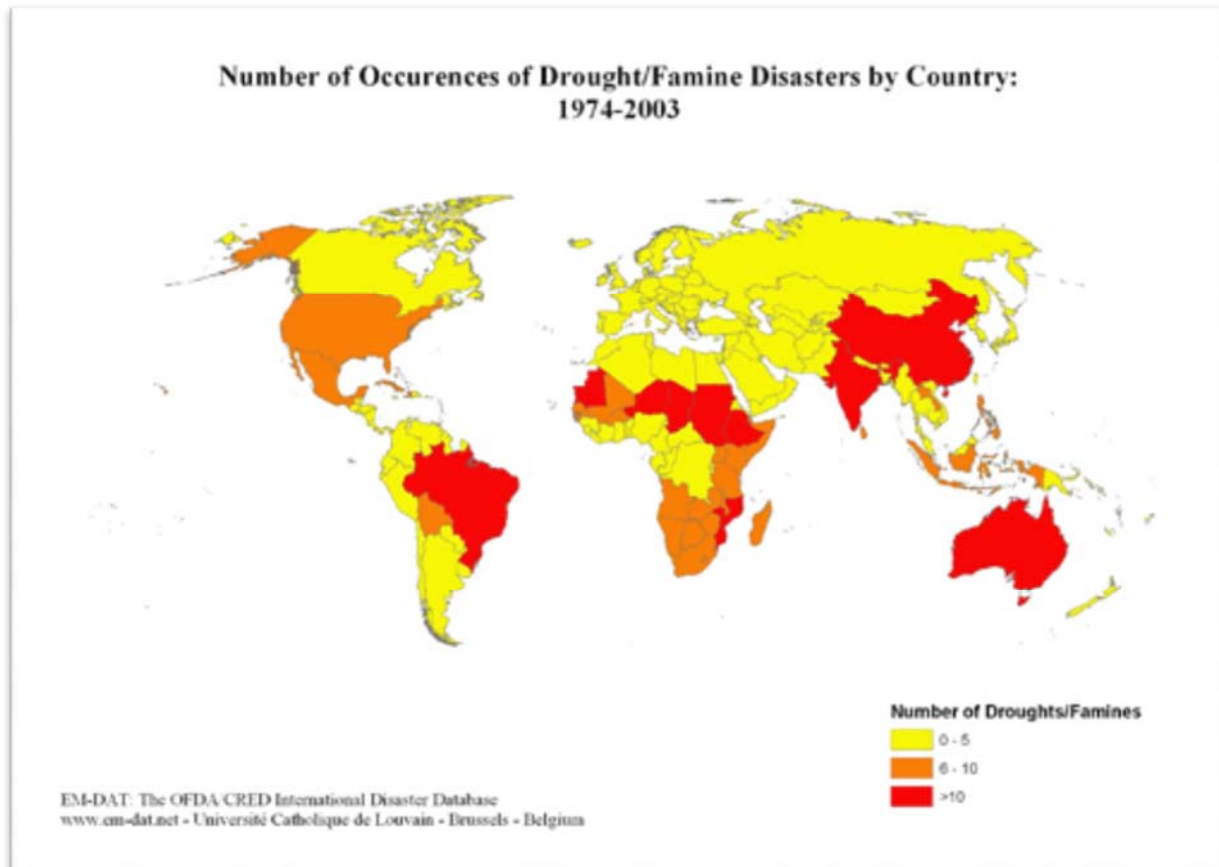
There are variety of drought definition depending on where it is occurring and the period it takes. Drought is a natural phenomenon that results from the amount of

precipitation that is received than what has been expected (Wilhite, 2002; Environmental Protection Agency, 2014). Meteorologist generally define drought as a prolonged period of dry weather caused by a lack of precipitation that results in a serious water shortage for some activity, population, or ecological system (Environmental Protection Agency, 2014). Drought is common in the semi-arid and arid environment and has severe impacts on the wildlife population (Duncan *et al.*, 2012). Some uncommon drought event occurred at the Amboseli in Kenya which led to the buffalos changing their site of grazing and moved to deeper swamps, while zebras and wildebeest followed at a later stage which led to the area becoming heavily depleted due to grazing (Amboseli Conservation Program, 2009).

Drought is characterised by three main aspects: intensity, duration, and spatial coverage (Dai, 2010). Intensity is the degree of precipitation, soil moisture, or water storage deficit. The duration of drought may be a period of few months to few years, but extreme drought can last for several years to decades. The spatial coverage of drought is the geographical area that was affected by drought (Mahajan *et al.*, 2016). Drought occurs differently in every continent, country and regions also depending on the geographical site (International Disaster Database (2015). The African continent in Figure 2.2 shows that the occurrence of drought in Southern Africa differs from the drought occurrence in the western and eastern parts of Africa. The African continent can experience drought at the same time but its intensity from country to country will differ, from low, moderate and high.

Drought is known to differ from region to region; a noble part of South Africa has been recorded and recognised as a drought disaster area for up to 70% of 30-year period. However, the eastern part of South Africa has not yet been declared as a drought disaster area (Department of Agriculture, 2004). It is possible for one region to experience localised drought while the other region experiences the drought conditions that may also lead to devastating impacts. Drought is a phenomenon that is characterised in three but they all originate from lack of rainfall as a result of climate change or climate variability (Wilhite, 2000). Drought does not only occur in the dry areas, but can also take place in the wet and humid regions (Dai, 2010). It occurs both in high and low rainfall areas and nearly in all climate regions (World

Meteorological Organisation, 2006). The commonly recognised types of drought are meteorological, agricultural and hydrological drought (Zargar *et al.*, 2011; Environmental Protection Agency, 2014; Monacelli, 2005).



**Figure 2.2: Number of occurrences of droughts/famine disasters by countries. (Source: International Disaster Database, 2015)**

Drought in the early 1990s reduced Kruger's buffalo population by more than half to about 14,000, but the buffalo population has since rebounded to more than 40,000 (Torchia, 2016). It has been observed that in the KNP, hippos have increasingly been seen grazing during the day than to be found in pools and rivers as usual (hippos are found in the rivers during the day and grazing during the night) (Sanchez, 2016). To meteorologists, this has been a sign that drought is to be expected in the next coming years and it is bound to kill some of the animals that will be exposed to the drought events with the zebra population being at risk too (Torchia, 2016; Sanchez, 2016). Every 20 years or so, a really severe drought comes along, and this was experienced in KNP in the thirties, sixties, early eighties and again in 1991/92 (van Vuuran, 2016). Drought experiences differ from country to

country and region to region. In the year 2000 the northern east part of South African and Mozambique experienced extreme floods conditions while in Kenya, Laikipa drought conditions were experienced from 1999 to 2000 (Georgiadis, 2003). This simply means that, within a given period of time one region can be experience drought while the other is experiences floods and what might be drought to one region might be floods to the other region.

#### **2.4. Zebra and its vulnerability to low rainfall**

Burchell's zebra are commonly referred to as the plain zebra Skinner and Chimimba (2005), and are the most common type and large population in Africa, ranging from southern Sudan to northern South Africa. These are areas that are characterised by only two seasons, the dry and wet season respectively. They are characterised by stripes on their body (Figure 2.3) which make them appear different from mountain and grey zebra. In South Africa they are commonly found in Limpopo and Mpumalanga where they are highly protected and conserved at the KNP (Maimela, 2015).

Burchell's zebra generally prefer open grasslands, open woodlands and open scrub environments and their means of survival during the dry seasons is through underground tubers and rhizomes (Maimela, 2015). If drought is to persist throughout the country, wildlife in KNP is to face dangers of water shortage as the grass within the park has already turned brown (South African National Parks, 2008). Migration allows zebras to optimize their nutrition by moving to prime grasslands during wet season (Bartlam-Brooks *et al.*, 2013). They have the ability to tolerate high infections of ticks and are not susceptible to food-and-mouth disease or to malignant catarrhal fever (Wildlife Ranching, 2009); hence they are able to survive through harsh disease conditions.



**Figure 2.3: Picture of Burchell's zebra (October, 2016)**

The major physical factors affecting the distribution of animals in any habitat are the availability of water, effect of fire, topography, temperature variability and relative humidity (Odum, 1971). In areas where artificial permanent waters such as dams and bore holes have been established, the distribution of ungulates that require water for drinking and wallowing is directly influenced by their presence. Thus, water becomes an important ecological factor affecting the distribution of animals in such areas.

Climate change threatens the zebra habitat and disturbs the relationship amongst the wildlife population (Wisconsin Initiative on Climate Change Impacts (WICCI), 2011). Therefore, zebra will be forced to shift to a new habitat through migration. Climate change can further affect zebras in two different ways. It can either be direct or indirect or both (WICCI, 2011). Species that are directly linked to climate and any change that is directly influenced by climate (temperature, pressure, and precipitation) are those that are directly impacted by any form of climate change.

Indirect impacts mainly focus on the surroundings of the wildlife population and not the life history.

According to Vetteler (2014), although most of wildlife species suffer or can be affected by low rainfall events, Texas most common wild species are adapted to periods of low rainfall through the type of food they consume such as succulent plants like cacti which contain high amount of water in them. The impacts of low rainfall become clear when they are observed or viewed from a range of geographical scale. A population of zebras in one geographical area cannot experience the same as the other population in the other geographical area (Masih *et al.*, 2014). Its impacts differ with the coping mechanism strategies such as advanced irrigation systems. Droughts from low rainfall are often associated with outbreaks of diseases, including epizootics of viral disease (Packer *et al.*, 1999). However, it is a challenge to assess the role of diseases and no die-offs are usually reported due to diseases. Nevertheless, extreme climate events increase the susceptibility of animals to disease outbreaks (Ogutu *et al.*, 2008).

There is quite a misconception that during prolonged drought events, wildlife animals die of thirst, while in fact they usually starve to death due to depleted grazing site (Kotze, 2015). It is therefore suggested that water should be provided in a way that creates conditions that are suitable for sustaining a wide range of biodiversity and not only for species that are water dependent and are found in areas that are close proximity to water . These species include the zebra and wildebeest, even though they migrate, they move in areas that are close to water sources. The impact of drought on zebras depends on the vulnerability of the affected system (Yone *et al.*, 2006). The West Asia/North Africa (WANA) region is an area that is very prone and vulnerable to natural disasters more especially drought events (International Strategy for Disaster reduction (ISDR) (2008). The vulnerability of drought depends on its stage. The stages of drought include normal conditions, potential drought, drought and post drought.

Recent studies have associated the vegetation dynamics, as assessed by the NDVI, with animal species distribution and the movement pattern of these animals (Boone *et al.*, 2006; Vina *et al.*, 2008). Rainfall variation is associated with substantial changes in the abundance of zebra population (Owen-Smith and Mills, 2006).

Fluctuations in rainfall play a fundamental role, in herbivore population dynamics in savannas, and should be evaluated and accounted for before effects of other factors (such as predation) can be reliably revealed (Ogutu *et al.*, 2008). In addition to the absolute quantity of rainfall therefore the variability of rainfall appears to be an important factor limiting savanna herbivore populations (Georgiadis *et al.*, 2003).

According to Marshal *et al.*, (2005), precipitation is the major influence of wildlife population in an ecosystem. Zebras depend on forage, and years of abundant rainfall means abundant forage for the survival of Zebra population. Variability in climate leads to climate change which accelerates climate warming which is a threat to zebra population, as it has increased the mortality rate of many common species in west and central Africa (Chidumayo *et al.*, 2011). As rainfall influences the movement of migrates in an area (Maddock, 1979), it may also influence zebra movement as opposed to changes in survival and reproduction of residents (Ogutu *et al.*, 2008). When the Serengeti plains experiences low rainfall, zebras head to the savanna and then trek north of the Maasai Mara in Kenya to Victoria where there is green vegetation year round (Kosmala, 2013). The distribution of zebra increases with the increase in rainfall and declines with further increase in rainfall availability (Ogutu *et al.*, 2008).

Georgiadis *et al.* (2003) argued that simulation models strongly suggest that dry season rainfall has only influenced the wildebeest from the Serengeti dynamics since the late seventies (Pascal and Hilborn, 1995; Mduma, *et al.*, 1999), but did not have much impact on the burchell's zebra, for which predation might have been considered to be the dominant factor. Studies have indicated that the biomass ungulates species in African savannas (Coe *et al.*, 1976) and of individual herbivore species increases with mean annual rainfall. This implies that, zebra species are more dependent and responsive to annual rainfall of an area. Zebras are migrant species and would only stop moving during the rains because usually the plains are a homogenous habitat with water universally available (Kingdon, 1979).

Rainfall has more influence on species reproduction as compared to temperature, most specifically in species that are found in the arid areas like the tropical Africa (Ogutu *et al.* 2009). Extreme drought events can affect any kind of animals in an ecosystem; it could either be large bodied or small bodied, herbivores or carnivores;

thus, they can all experience the large-scale die offs and eventually decline in population and increase in mortality rate (Marshal *et al.*, 2002). “The abundance of new-born calves migratory zebra are best correlated with monthly rainfall and it had exerted both negative and positive effects on abundances of zebra in Mara-Serengeti ecosystem of East Africa” (Ogutu *et al.*, 2009) As compared to other ungulates, zebra are more responsive to monthly rainfall, suggesting that rainfall affects their movement (Ogutu *et al.*, 2008).

According to a study that was conducted in Laikipia (Kenya), zebra die-offs were observed during the severe drought in 1984 and these droughts were thought to be the cause of these die-offs because the number of zebras went down. However, population of zebra began to increase over a succession of average to wet years (Georgiadis *et al.*, 2003). Each and every period where there was severe drought a number of drought die-offs were observed. This can be an indication that drought might have an impact in the distribution of zebra population. These die-offs were not only observed in Kenya only but other areas like in the Kruger National Park as the amount of rainfall received was not the expected amount of rainfall. Reduced rainfall during the dry season, which is projected to be exacerbated in the future on continental Africa (Hulme *et al.*, 2001), will probably reduce zebra populations (Ogutu *et al.*, 2008). Based on the 2015/16 South African National Park Annual Report, if the park did not receive rainfall the next two months mortalities would begin to be experienced because there would be no food and the dams would dry up and the water levels would be quite low. An interesting observation by Georgiadis *et al.* (2003) was that zebras in Lakipia (Kenya) do not migrate seasonally, but would shift habitats locally in response to patchy rainfall. The same could be true with KNP suggesting high vulnerability of zebras to drought.

Harrington *et al.* (1999) hypothesised about the cause of the decline of ungulates in the KNP by stating that the series of drought years led to progressive aridity of the habitat with below average rainfall during the eighties (1982/83 and 1986/87/) and early nineties (1991/92), following years of above rainfall in the seventies (Grant and van der Walt, 2000) For any large-bodied grazer population limited by rainfall, rates of decline in drought years are typically higher than rates of increase in wet years

(Illius and O'Connor, 2000). Thus, the greater the variation in annual rainfall, the lower the ratio of mean rate of increase to mean rate of decline, and the greater the proportion of time the population spends below carrying capacity (Georgiadis *et al.*, 2003).

The immediate problems caused by drought include predator starvation, local extinction of several species of wildlife, increased human-wildlife conflict, and stepped up poaching and unsustainable use of natural resources (Kenya Wildlife Services (KWS), 2009). Water shortage is primarily the main cause of zebra concentrations along the lower lying drainage lines during the dry season (Kingdon, 1979). Rainfall conditions can affect the vulnerability of zebra to disease outbreaks, particularly of anthrax (du Toit *et al.*, 2003). The population of buffalo population in Kenya decreased by about 60 per cent from a total of 30 000 to 14000 and many other herbivore population numbers declined, including hippo, warthog, common reedbuck, kudu and giraffe. However, many of these animal populations rebounded in the wet years after the drought period has passed (Kotze, 2015). Several studies have indicated that the amount of rainfall has an influence on the distribution of zebra. When rainfall is high, the population of zebra increases and when rainfall is low, the population also decreases (Georgiadis *et al.*, 2003). The park is dependent on its perennial rivers (Luvuvhu, Sabie, Crocodile, Olifants, and Letaba) for water supply. However, these rivers have been showing a sign of drying up to due availability of water (South African National Parks, 2008). Rainfall within the park has recently shown wider annual variation than during the earlier historical records (Ogutu and Owen-Smith, 2003).

Zebra is an herbivorous that is drought resistant. Nonetheless, these species are facing the greatest threat of starvation that can also lead to death because of lack of food (South African National Parks, 2008) and become easy prey for predators. Burchell's zebra tend to converge in areas with strategic and scarce resources such as water and pasture during the dry season but during wet season these resources are well distributed in range. Therefore, zebras scatter over a large area, reducing their density (Regassa and Yirga, 2013). The start and pace of zebra migration is controlled by the environment. It is initiated by cumulative precipitation, with daily movement being a function of precipitation rate and Vegetation (Bartlam-Brooks *et*

*al.*, 2013). If the number of zebras is to decrease with an increase in rainfall, it could be influenced by the predation factor (Sencota, 1988).

## **2.5. Low rainfall as a drought indicator**

Drought is influenced by the amount of precipitation received than what has been expected, the change in the weather patterns tightens the occurrence of drought (Economic Commission for Africa, 2007). One of drought causes in South Africa is the variability of rainfall which is influenced by the El Nino phenomenon which accounts for approximately thirty percent (30%) of the rainfall received in South Africa (Tyson and Preton-Whyte, 2000). Southern Africa experienced one of the worst drought episodes during period 1991-1992, where rainfall below average was received and it was caused by the powerful El Nino (Water Research Commission, 2015).

Wessels and Dwyer (2011), define El Nino Southern Oscillation (ENSO) as a phenomenon that results from the abnormal sea temperatures that would last for a period of five months or more strictly being at an average of 0.5°C. They are also referred to as the anomaly episodes. In the past 200 years, the ENSO episodes have been recorded to be at their greatest peak in South African history and they have caused drought Wessels and Dwyer (2011). Positive ENSO phases (El Nino) have been recorded to have an influence over Southern Africa. For example, In Italy, when drought period ends it is accompanied by flashes of floods and some intense hurricanes (Rojas *et al.*, 2014).

When drought period expands and goes beyond the expectation; precipitation becomes insufficient and scarce impacting on human activities and the ecosystem (Lewis *et al.*, 2011). Both the ENSO and drought are a threat to vegetation. Nonetheless, drought causes more threat to vegetation, while the ENSO causes a variety of climate conditions such as floods and hurricanes. Kenya experienced the El Nino induced rains that led to drought in the period 1997 and 1998 which in many different areas have led to famine, starvation and the loss of wildlife population (ISDR, 2002). Rojas *et al.* (2014; 3) concluded that the potential impacts caused by El Nino are the potential damages caused by drought events depending on the intensity and duration of the phenomenon.

According to a study by Ropelewski and Halpert (1987), on global precipitation and ENSO events, it was found that in the North-Eastern South America from Brazil to Venezuela, the region had experienced at least 17 ENSO events of which during the events there were dry episodes within the region (Svoboda, 2016). That drew much attention because rainforests began to burn during the dry periods as an indication of drought. It was also concluded that during the ENSO events these regions become dry. ENSO events would be accompanied by bush fires and a reduction of crops (Ropelewski and Halpert, 1987; Svoboda, 2016).

El Nino episode occurs and impacts differently from place to place. According to SADC Climate Services Centre (2011), El Nino episodes in the East of Southern Africa cause dry conditions and these conditions are referred to as droughts periods. The dry periods resulted or impacted on crop malnutrition and disastrous famine. Nonetheless, the El Nino episodes cause wet episodes in the middle of Africa. Meteorological drought happens when dry weather patterns dominate an area and this occurrence can be related to El Nino Southern Oscillation (Owen-Smith *et al.*, 2005).

## **2.6. NDVI to indicate rainfall variability**

Normalised Difference Vegetation Index (NDVI) is a remote sensing-based index that measures vegetation conditions (Rouse *et al.*, 1974; Zarger *et al.*, 2011). Tools such as the NDVI may be used to measure the greenness of vegetation associated with rainfall patterns (Pettorelli *et al.*, 2005). It can also be used as proxy for grass quality (Groom and Harris, 2010) Vegetation index has been used by several scientists as one of the parameters for calculating drought conditions and determining the vigour of the vegetation (Tucker *et al.*, 1982; Justice *et al.*, 1985; Hielkema *et al.*, 1986). There are various kinds of vegetation indices that can be considered or used, but the NDVI is regarded as the simplest, efficient and commonly used (Liu and Huete, 1995). It uses the Advanced Very High Resolution Radiometer (AVHRR) reflected red and near-infrared channels to determine if vegetation is suffering from drought or insect infestation (Zarger *et al.*, 2011). It has been extensively used for vegetation monitoring, crop yield assessment, and drought detection (Benedetti and Rossini, 1993; Moulin *et al.*, 1998). Satellite data processed

into NDVI can be used to indicate deficiencies in rainfall and portray meteorological drought patterns both temporally and spatially, thus serving as an indicator of regional drought patterns ( Erdenetuya *et al.*, 2010).

Vegetation monitoring is essential for dealing with many environmental issues that include climate change that could result in drought (Karabulut, 2003). While NDVI has proven useful for timely estimation of vegetation condition, however, it does not allow for relative comparison at a pixel location or time period (Burgan and Hartford, 1993; Kogan, 1995; Peters *et al.*, 2002). NDVI data has been extensively used for more than a decade in classifying vegetation condition (Dutta, 2016). NDVI is calculated on a per-pixel basis as the normalised difference between the red and near infrared bands from an image:  $NDVI = \frac{NIR - RED}{NIR + RED}$  (Karabulut, 2003; Zargar *et al.*, 2011; Tucker, 1979; Singh *et al.*, 2016).

Where NIR is the near infrared band value for a cell and RED is the red band value for the cell. NDVI can be calculated for any image that has a red and near infrared band. The biophysical interpretation of NDVI is the fraction of absorbed photosynthetically active radiation. NDVI decreases as leaves come under water stress, become diseased or die. Bare soil and snow values are close to zero, while water bodies have negative values. Time series of satellite vegetation index data allows for the monitoring of vegetation production and thus the impacts of droughts over multiple years (Wessels and Dwyer, 2011). Unhealthy plants reflect higher R value resulting in lower NDVI. NDVI has extensively been used as a base index for a number of remote sensing indices that similarly measure vegetation conditions, e.g., Vegetation Condition Index (VCI) (Kogan, 1990; Zargar *et al.*, 2011).

According to a study conducted by Gu *et al.*, (2007), the average values of NDVI are consistently lower during the summer months under the drought conditions than in non-drought conditions (normal climate). NDVI decreases in response to drought, thus; NDVI could be used as an indicator for drought by being able to identify and quantify its disturbances in the semiarid and arid lands, with low values representing stressed vegetation and high values representing abundant vegetation (Tucker and Choudhury, 1987). NDVI has been used to estimate drought in Mongolia where Remote Sensing Drought Index (RSDI) was used based on long term NDVI and

Normalised Difference Drought Index (NDDI) based on NDVI and Normalised Difference Water Index (NDWI) data (Erdenetuya *et al.*, 2010).

Karabulut (2003) was able to conclude that rainfall total indicates a strong impact of on vegetation state because the correlation coefficients between NDVI and rainfall were statistically significant for all vegetation formation, which in turn demonstrates a relationship between rainfall and NDVI. High NDVI values are usually associated with well-developed green vegetation such as closed canopy in woodland or a continuous green grass layer, whereas low NDVI values are generally associated with a non-continuous vegetation cover or a non-green cover like exposed bare soil, water or plant senescence (van Bommel *et al.*, 2006; Boyers, 2011).

## **2.7. Vegetation response to climate**

Reduced rainfall and rising temperatures can diminish vegetation production and availability of surface water (Ogutu *et al.*, 2007; Ogutu *et al.*, 2008). Besides the scarcity of rainfall, high temperatures are considered to influence the lack of forage for animals in the Kruger National Park (van Vuuran, 2016). The Serengeti usually experiences very little rainfall on the plains from June to October; thus, the grass dries up and the land turns yellow and then chalky brown again (Kosmala, 2013). A study was conducted in the Amboseli ecosystem in 2009 by the Kenya Wildlife Services and it was observed that there was a steady decline in the standing of pastures due to drought of 1980's and this decline was only reversed temporarily by the heavy EL Nino rains of 1998, then continued to fall after the 2000 drought events (Kenya Wildlife Service, 2009).

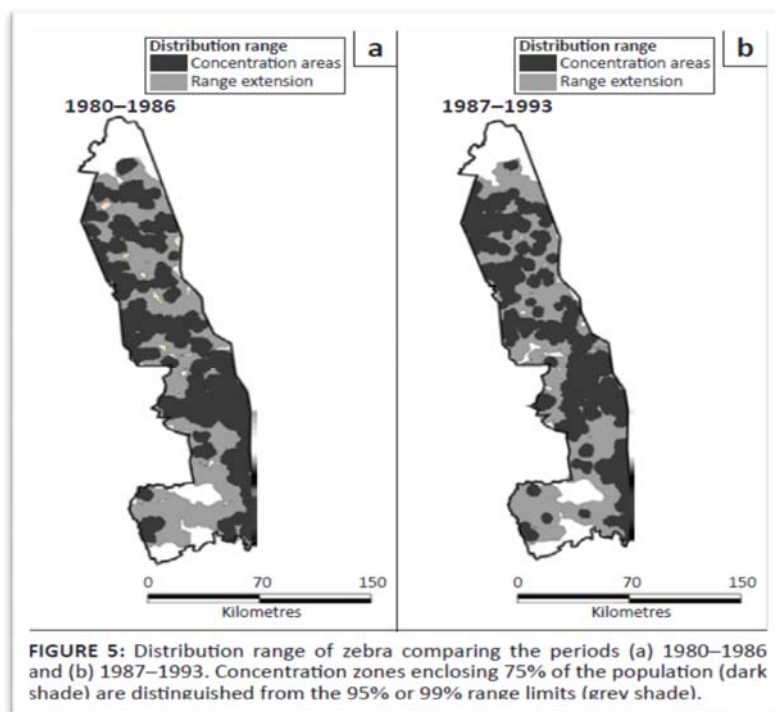
The dry season is a critical period for African ungulates because low rainfall causes the quality of food to decline during this part of the year (Boyers, 2011). The East Africa does not experience seasonal rainfall which has an impact on the forage availability and productions of animals (Galvin *et al.*, 2004). Feeding specialisations determines the movement of zebra population while rainfall seasonality determines the direction of their movement (Ogutu *et al.*, 2008). Dry season rainfall may be directly important by influencing the retention of some green forage during critical period when malnutrition takes hold (du Toit *et al.*, 2003). Higher forage quantities should occur during years with higher average rainfall (Redfern *et al.*, 2005)

## 2.8. Mapping distribution techniques

An aerial survey technique is one of the methods adopted for collecting data on animal numbers and distribution patterns (Gandiwa *et al.*, 2016). A systematic sampling design is used with parallel east-west transects, 5 to 10km apart. These transect follow universal transverse Mercator grid lines. Data is collected and stored in a bank for 5 km subunits along each transect according to geographic code developed for the project (Wetmore and Townsend, 1975). The census flights are carried out for monitored period of years of interest in the Unit's 3 Cessna 185 aircraft that are fitted with radar altimeters, VLF navigational devices and intercom systems. During the data collection the pilot is responsible for navigating, maintaining a flying height of about 91.4 m(300ft) above ground and ground speed of about 160 km/h, and for calling out the begging of each subunit (Dirschl *et al.*, 1981). Observers sitting towards the rear of the aircraft are responsible for counting live animals (zebras) sighted in the plotted rod. The zebras are also photographed and a rough estimation is made. The other observer is also required to record information on a range of environmental factors such as vegetation type and their condition and water bodies.

Field survey has always been one of the methods used to monitor changes in vegetation and distribution of wildlife animals (Osborne *et al.*, 2001). Therefore, it was seen that there is an urgent need to develop ways for mapping threatened species at large spatial scales with reduced field effort (Gaston and Blackburn, 1995; Williams *et al.*, 1997). Remote sensing techniques offer opportunities to map both wildlife habitat and the availability of forage in an area of interest (van Bommel *et al.*, 2006). Past studies on the modelling of animal habitat using remote-sensing techniques at landscape scale include bird habitat analyses (Homer *et al.*, 1993, Osborne *et al.*, 2001, Saveraid *et al.*, 2001). The increasing availability of remotely sensed data acquired by operational satellites, coupled with the development of geographic information systems (GIS) capable of storing and analysing the enormous amounts of spatial data generated by remote sensing techniques, has led to their widespread use in habitat mapping (Rushton *et al.*, 2004). This technique has made the mapping of habitat for wildlife species to be easy and more accurate (Vina *et al.*, 2008),

Pienaar (1963) and Chirima *et al.* (2012) used the mapping techniques to map the distribution of different ungulates that included the zebra, impala, buffalo, wildebeest, kudu, giraffe, waterbuck, warthog, sable antelope, roan antelope, eland, and tsessebe. This was done to assess the preferable and avoided habitat by the ungulates in the Kruger National Park. Point shapefiles of the geographical locations of animal herds were generated in ArcMap 10.0 (Chirima *et al.*, 2012) and applied the adaptive local convex hull (a-LoCoH) spatial analyst tool (Getz *et al.*, 2007). They made use of the Nonparametric Kernel methods for constructing home ranges utilization distribution. By the use of this method, this distribution of zebra from 1980-1986 and 1987-1993 gave the results in Figure 2.5.



**Figure 2.4: Distribution range of zebra comparing the periods (a) 1980-1986 and (b) 1987-1993 (Source: Pienaar, 1963)**

Figure 2.5 shows the distribution of zebra in the Kruger National Park comparing the periods (a) 1980-1986 and (b) 1987-1993. The Nonparametric Kernel method in the ArcMap 10.0 was used to create this map (Pienaar, 1963; Getz *et al.*, 2007; Chirima *et al.*, 2012; 11). Data availability is one of the limiting factors in building large-scale models of species distributions within an area. However, two basic approaches have lately seemed to be emerging to make best use of available resources. Interpolation methods, ranging from simple linear interpolation (Farina,

1997) to kriging (Palma, Beja and Rodrigues 1999), estimate species' occurrence between sample points based on their spatial arrangement. This is likely to be most successful where habitat discontinuities are few, but there are no published studies that assess model performance (Osborne *et al.*, 2001). The other approach is called the correlative mapping, which relates species occurrences at points to a suite of predictor variables that are available across the whole study area (Osborne and Tigar, 1992; Buckland and Elston, 1993; Augustin *et al.*, 1996).

According to Boyers (2011), various studies have used NDVI to show animal movement patterns at large scales (Osborne *et al.*, 2001; Vina *et al.*, 2008). Vina *et al.* (2008) managed to conduct a study to evaluate the effectiveness of MODIS time series imagery, as compared to the traditional classification of single-date Landsat TM imagery for mapping the habitat for the endangered giant pandas in the Wolong Nature Reserve in China. Osborne *et al.* (2001) did a pilot study attempting to model the breeding distribution of great bustards in central Spain from remotely sensed data and digitally mapped data layers. Rogers *et al.* (1997) also used NDVI to differentiate wildlife habitat. Vegetation alone can provide accurate predictions of wildlife habitat at some spatial scales within an area of conservation and other related areas (Osborne *et al.*, 2001).

The related distribution of migratory large herbivores to rainfall data and satellite derived NDVI at a regional scale, in the Masai Mara and the Kalahari was also modelled using the remote sensing techniques (Ottichilo *et al.*, 2000; Verlinden and Masogo, 1996). Zinner *et al.* (2002) studied the distribution of grivet monkeys (*Cercopithecus aethiops*) in Eritrea, also at a regional scale, using vegetation classes and NDVI derived from Landsat satellite imagery, as well as auxiliary data concerning altitude, annual rainfall, and distance to settlements and rivers. These studies indicate the usefulness of NDVI and remotely sensed vegetation classes to herbivore distribution at landscape and regional scales (van Bommel *et al.*, 2006).

Conclusively, some of the studies on rainfall have focused primarily on populations of the entire park rather than individual populations as they would adapt differently from low or high rainfall. From the preceding literature, studies on the impact of rainfall have focused most heavily on agriculture, hydrological system and social economy, only a few have focused on animal behaviour, animal growth and

movement. However these animals are part of the system that impacts on the natural processes within an ecosystem. Hence they do not see the importance of conserving wild species.

## CHAPTER THREE: RESEARCH METHODOLOGY

### 3.1. Introduction

This chapter introduces the data sets that were used and procedures that were also followed during the course of the study. The methodology used were dependent of the objectives that included mapping and establishing the relationship between annual rainfall and zebra population distribution over time, examining changes in the normalised difference vegetation index from time to time and mapping the relationship between rainfall and vegetation distribution over a period of 29 years.

#### 3.1.1. Rainfall data

Rainfall data that was used was obtained from the Kruger National Park (KNP). The rainfall data that was used was for stations that had consistent historical rainfall records. Therefore, out of 28 stations in the park, a total of only 22 stations were used because they were the only stations that contained rainfall records for the period of 29 years from 1983 to 2012, while the rest of the stations had missing information. A period of 29 years was considered appropriate because of high the variation in the rainfall patterns and the long-term average becomes more accurate (Hofmeyr, 2007). Rainfall data was used to determine the variability of rainfall within the park and how this affected the density and distribution of *Buchelli zebra*.

#### 3.1.2. Zebra data

The zebra data that was used also covered a period from 1983 to 2012. The zebra data that was obtained from the KNP provided records of zebra abundances of particular years. This data was correlated with rainfall data to determine whether rainfall is directly related to zebra abundances. Zebra population abundance was analysed using the Kernel density tool. The analysis technique accounts for the location of zebra distribution relative to the other (King *et al.*, 2015). Kernel density was used to improve the count or proximity measures of access by transforming point data onto a continuous surface as it was also done by Thornton *et al.*(2011), thereby enabling the density of a feature to be estimated at any point on the map surface as it was also proven by Kloog *et al.* (2009).

### **3.1.3. Zebra Distribution Mapping**

Zebra and rainfall data was exported from Excel spread sheet into ArcGIS in order to establish the relationship of rainfall and zebra through maps. Landsat images, rainfall data and zebra data of 1993, 2001, and 2003 were used. Using excel, zebra and rainfall data were converted to CSV (comma delimited) function so that it could be read in the ArcGIS system. It was then converted to shapefiles in ArcMap. The Isohyet map was used to show rainfall patterns to indicate places that received the same amount of rainfall at a particular time. This was done using the ArcMap analysis tool called the spline. To create a zebra distribution map a kernel tool was used. The NDVI maps were produced from the Landsat imagery through the ArcMap software by enabling the image analysis toolbar. The maps were produced to study the distribution of vegetation in the park and how this vegetation influenced the abundance and distribution of zebra. It was to be expected that the foraging of the zebra population be dependent on the distribution of vegetation of the area.

## **3.2. Interpretation and analysis**

### **3.2.1. Data analysis**

Data was analysed using both descriptive and inferential statistics. Descriptive statistics was used to analyse properties and characteristics of the zebra population and presented it in the form of graphs and maps to describe the distribution or abundance of zebras. Descriptive statistics was also used to portray rainfall distribution within the KNP. Inferential statistics was also used to predict future rainfall and zebra distribution trends across the KNP.

### **3.2.2. Statistical analysis**

#### **3.2.2.1. Semi-log analysis**

A record of annual rainfall at KNP observatory for period 1983-2012 was calculated and plotted on a sheet of arithmetic probability (also called a semi-logarithmic). Semi-log analysis was used because it was the convenient way to show variation of hydrological quantities through the monitored years of study, by means of frequency curves, where each frequency curve indicated the magnitude of the quantity for a

specific probability of non-exceedance. The semi-log graph was used to show the probability of rainfall occurrence within the given specific years and how zebra during the very same years would be influenced. This was done to verify the existence of the relationship between zebra and rainfall and how rainfall influences the abundance of zebras in a geographical area.

The graph was plotted to indicate period of low, moderate and high rainfall based on the logarithmic percentages of 16%, 50% and 84%. The three years were selected to represent lower, middle and high rainfall using average rainfall respectively. Years 1993 (50%), 2001 (84%) and 2003 (16%) were the end results of the analysis. From these years, percentages of zebra totals were also calculated and zebra totals were estimated. The estimated years were then used to further establish the relationship between rainfall and zebra within the monitored periods in the study.

Statistical analysis was also used to determine how strong the relationship between rainfall and zebra distribution existed. Spearman's Rank-Order Correlation Coefficient was used to determine whether there was a relationship between rainfall and zebra population abundances. According to *Welman et al. (2005)* correlation helps in assessing the extent to which one variable influences another. Rainfall data was therefore paired with zebra abundances and a total of 30 pairs were used. In order to determine the relationship between rainfall and zebra abundance therefore hypothesised as follows:

$H_0$ : There is no relationship between rainfall and zebra population abundances.

The alternative hypothesis (1) was stated as follows:

$H_1$ : There is a relationship between zebra population abundances and rainfall.

The significance level for testing the hypothesis (non-directional) was chosen at 0.05. For the significant level to be valid, the t-test using two-tailed and one-tailed method was used with the significant value of 0.05. The null hypothesis will be rejected if p-value is less than 0.05. This test was done to test that the rainfall level during winter period is the same across the monitored year. Rainfall is the independent variable, while zebra is the dependant variable.

The Spearman's Rank Order Correlation Coefficient was calculated from the following formula adapted from Bless and Kathuri (1993); Gibbons and Chakraborti (2011)

$$r_r = 1 - \frac{6 \sum d^2}{n^3 - n}$$

Where  $d$  = the difference in ranks of the values of each matched pair

$n$  = number of pairs

$\sum$  = the sum of

The results were then interpreted as follows:

If the critical value of  $r_r$  was greater or equal to the corresponding value from the Spearman Rank Order table then  $H_0$  was rejected. If the  $r_r$  value was less than the critical value from the rank order correlation coefficient table then  $H_0$  was not rejected.

### 3.2.3. Rainfall analysis

A spline method tool in ArcMap was used to interpolate rainfall instead of the Inverse Distance Weighted (IDW). A decision to use the spline tool was made because the range of sample values could have not included the extremes of the phenomenon being interpolated and the number of sample values was relatively small. Spline generally produces better surfaces and has smooth distribution of values than IDW with sparse sample datasets. The spline surface passes exactly through each sample point, while the IDW passes through none of the points, hence the spline surface becomes smoother and for the study a smooth surface was desired. The analysis of rainfall was from the years that were predicted from the semi-log analysis and monthly rainfall from those years was also analysed to further understand annual patterns of rainfall in the park. These averages were then used to make isohyets maps that represented rainfall of the area.

### 3.2.4. NDVI analysis

Normalised Difference Vegetation Index (NDVI) was used to produce vegetation cover maps. NDVI was used to depict the degree of land cover. Because it

measures the “greenness” of vegetation cover, lower NDVI values represent areas of unhealthy and mixed vegetation of degraded grassland and bare land, while higher NDVI values represent areas of *greener* vegetation such as open forests and closed forests. The interpretation of the maps was done using NDVI classification range as described by Simonetti *et al.*, (2014:38). With reference to Table 3.1, areas with a red colour signified sections of the land with no vegetation cover, while those with green colour represented dense vegetation. The degree of land cover ranged from green to red colour. NDVI maps represented vegetation maps or forage maps as foraging of zebra species is dependent of vegetation availability. Woodcock *et al.* (2002); Lunetta *et al.* (2006) used the NDVI to study changes in vegetation cover.

**Table 3.1:** NDVI land cover classification range (Tucker *et al.*, 1985; Simonetti *et al.*, 2014)

NDVI colour	Values	Cover classes	Description
Red	-1	Bare land	No vegetation cover
Orange	-0.5	Degraded grassland	Sparse vegetation
Yellow	0	Grassland and shrubs	Moderate vegetation
Lime	0.5	Open forest	Woody vegetation
Green	+1	Closed forests	Dense vegetation

## CHAPTER FOUR: RESULTS AND DISCUSSION

### 4.1. Introduction

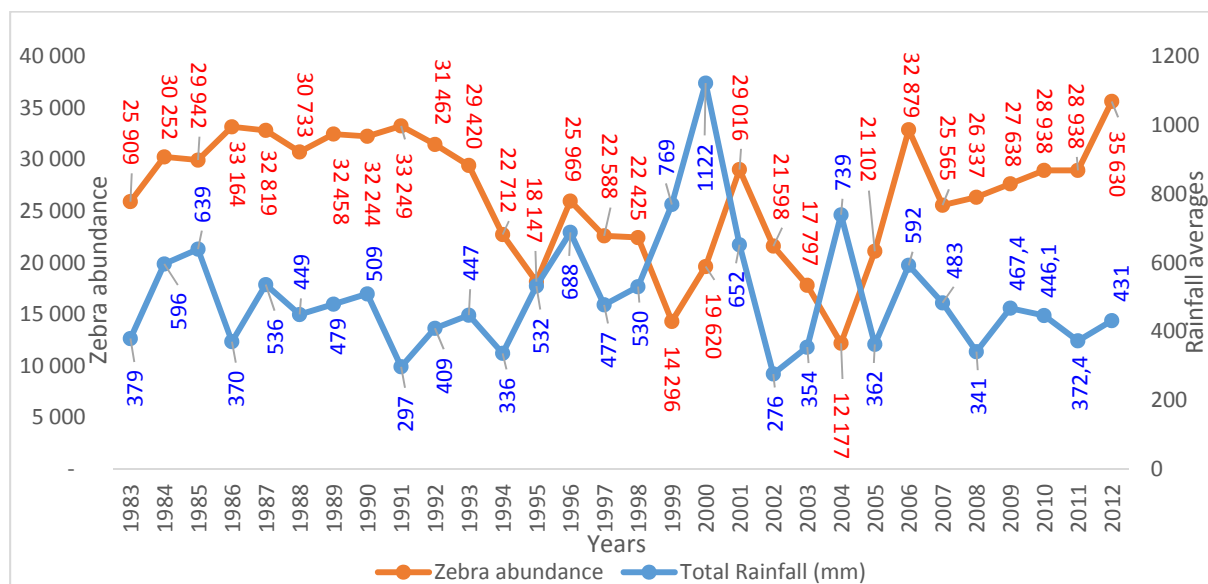
This chapter describes the results followed by a discussion of the research findings. The findings relate to the research questions that guided the study, the questions include the following: Is there a significant relationship between the distribution of zebra species and the availability of rainfall? Does the distribution of vegetation influence the movement of zebra species on the park? Does rainfall availability influence the distribution of vegetation during the period of low rainfall? Is the movement of zebra species in the park influenced by rainfall variability or by the distribution of vegetation? Data was analyzed to identify, describe and explore the relationship that exists between the rainfall, vegetation species and zebra's species movement in the Kruger National Park. The three years period of high to low , is used to determine what happens to the zebra and vegetation species during low rainfall period across high to low rainfall year. Landsat images from three distinct years and statistical analysis was used to answer the research questions.

### 4.2. Zebra and Rainfall statistics

Figure 4.1 shows the relationship between rainfall and zebra abundances. From Figure 4.1 there are years where rainfall increased but zebra abundances remained the same or decreased as it was evident with other years. Zebra abundance showed an increase from 29942 in 1985 to 33164 in 1986. During the same years, total annual rainfall dropped from 639 mm in 1985 to 370 mm in 1986. This was a sharp drop by 269 mm. surprisingly, zebra population increased by 3222 when total annual rainfall dropped by 269 mm. The same happened in 1991 when KNP experienced drought. Total annual rainfall dropped from 509 mm (1990) to 297 mm (1991). During the same period zebra population increased from 32244 (1990) to 33249 (1991). This was an increase by 1005 while total annual rainfall dropped by 212 mm. This shows that the 1991 KNP drought did not impact on zebra abundances. The same happened between 2004 and 2005 as well as between 2007 and 2008. During these year's total annual rainfall dropped while zebra abundances increased. With this, it can be said that zebra species were able to survive during low rainfall periods or they were able to find other mechanisms of survival just like the observation made

by du Toit et al. (2003) that the expansion in the zebra population may have been a response to the universal provision of artificial water points throughout the park. Zebra high totals during period of low rainfall can also indicate that they were not directly dependent on rainfall, thus Kingdon (1979) in his/ her study was able to depict that the success of zebra during period of low rainfall is assisted by its lack of forage selectivity or by migration of zebra into drainage lines which are usually waterlogged during rainfalls.

However, during other years such as 1984, 1996, 2009 and 2012 zebra abundances were positively correlated with rainfall. Nonetheless, this seemed not to be true with other years. It therefore means that there is no correlation between zebra abundance and rainfall because zebra abundances increased even when rainfall decreased and in some instances abundances declined when rainfall declined and increased when it increased. The increase and decrease of rainfall also plays a role in the decline of zebra populations as it can be seen between 1995 and 2007. Even though zebra are drought resistant it has been proven by Georgiadis et al. (2000) in a study conducted in Laikipia that the number or population of zebra would decline with every period of drought in the area, such as the drought period in 1984 and 1999-2000 drought.



**Figure 4.1: Historical Total Rainfall and Zebra species at Kruger National Park**

To verify the correlation between zebras and rainfall the results were later tested using the Spearman's Rank-Order Correlation Coefficient. The results that were obtained were calculated as follows:

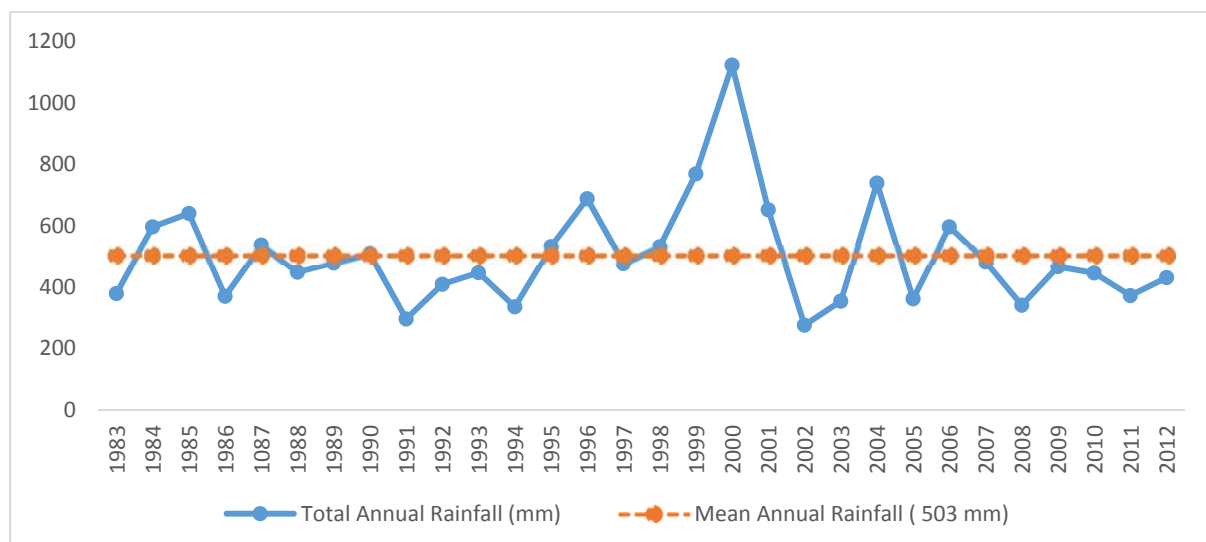
$$\begin{aligned}
 r_r &= 1 - \frac{6 \sum d^2}{n^3 - n} \\
 &= 1 - \frac{6 (5658.5)}{303 - 30} \\
 &= 1 - \frac{33951}{26970} \\
 &= -0.26
 \end{aligned}$$

The corresponding value from the Spearman's Rank Order correlation coefficient table at 0.05 significance level was 0.363. Since the critical value of  $r$  (0.26) was less than 0.363 the  $H_0$  was not rejected and it was true that there is no relationship between rainfall and zebra abundances.

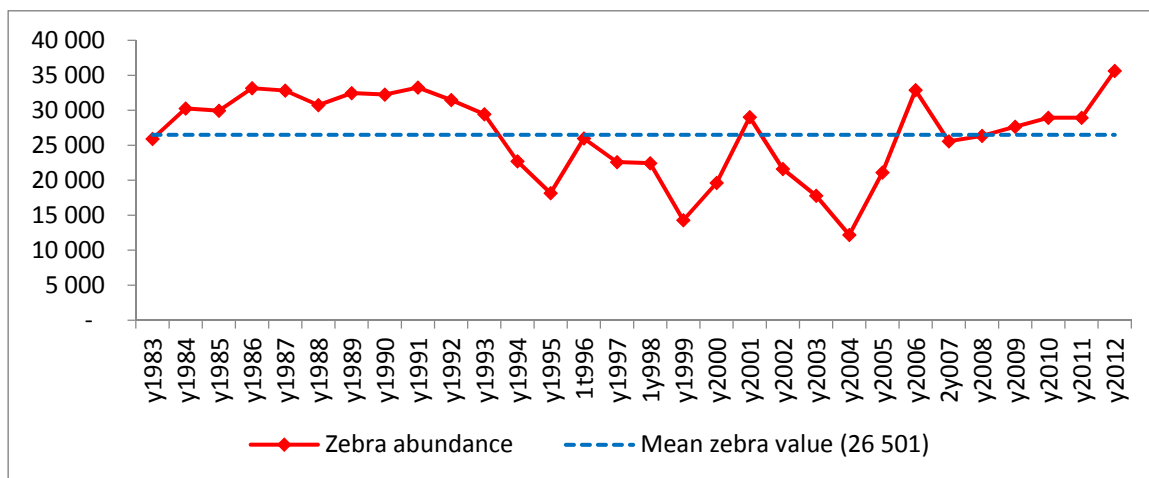
This shows that zebra abundances are not always dependent on rainfall and this also suggests that zebras tolerate drought conditions better than many herbivores (Kingdon 1979).

Figure 4.2 shows the trends in the decline and increase in zebra abundance (Figure 4.2b) against total annual rainfall. The average annual rainfall was calculated as 503 mm and from Figure 4.2a it can be noted that many years were characterised by rainfall that was below annual average of 503 mm.

(a)



(b)



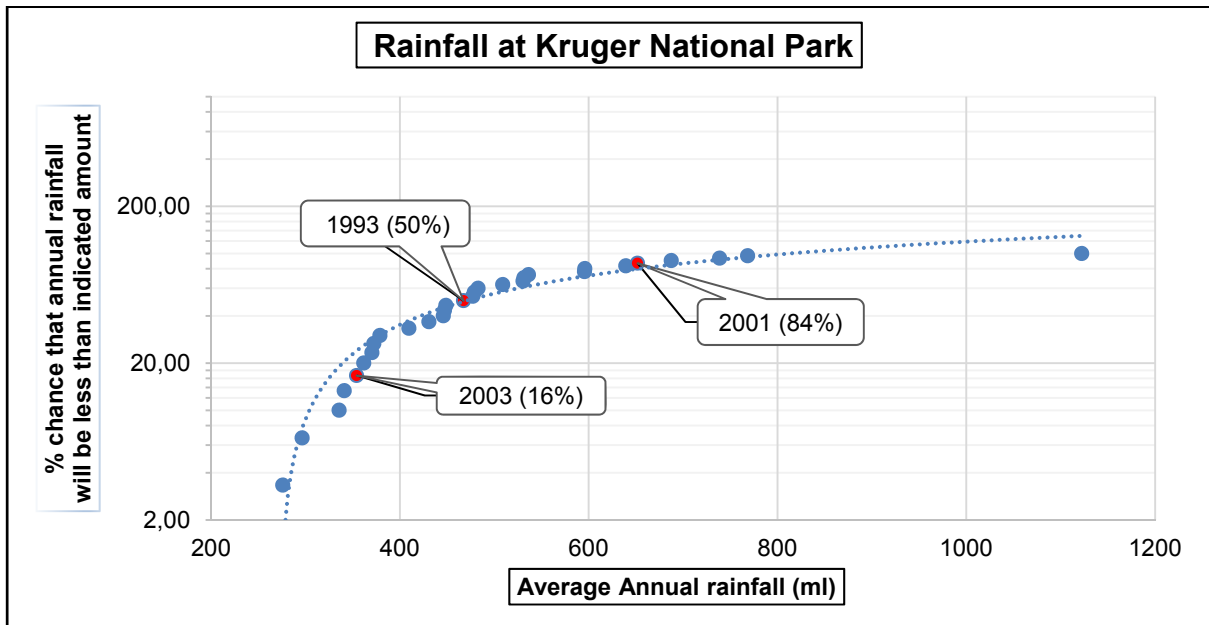
**Figure 4.2: Total annual rainfall (mm) (a) and zebra abundance (b)**

Just like in Figure 4.1 an interesting observation was that in almost all years from 1983 to 1994 (except for 1991) zebra abundances were above the zebra mean value of 26 501 (Figure 4.2b ). However, between 1994 and 2000 (Figure 4.2b) zebra abundances declined while total annual rainfall was above the annual average (Figure 4.2a), except in 1994 and 1997. Between 1983 and 2000 there was a negative correlation between rainfall and zebra abundance because when rainfall was above average zebra abundance was lower than an average of 26 501 but during years when rainfall was below 503 mm (1995 to 2000) zebra abundance was above the average of 26 501. This does not show that zebra abundance is dependent on rainfall but other factors contribute to their increase and decrease in numbers. The same pattern of change in zebra abundance in response to rainfall can also be observed during certain years between 2001 and 2012. It can therefore be concluded that there is no relationship between rainfall and zebra abundances. This has been confirmed by the results obtained from the Spearman’s Rank-Order correlation coefficient.

To understand the zebra-rainfall relationship and how the movement of zebra species is influenced by rainfall over time, three distinct years of low, middle and high rainfall were selected for further analysis. Between the same periods, the

percentage of zebra totals distribution differed from the chances of rainfall to be received in the park.

(a)



(b)

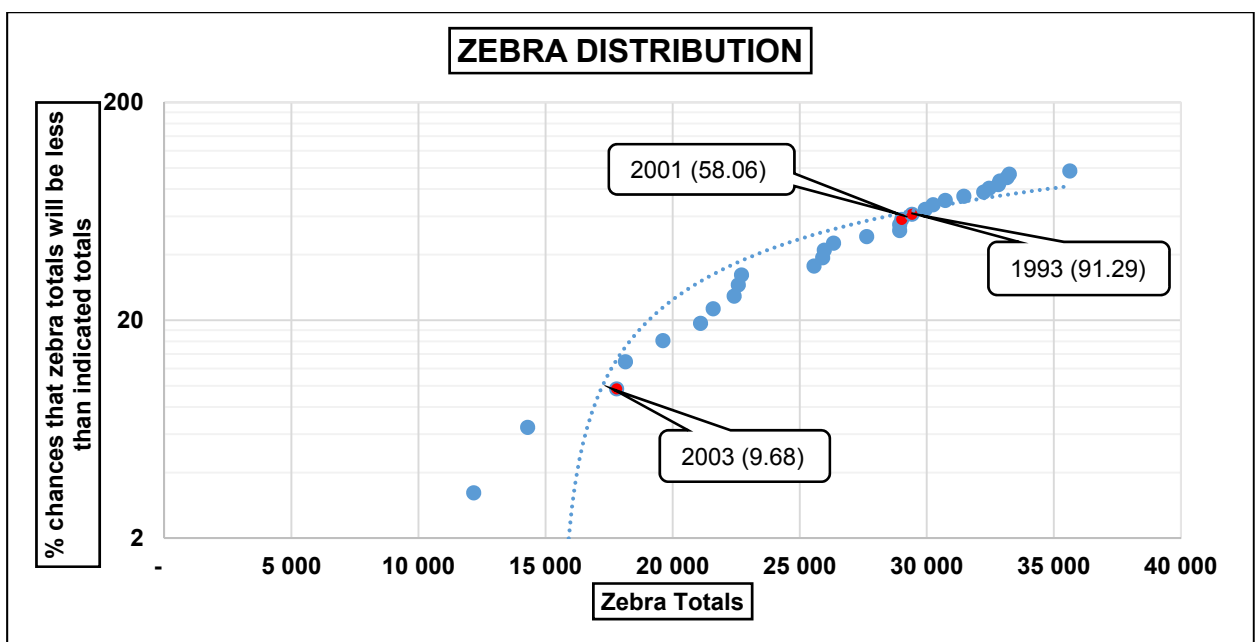


Figure 4.3: Semi-logarithmic graph for average rainfall (a) and Zebra distribution (b) in KNP

Figure 4.3b (Zebra) shows percentages that differ from that of the Figure 4.3a (rainfall). During period 1993 there was 50% chances of rainfall that was expected and there was 91.29% chances of zebra to occur. In period 2001, there were 84% chances of rainfall to occur, and 58.06% of zebra total to occur. In 2003, there were 16% chances of rainfall to occur and 9.68 chances of zebra to occur. This being the observation it can be said that with every low and high chances of occurrence of rainfall, zebra occurrence is minimal. But when rainfall is expected at 50% chances, high occurrence of zebras is expected. The graphs (Figure 4.3a) shows average annual rainfall between 200mm and 800mm being clustered together and having only one far point at the far point being at 1122 mm at 96.77%. This could mean that annual rainfall received within the park normally ranges between 200mm and 800mm would reach extreme conditions once in a while to a point of 1200mm.

The gap that is visible between received rainfalls of 800mm and 1200mm can give a clear indication that there was once an extreme period of rainfall in the park that could have led to floods. The lowest chances of occurrence of rainfall were recorded in 2003 and this was found to be 16%. This indicated that there was 16% chance that rainfall in the park in 2003 would be below 354mm. As shown in Figure 4.1 the number of zebras in 1993, 2001 and 2003 was decreasing with increasing chances of rainfall occurrences. This could possibly mean that, zebra distribution is not entirely dependent on the availability of rainfall but could be influenced by the distribution of vegetation.

### **4.3. Monthly rainfall statistics**

Table 4.1 below shows the total monthly rainfall, mean and standard deviation for the three years (1993, 2001 and 2003) respectively. It is evident from Table 4.1 and Figure 4.4 below that there is no much difference in average rainfall during the low rainfall season across the three years, thus rainfall remains high during November and February period.

From Table 4.1 the months that have been highlighted in a red colour are monthly periods when low rainfall was recorded in the park. They are normally referred to as the dry periods (Zambatis and Biggs, 1995) hence the total monthly rainfall for these

months was below 200 mm. From Table 4.1 it can be observed that only two months in 2001 (June and September) received rainfall above 200 mm compared to 1993 and 2001 months which recorded rainfall lower than 200 mm. This means that the KNP normally experience lower rainfall in winter and this means that conditions become severe during drought periods. This can therefore impact negatively on the density of zebras.

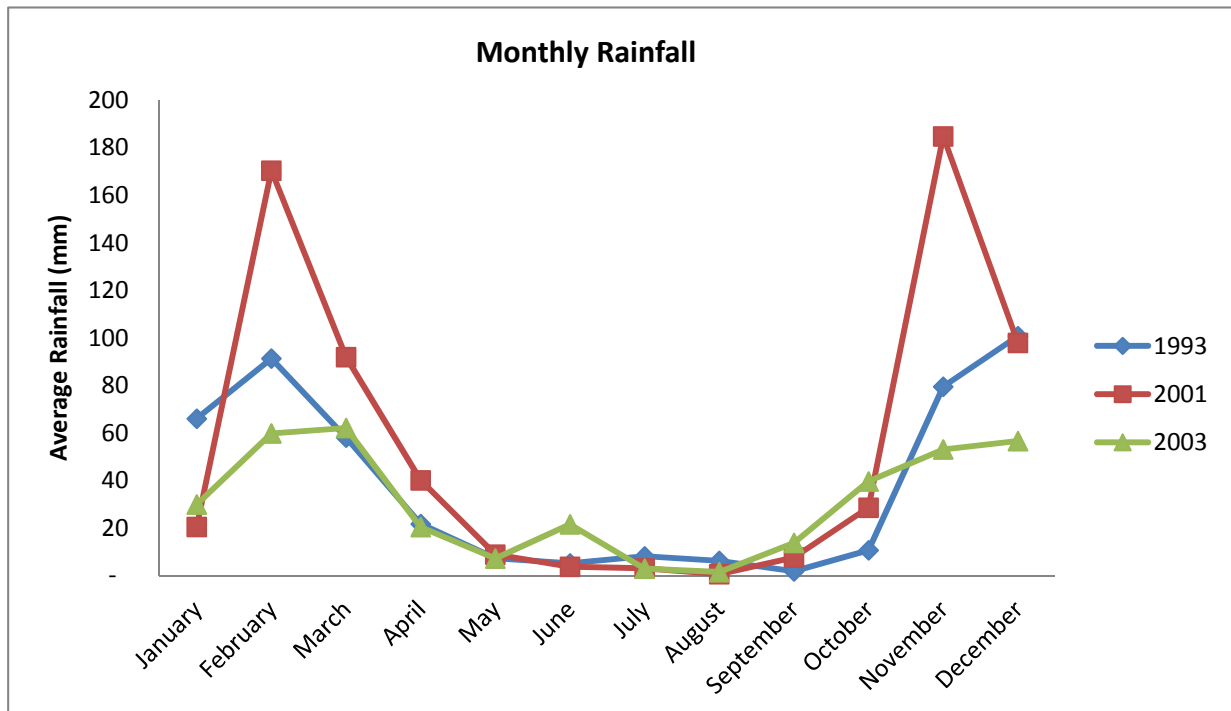
**Table 4.1: Total, mean and standard deviation of monthly rainfall for year 2003, 1993 and 2001**

Year	1993			2001			2003		
	Total Rainfal	Mean Rainfal	Std Dev Rainfal	Total Rainfal	Mean Rainfal	Std Dev Rainfal	Total Rainfal	Mean Rainfal	Std Dev Rainfal
January	1,851	66	46	555	21	20	779	30	22
February	2,467	91	50	4,942	170	65	1,676	60	34
March	1,628	58	55	2,668	92	29	1,740	62	36
April	610	22	17	1,165	40	28	553	21	25
May	184	7	7	196	9	7	130	7	7
June	89	5	4	76	4	5	562	22	13
July	172	8	10	78	3	3	30	3	5
August	145	6	6	8	1	0	9	2	3
September	28	2	2	123	8	8	345	14	13
October	300	11	9	803	29	24	1,072	40	27
November	2,227	80	46	5,359	185	52	1,434	53	36
December	2,822	101	47	2,841	98	51	1,586	57	34
Annual totals	12,522	457	299	18,814	659	292	9,917	369	254
Average	1,043	38	25	1,568	55	24	826	31	21

Figure 4.4 also shows the average monthly rainfall for the three years. It is evident that rainfall was the highest between November and February for all the three years. It can be concluded that the KNP receives much of its rainfall from October to March and this can be regarded as its wet season. Monthly rainfall also plays a significant role in the distribution of zebra in the park. Species such as zebra which are water-dependent on annual rainfall are easily impacted by drought. An interesting observation by Ogutu *et al.* (2008) was that monthly rainfall has both positive and negative effects on zebra. This means that even though they are drought resistant, they are also regarded as water-dependent species (Harrington *et al.*, 1999) that can also be affected by drought conditions.

The year 2001 had the highest total monthly rainfall that ranged from an average of 1 mm to 185mm. This was followed by the year 1993 that was considered to have moderate rainfall ranging from 2 mm to 101 mm. lastly, the lowest rainfall was

experienced in 2003 and it ranged from 2mm to 62 mm. It is also evident on the graph that rainfall is high from October to November and decreases in December to January it increases again from February to March for all the three respective years. Thus, the lowest season of rainfall falls between May and September respectively.



**Figure 4.4: Monthly Rainfall for year 2003, 1993 and 2001**

Table 4.2 illustrates the t-test statistics for mean score difference between May and September (low rainfall period) for the years 1993, 2001 and 2003. It shows the p-value differences for the three years the t-test Two-Sample Assuming Unequal Variances. The theoretical hypothesis is that there exists a difference in rainfall between the three years during low rainfall period. Considering the p-value there is insignificant evidence that there exist differences on average rainfall during low rainfall season between 1993, 2001 and 2003.

**Table 4.2. Mean score difference of low monthly rainfall for year 2001, 1993 and 2003**

t-Test: Two-Sample Assuming Unequal Variances			
P Value	1993 & 2001	1993 & 2003	2001 & 2003
P(T<=t) one-tail	0.314	0.196	0.153
P(T<=t) two-tail	0.628	0.391	0.305

The outcome of the t-test in Table 4.2 is in support with the observations that were made in Figure 4.4 and Table 4.1. It was indicated that the average monthly rainfall during low rainfall period was characteristically the same irrespective of whether it was high or low rainfall within a year period or summer season. The outcome of the t-test indicates that rainfall variability does not relatively play a role in the distribution of zebra populations in the park; hence its mapping cannot completely be dependent on rainfall alone but also vegetation. The observation of the vegetation and zebra mapping is not influenced by rainfall differences during a low rainfall season but rather the rainfall prior to the low rainfall season (summer rainfall).

#### **4.4. Rainfall, vegetation and Zebra mapping**

##### **4.4.1. Rainfall, Zebra and Vegetation Mapping of 1993**

Figure 4.5 shows the relationship between rainfall, zebra distribution and vegetation characteristics. The average annual rainfall that was received in the park (1993) ranged from 500 to 700 mm while in the northern region the average rainfall ranged from 300 to 500 mm per annum. The total number of zebras which were recorded during 1993 was 29 420 throughout the park, which was a total decline from what was recorded in the previous year (1992) with a total of 31 462. The distribution and density of zebra species could have been influenced by the distribution of vegetation in response to rainfall. Vegetation was sparsely distributed across the entire park and this influenced the distribution and movement of zebras. Based on these findings it could be agreed with Pinaud (2008) that factors such as rainfall and vegetation influence the movement and distribution of animals within a given area and at a particular period of time.

In Map A, the lowest rainfall was received in the central region of the park as indicated in grids B3 and C3. Even though zebra density seemed to be evenly distributed over the entire park, some areas had high densities of zebra population than the others. High densities of zebra species were mostly concentrated where rainfall ranged from 500 to 700 mm. The drought in the previous year (1992) could have influenced the high density of zebra population in areas with high rainfall. Wessels and Dwyer (2011) and Zambatis and Biggs (1995) were able to depict that the driest years recorded were 1991 and 1992 and these drought events were caused by the El-Niño episodes which had a negative impact on the vegetation production in the Kruger National Park and this was evident in the satellites that were produced to conduct an NDVI analysis of the park in 1993.

Map B shows the distribution of vegetation in the park that could have also played a role in the distribution of zebra and density of zebras in the area. It shows that vegetation distribution ranged from -0.5 to 1 and this was characterised by moderate and sparse vegetation (Table 3.1). This shows that in 1993 vegetation was still in the regeneration stages after the 1991-92 droughts. This explains the sparse nature of vegetation in 1993. The rainfall that was received in 1993 could not lead to significant changes in vegetation density hence its sparse characteristics. It would be expected that when rainfall is at average, vegetation will be influenced and becomes moderate. In Map A rainfall in grid C5 was 500mm while in grid C3 rainfall ranged at 300 to 400mm, but vegetation in Map B of the same grid references remained the sparse and less dense. Thus, rainfall was not enough to trigger significant vegetation changes.

Observations of the decline in the number of zebras from 1991 to 1995 were not only made in this study, Gandiwa et al., (2016) also made a study in the KNP and Zimbabwe (Gonarezhou), and they were able to depict the same decline in the number of zebra post the 1991/2 drought event. They also managed to depict that the abundances of these species slightly increased following the wet year, i.e., 2000. However, after the year 2002, the population of zebra began to decline again (Figure 4.1). Based on these findings from the study and observations made by Gandiwa et al., (2016), it can be concluded that drought seems to have an impact in the abundance of zebra. Therefore, it can be concluded that the wet-dry rainfall cycles of KNP impacted on zebra abundances differently.

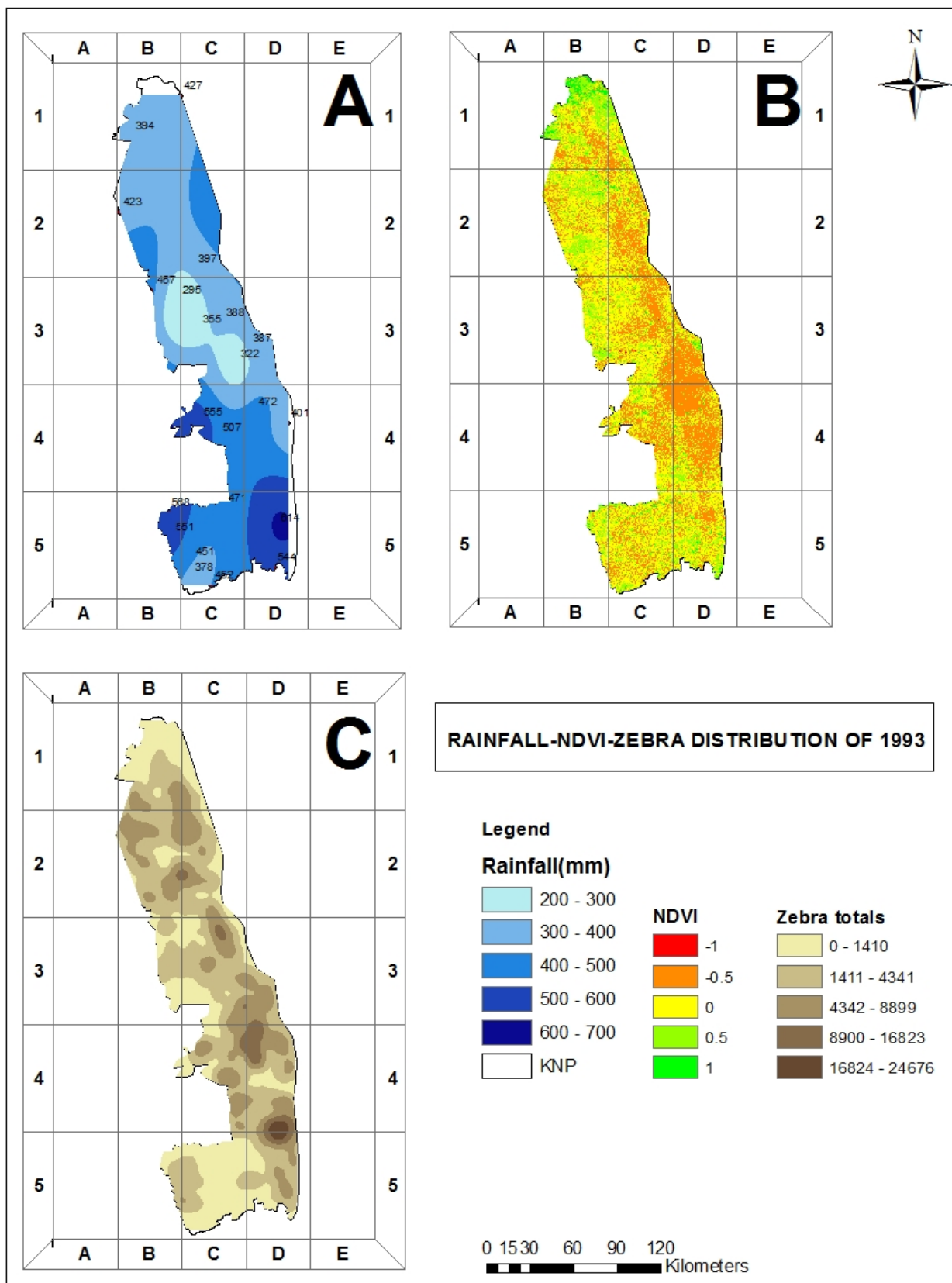


Figure 4.5: Distribution range of rainfall, vegetation and zebra abundance in 1993

#### 4.4.2. Rainfall, Zebra and Vegetation Mapping of 2001

Figure 4.6 shows the relationship between rainfall, zebra distribution and vegetation characteristics. The distribution of zebra was limited to the northern region of the park. The south had higher densities than the rest of the park (Map C) and rainfall in the northern and southern regions of the park was also the highest (Map A). However, it can be seen from map B (NDVI map) that the area where densities were high was characterised by sparse vegetation and bare land, compared to the rest of the park. The northern part of KNP has traditionally been a low ungulates area (Harrington *et al.*, 1999) which is associated with tall grass, hence hardly influenced by low rainfall. This could have been the results of more zebra being found in the southern part than the northern part of the park. Distinct from 1993, density and distribution of the zebra species was concentrated in the same area.

Map A shows that rainfall in the central region was the lowest and ranged from 494 to 575mm in grid C3. Looking at vegetation distribution in the same grid reference on map B vegetation ranges from 0.5 to 1 (woody and dense vegetation). Prime climate feature likely to be influential is rainfall, which largely controls annual vegetation growth and hence food production for large herbivores Owen-Smith and Ogutu (2003). There is no sign of high densities of zebras in the area. This could mean that zebras do not prefer woody and dense vegetation but areas that are characterised by sparse vegetation. Vegetation in the northern part of the park is greener than the central and southern parts of the park, hence; zebras avoided the northern part of the park. This could have been the result of vulnerability to predation due to dense vegetation, as Owen-Smith and Ogutu (2003) indicated that vegetation associated with high rainfall conditions render zebra more vulnerable to predation.

The distribution of zebra would have been expected to occupy the entire park since vegetation is characterised by woody and dense characteristics. However, this was not what was portrayed because most of the zebras were recorded in areas where vegetation was sparse. This could have been the results of dense vegetation as predation becomes a dominant factor.

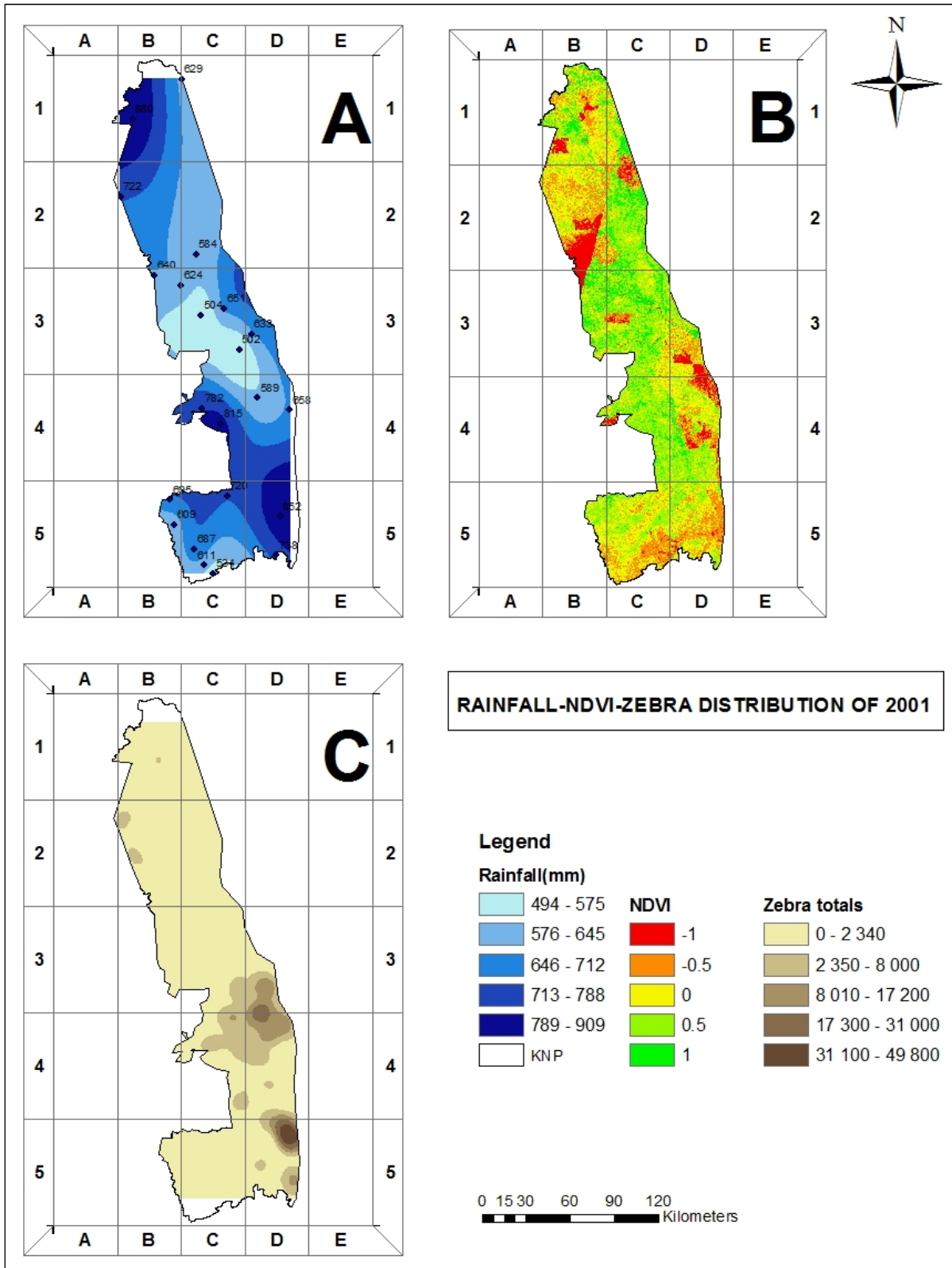


Figure 4.6: Distribution range of rainfall, vegetation and zebra abundance in 2001

The other explanation for the low numbers of recorded zebras during high rainfall seasons could be attributed to the role of dense vegetation which made zebra counting difficult. For example the total number of zebras that were counted in 1993 when vegetation was sparse was 29 420 and this was the period when the total annual rainfall was 447 mm. However, in 2001 when vegetation was denser with total annual rainfall of 652 mm a total of 29 016 zebras were counted. This was 404 less zebras that were recorded in 1993. However, Map C shows that zebra densities were higher in the central eastern part and the south eastern part of the park. Unlike the even distribution of zebras during the 1993 conditions higher densities were recorded in places where vegetation was moderate or sparse.

The 2001 vegetation condition was generally denser than the 1993 conditions with fewer areas of sparse to moderate conditions occurring in the south eastern and central eastern parts of the park (Map B). Nevertheless, avoiding these places does not mean they do not go to them at all. They are observed in areas where vegetation is less dense, which could also be an area of forage and there is likely shortage of water in that area. The foraging areas of zebra were usually more open with shorter trees (Macandza, 2012); hence they cannot be found in areas with closed canopy.

#### **4.4.3. Rainfall, Zebra and Vegetation Mapping of 2003**

Figure 4.7 shows the relationship between vegetation and rainfall as well as zebra distribution densities and rainfall ranged from 244 to 577 mm (Map A). However, the total annual rainfall recorder at the KNP during the same period was 352 mm (Figure 4.1 and was above the annual average of 503 mm (Figure 4.2a). From Figure 4.7 it can be seen that vegetation was denser and greener than in 1993. This could have been the results of the abundant rainfall that was received in the year 2000 (1122 mm). This explains the greenness and denser vegetation of the park in 2001 (Map B). However, during the same period zebra densities were higher in the south eastern part (Map C) of the park where rainfall ranged from 243 to 577 mm. These higher densities ranging from 2 028 to 23 079 were confined to areas where vegetation distribution ranged from moderate to sparse area. This is an indication of preference of open areas for avoidance of predators and the palatability of sweetveld

which is not a characteristic of high rainfall areas (Harrington *et al.*, 1999); (Macandza, 2012).

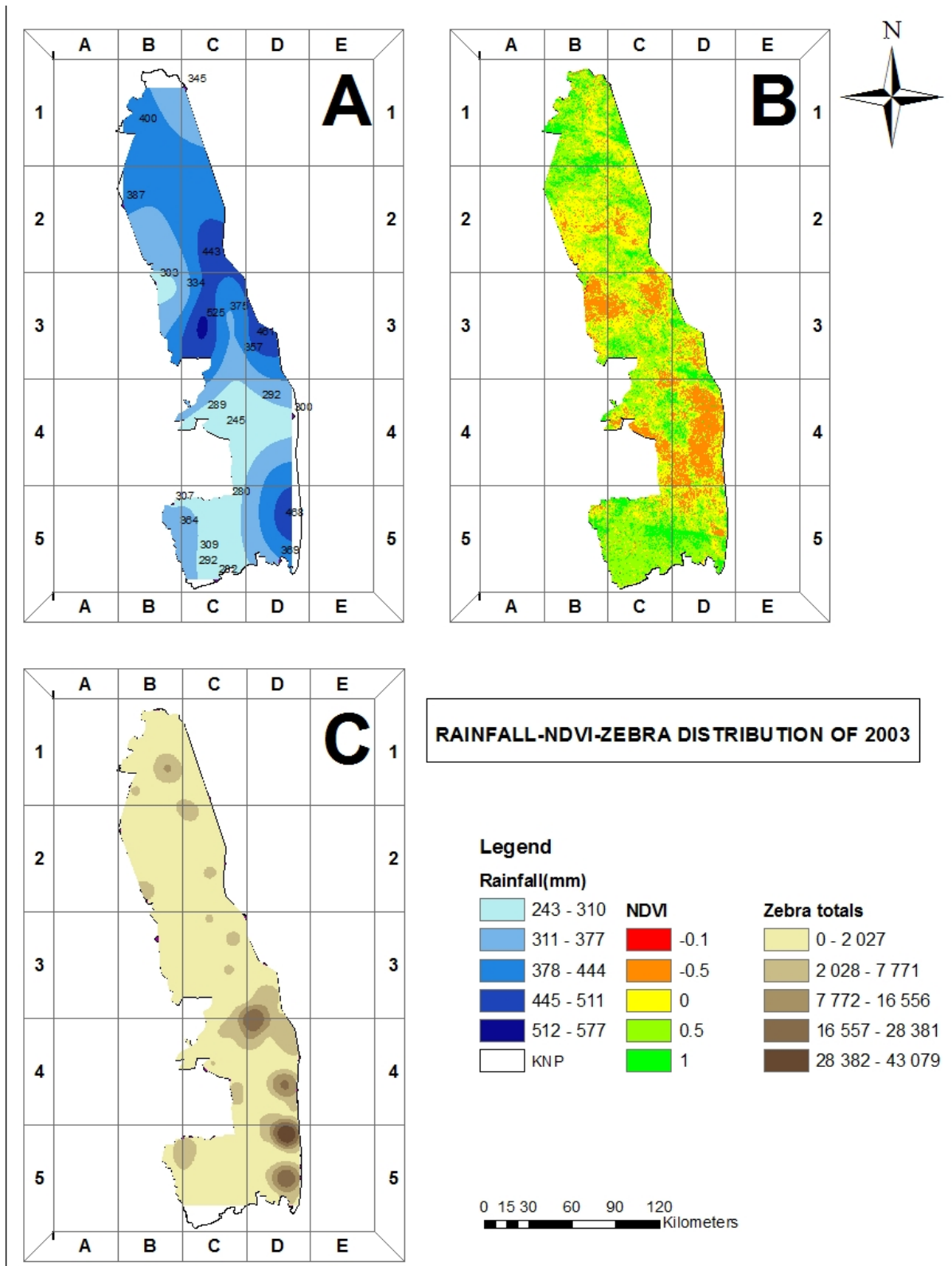


Figure 4.7: Distribution range of rainfall, vegetation and zebra abundance in 2003

Based on the results from the Figure 4.3a, the year 2003 was depicted to be period when there was on 16% chances of receiving rainfall below 534mm which is below the average rainfall of the KNP (South African National Parks, 2008). Had the park received rainfall less than this the vegetation would probably not be as green as depicted in Map B. Vegetation during this period appeared greener than in 1991 and 2001 and the total number of zebra that was captured was 17797 which was less than what was recorded in 2001 and 1993. The highest abundances of zebra population were captured in the southern part of the park, when rainfall was the lowest and vegetation is sparse ranging (-0.5).

Greener vegetation is characterized by woody and dense vegetation (ranges from 0 to 1). Zebra try by all means to avoid these kinds of areas because they are avoiding predation. From 2001 to 2003 the number of recorded zebras declined from 29 016 to 17 797. This decline in the number of zebra could have resulted from predation because the vegetation was dense. In the year 2000, the Kruger National Park had experienced floods (Wessels& Dwyer, 2011) and from the image analysis vegetation responded positively to the rainfall received with reference to map B of both Figures 4.5 and 4.6. However the distribution of zebra was decreasing.

#### **4.4.4. NDVI-Zebra Distribution during low and high rainfall**

Figure 4.8 shows the relationship between rainfall, zebra distribution and vegetation characteristics. The highest rainfall was experienced in 2000 with a total amount of 1122mm which eventually led to flood in the area, while the lowest was experienced in 1991 with a total of 297mm which eventually led to drought conditions (Figure 4.1). High densities of zebra occupied the southern part during period of high rainfall; however this was not the case when rainfall was the lowest, as they were evenly distributed on the entire park. When rainfall was the lowest, vegetation (Map b) was very sparse, generally ranging from bare land to sparse vegetation (-1 to 0).

The total population of zebra was at 33 249 during the period of low rainfall, while in the period of high rainfall, the total population of zebra was at 19 620 (Figure 4.1). It

would be expected that when rainfall is at the highest, zebra population would also increase. However, population of zebra is found to be the greatest when rainfall is at its lowest or moderate. It can thus be argued that zebra species are resistance to drought or they are just able to find better mechanisms strategies during period of low rainfall.

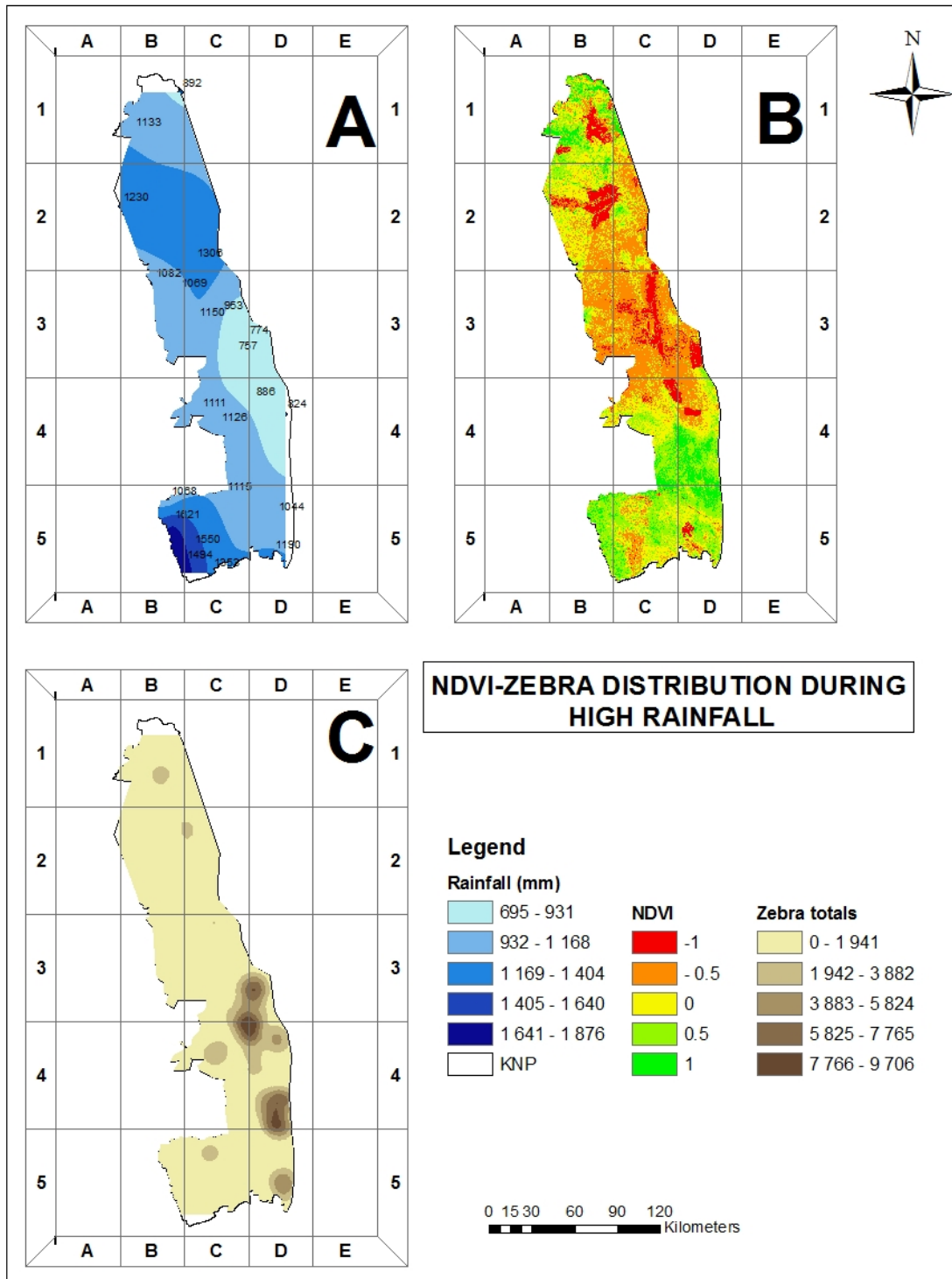


Figure 4.8: NDVI-Zebra Distribution during low rainfall (2000)

Vegetation (Map B), during period of low rainfall seems to have resulted from the unavailability of rainfall during the period of low rainfall. However, when rainfall was the highest, vegetation did not seem to have responded to the rainfall either. This could mean that, some of the vegetation in the park does not immediately respond to the increase of rainfall, but turn to respond at a later stage of the rainfall or the rainfall was too high in such a way that it killed most of the vegetation that was trying to germinate.

During the period of high rainfall, vegetation remained higher in the southern part of the park than the northern part, with rainfall being the highest in the northern region than the southern. In actual theory, the northern part would be expected to be greener than the southern part since rainfall is the highest in that region. Period 2000 was different from any other years that have been monitored in the study, as higher rainfall was received in the northern region than the southern region of the park (Map A) and zebra densities were still found in the southern region of the park.

Figure 4.9 shows the relationship between vegetation and rainfall as well as zebra distribution densities for the year 1991 and rainfall ranged from 63 to 660 mm (Map A). However, the total annual rainfall recorder at the KNP during the same period was 297 mm (Figure 4.1) and was below the annual average of 503 mm (Figure 4.2a). From Figure 4.9 it can be seen that vegetation was sparse than in 1993. This could have been the results of the low rainfall that was received in the year 1991 (297 mm). This explains the occurrence of sparse vegetation of the park in 1991 (Map B). However, during the same period zebra densities were higher in 2000 when rainfall was high (1122 mm) (Map C). These higher densities ranging from 7 273 to 231 832 were confined to areas where vegetation distribution ranged from moderate to sparse area. This is an indication of preference of open areas for avoidance of predators and the palability of sweetveld which is not a characteristic of high rainfall areas (Macandza, 2012).

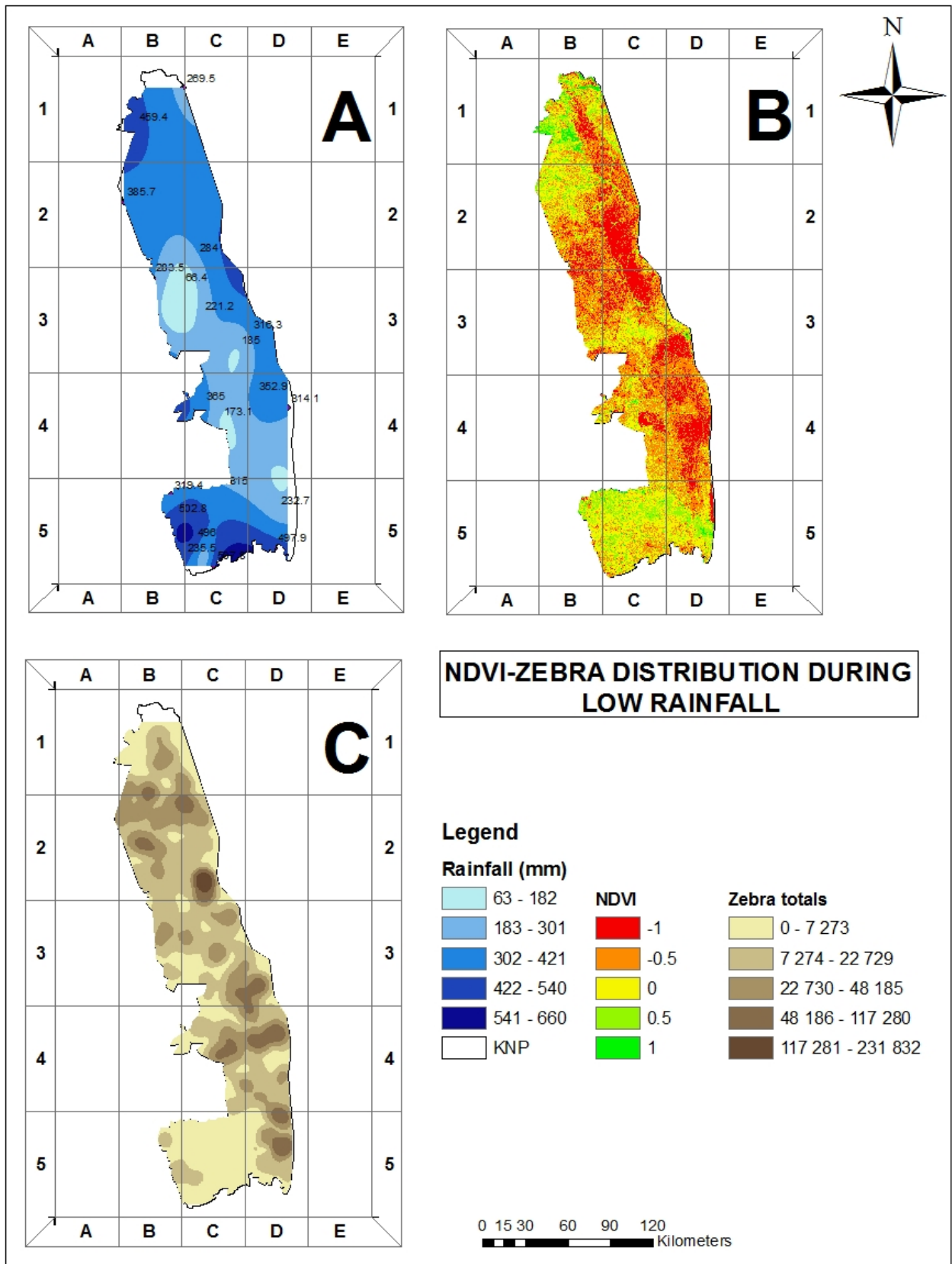


Figure 4.9: NDVI-Zebra Distribution during low rainfall (1991)

## CONCLUSIONS AND RECOMMENDATIONS

### 5.1. CONCLUSIONS

From the findings of the research it cannot be concluded that rainfall does not influence zebra abundances. Results from research indicated that there is no relationship between zebra abundances and annual rainfall in the KNP. The results from Spearman's rank-order correlation coefficient showed that there is no strong relationship between zebra abundances and rainfall. Data from graphs also indicated that in some instances when rainfall increased zebra abundances decreased, but there have been instances when rainfall increased zebra abundances increased too. These positive and negative correlation results indicate that it is entirely not easy to justify that rainfall was responsible for zebra abundances in the KNP.

However, an interesting finding from the results was that high zebra densities were observed in areas of low to moderate rainfall. From the NDVI maps high zebra densities were recorded in low cover or less dense areas characterised by low rainfall. Higher densities were also recorded in the central and southern parts of the park. Therefore, the explanation behind the decline of zebra abundances during high rainfall periods could be attributed to the role of dense vegetation during field survey. It can therefore be concluded that the drop in zebra numbers during high rainfall periods was due to the effect of dense vegetation in making counting and recording of zebra behaviour difficult. This is because dense vegetation obscured the observers during counting. This is why high zebra abundance values were recorded during low rainfall periods.

The role of vegetation and rainfall therefore needs to be clearly understood and studied to determine how these two variables affect zebra abundances during normal and low rainfall periods. The response of vegetation to rainfall changes in the KNP has accounted for the minor variations in the number of zebras recorded at a particular point in time. This has made it difficult for a conclusion to be drawn that rainfall changes, especially a drop in rainfall, severely affect zebra populations but the magnitude of impact needs to be thoroughly examined. Results were able to show that rainfall severely affected vegetation as it has shown significant response to changes in rainfall.

Therefore, the slow decline or low drop in zebra numbers during high rainfall period in the park was due to the vegetation characteristics. During low rainfall events some parts of vegetation in the park resemble vegetation of low rainfall areas. Thus, moist sourveld of the northern regions during drought will resemble sweetveld and zebras will survive from feeding on this vegetation. This means that areas of low rainfall during drought are degraded and force zebras to migrate to formally moist sourveld areas. When normal conditions are restored the degraded sweetveld of the low rainfall zones within the park regenerates and allows zebras to migrate to these areas. These alternating cycles of vegetation characteristics within the park during drought and high rainfall periods allow for the continuous existence of zebra populations. The NDVI maps clearly show these relationships between zebra distribution and vegetation characteristics. For example, from the 1991 and 1993 NDVI maps vegetation was generally sparse due to low rainfall events and that led to an even distribution of zebras across the park. In the 1991 NDVI map high zebra densities were recorded even in the northern parts of the park. This could be attributed to changes in vegetation characteristics during low rainfall or drought.

In the 2001 NDVI map high zebra densities were recorded in the southern part of the park because during this period vegetation in the northern part was generally green and dense due to high rainfall (652 mm) that was recorded compared to the 1991 (297 mm) event. This means that when vegetation of the northern regions transforms back into sourveld zebras migrate to the south and only head northwards during drought when sourveld is transformed into sweetveld due to low rainfall events. These alternating changes in vegetation dynamics due to changes in rainfall events favoured the zebras and this explains why impact of rainfall is insignificant.

It can therefore be concluded that the relationship between rainfall and zebra population within the KNP can be clearly understood by examining the nature and characteristics of vegetation during drought and high rainfall seasons. The palatability indices due to changes in rainfall need to be fully understood before conclusions about impact of rainfall on zebras are drawn. Therefore, based on the conclusions of this research the following recommendations can be made:

- More approaches to the studies of zebra and their relationship with rainfall need to be adapted to fully understand the existence of such a relationship.
- Have more individual scholars than compared to associations and organisations that would continuously publish information on climate change and how it influences the survival of ungulates in the environment across world and locally.
- Changes in vegetation dynamics due to changes in rainfall should be well studied and understood in order to understand how this influences migration of ungulates especially zebra migration patterns.
- The parks needs to be divided up in sizable study units and abundance measures are taken within the shortest time interval.
- Zebra count should only be made when vegetation is sparse to avoid not counting some of the zebra that could be hidden by the dense vegetation.
- The relationship between mortality, birth rates and rainfall variability is necessary to determine whether rainfall truly affects zebra abundance.
- Direct influence of changes in vegetation characteristics and the impact on zebra birth and mortality patterns needs to be extensively studied.

## 6. REFERENCES

Amboseli conservation program. 2009. *Impact of the 2009 drought on wildlife, livestock and tourism in the Amboseli ecosystem: Recommendations for prompt action and ecosystem restoration*. Kenya wildlife services.

Assessment, A.C.I., 2004. Impacts of a Warming Arctic-Arctic Climate Impact Assessment. *Impacts of a Warming Arctic-Arctic Climate Impact Assessment, by Arctic Climate Impact Assessment, pp. 144. ISBN 0521617782. Cambridge, UK: Cambridge University Press, December 2004, pp.144.*

Augustin, N.H., Mugglestone, M.A. and Buckland, S.T., 1996. An autologistic model for the spatial distribution of wildlife. *Journal of Applied Ecology* 33, pp.339–347.

Austin, W.D., 2008. *Drought in South Africa: Lessons lost and/or learnt from 1990 to 2005*. PhD. University of Witwatersrand: Johannesburg.

Bajgiran, P. R, Darvishsefat, A. A, Khalili, A, and Makhdoum, M. F., 2008. Using AVHRR-based vegetation indices for drought monitoring in the Northwest of Iran, *Journal of Arid Environments* 7, pp.1086-1096.

Bartlam-Brooks, H.L.A, Beck, P.S.A., Bohrer G, and HARRIS, S., 2013. In search of greener pastures: using satellite images to predict the effects of environmental change on zebra migration. *Journal of Geophysical Research: Biogeosciences*, 118, pp.1427-1437.

Bartolo, R., 2004. *The status of climate change research in the Kucadu landscape context*. Australian government. Department of the environment and water resources.

Benedetti, R. and Rossini, P., 1993. On the use of NDVI profiles as a tool for agricultural statistics: the case study of wheat yield estimate and forecast in Emilia Romagna. *Remote Sensing of Environment*, 45(3), pp.311-326.

Birkett, P.J., Vanak, A.T., Muggeo, V.M., Ferreira, S.M. and Slotow, R., 2012. Animal perception of seasonal thresholds: changes in elephant movement in relation to rainfall patterns. *PloS one*, 7(6), p.e38363.

Bless, C and Kathuria, R., 1993. *Fundamentals of sound statistics: An African perspective*. Juta Academics

Boone, R., Thirgood, S., & Hopcraft, J., 2006. Serengeti wildebeest migratory patterns modelled from rainfall and new vegetation growth. *Ecology* 87(8), pp.1987-1994.

Boyers, M., 2011. *Do zebra (Equus Quagga) select for greener grass within the foraging area*. University of Witwatersrand.

Brassett, B., 2016. *The effects of drought in Kruger*. Africa Geographic news.

Buckland, S.T. and Elston, D.A., 1993. Empirical models for the spatial distribution of wildlife. *Journal of Applied Ecology* 30, pp.478–495.

Burgan, R.E, and Hartford, R.A., 1993. *Monitoring Vegetation Greenness with Satellite Data*. Gen. Tech. Rep. INT- 297, US Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, Utah, pp.13.

Burung, I. 2014. *Wallace biodiversity hotspot*. Critical ecosystem partnership fund

Celesia, G.G., Peterson, A.T., Peterhans, J.C.B, and Gnoske, T.P., 2009. Climate and landscape correlates of African lion (*Panthera Leo*) demography. *African Journal of Ecology* 48, pp.58–71.

Chainey, S., Tompson, L, and Uhlig, S., 2008. The utility of hotspot mapping for predicting spatial patters of crime. *Security journal* 21, pp. 4-28.

Chakraborty, A., and Sehgal, V.K. (2010), Assessment of Agricultural Drought Using MODIS Derived Normalized Difference Water Index, *Journal of Agricultural Physics* 10, pp.28-36.

Climate Change, I.P.C.C., 2007. Climate change 2007: The physical science basis. *Agenda*, 6(07), pp.333.

Chapin, F.S III., Schulze, E.D. and Mooney, H.A., 1990. *The ecology*. Annual rev. entomol 24, pp.417-447.

Chatterjee, S., and Hadi, A.S., 2012. *Regression analysis by example*. (5<sup>th</sup>). John Wiley & Sons. Canada.

Chidumayo, E., Okali, D., Kowero, G. and Larwanou, M., 2011. (Eds.). *Climate change and African forest and wildlife resources*. African Forest Forum, Nairobi: Kenya.

Chirima, G.J., Owen-Smith, N., and Erasmus, B.F.N., 2012. Changing distribution of larger ungulates in the Kruger National Park from ecological aerial survey data. Cape Town. *Koedo* 54 (1).

Cihlar, J., St Laurent, L., and Dyer, J. A., 1991. Relation between the Normalized Difference Vegetation Index and Ecological Variables. *Remote Sensing of Environment* 35, pp.279-98.

Coe, M.J., Cummings, D.H., and Phillipson, J., 1976. Biomass and production of Large African herbivores in relation to rainfall and primary production. *Oecologia* 22, pp.341–354.

Dabrowska-Zielinska K., Kogan F., Ciolkosz A., Gruszczynska M., and Kowalik W., 2002. Modelling of crop growth conditions and crop yield in Poland using AVHRR based indices, *International Journal of Remote Sensing* 23(6), pp.1109-1123.

Dai, A., 2010. *Drought under global warming: a review*. John Wiley and sons, Ltd.2, pp.45-66.

Data, C., 2009. Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation. *World Meteorological Organization*.

Davis, C., 2010. *Climate change handbook for north-eastern South Africa*. Council for Scientific and Industrial Research (CSIR).

Department of Agriculture., 2004. *Drought management plan*. 7<sup>th</sup> edition. Republic of South African.

Di L. P., Rundquist, D. C., and Han, L., 1994. Modelling relationship between NDVI and precipitation during vegetative growth cycles. *International Journal of Remote Sensing*, 15(10), pp.2121–36.

Dirschl, H.J., Norton-Griffiths, M. and Wetmore, S.P., 1981. Training observers for aerial surveys of herbivores. *Wildlife Society Bulletin*, pp.108-115.

duToit, J.T., Rogers, K.H., and Biggs, H.C. (ed.) ., 2003. The Kruger experience: ecology and management of savannah heterogeneity. British cataloguing, Island press United States, pp. 328

Duncan, C., Chauvenet, A.L.M., McRae, L. M., and Pettorelli, N., 2012. Predicting the Future Impact of Droughts on Ungulate Populations in Arid and Semi-Arid Environments. *PLoS ONE* 7(12): e51490. doi:10.1371/journal.pone.0051490.

Dutta, R., 2016. *Review of Normalized Difference Vegetation Index (NDVI) as an Indicator of Drought*. Coordinates.

Economic Commission for Africa. , 2007. *Africa review report on Drought and desertification*. Economic and Social Council. United States.

Elalem, S., and Pal, I., 2015. Mapping the vulnerability hotspots over Hindu-Kush Himalaya region to flooding disasters. *Weather and climate extremes*, 8, pp.46-58.

EM-DAT: *The OFDA/CRED International Disaster Database* – www.emdat.be, University Catholique de Louvain, Brussels (Belgium).

Environmental Protection Agency. 2014.*Climate Change Indicators in the United States: Drought*. Environmental Protection Agency, 1

Erdenetuya, M., Bulgan, D., and Erdenetsetseg, B., 2010. *Drought monitoring and assessment using multi satellite data in Mongolia*.

Erian, W., Katlan, B., Ouldbedy, B., Awad, H., Zaqtity, E. and Ibrahim, S., 2013. Agricultural Drought in Africa Mediterranean and Middle East. *Background Paper Prepared for the Global Assessment Report on Disaster Risk Reduction*, p.402.

Estes, R.D., 1997. *Behavioural Guide to African Mammals - Including Hoofed Mammals, Carnivores, and Primates*. Russell Friedman Books CC, Pretoria.

Farina, A., 1997. Landscape structure and breeding bird distribution in a sub-Mediterranean agro-ecosystem. *Landscape Ecology*, 12, pp.365–378.

Fritz, H., Duncan, P., Gordon, I.J. and Illius, A.W., 2002. Megaherbivores influence trophic guilds structure in African ungulates communities. *Oecologia*, 131(4), 99.620-625

Galvin, K.A., Thornton, P.A., Boone, R.B., and Slunder, j., 2004. Climate variability and impacts on east African livestock herders: the Maasai of Ngorongoro Conservation Area, Tanzania. *African Journal of range and forage science*.

Gandiwa, E., Heitkönig, I.M., Eilers, P.H. and Prins, H.H., 2016. Rainfall variability and its impact on large mammal populations in a complex of semi-arid African savanna protected areas. *Tropical Ecology*, 57(2), pp.163-180.

Gaston, K.J., and Blackburn, T.M., 1995. Mapping biodiversity using surrogates for species richness – macro-scales and New World birds. Proceedings of the Royal Society of London, Series B, *Biological Sciences*, 262, pp.335–341.

Georgiadis, N., Hack, M. and Turpin, K., 2003. The influence of rainfall on zebra population dynamics: implications for management. *Journal of Applied Ecology*, 40(1), pp.125-136.

Getz, W.M., Fortmann-Roe, S., Cross, P.C., Lyons, A.J., Ryan, S.J, and Wilmers, C.C., 2007. LoCoH: Nonparametric kernel methods for constructing home ranges utilization distribution. *PLoS ONE*, 2, pp.1-11.

- Gibbons, J.D. and Chakraborti, S., 2011. Nonparametric statistical inference. In *International encyclopaedia of statistical science* (pp. 977-979). Springer Berlin Heidelberg.
- Grange, S. and Duncan, P., 2006. Bottom-up and top-down processes in African ungulate communities: resources and predation acting on the relative abundance of zebra and grazing bovids. *Ecography*, 29(6), pp.899-907.
- Grant, C.C., and van der Walt, J.L., 2000. Towards an adaptive management approach for the conservation of rare antelope in the Kruger National Park-outcome of a workshop held in May 2000. *Koedoe*, 43(2), pp.103-112.
- Grasmus, I.F., 1991. *Methodologies for drought monitoring using meteorological data*. Ph.D. thesis. University of the Orange Free State: Bloemfontein.
- Greenfield, T., 2002. *Research methods for postgraduates*. 2<sup>nd</sup> ed. London: Arnold
- Groom, R. and Harris, S., 2010. Factors affecting the distribution patterns of zebra and wildebeest in a resource-stressed environment. *African Journal of Ecology*, 48(1), pp.159-168.
- Gu, Y. Brown, J.F., Verdin, J.P., and Wardlow, B., 2007. A five-year analysis of MODIS NDVI and NDWI for grassland drought assessment over the Central Great Plains of the United States. *AGU Journal*, 34(6).
- Gyedu-Ababio, T., Hechzermeyer, D., Govender, D., pienaar, D., Botha, H., and Sibiya, O., 2012. *Crocodile deaths in the Olifants River, Kruger National Park South Africa: A potential health risk to biodiversity and humankind*. SANParks.
- Hamilton, W.T., 2003. *Drought: managing for and during the bad years*, pp. 133-152 in Ferguson, C.A. Bryant, F.C., and Genho, P.C. eds. Ranch management: integrating cattle, wildlife, and range. King ranch, Kingsville, TX.
- Hanak, E., Mount, J. and Chappelle, C., 2014. California's latest drought. *Public Policy Institute of California*.
- Harrington, R., Owen-Smith, N., Viljoen, P.C., Biggs, H.C., Mason, D.R. and Funston, P., 1999. Establishing the causes of the roan antelope decline in the Kruger National Park, South Africa. *Biological conservation*, 90(1), pp.69-78.

Hielkema, J. U., Prince, S. D., and Astle, W. L., 1986. Rainfall and vegetation monitoring in the Savanna zone of Democratic Republic Sudan using NOAA Advanced Very High Resolution Radiometer. *International Journal of Remote Sensing*, 7, pp.1499–1514.

Hofmeister, E., Moede-Rogall, G., Wesenberg, K., Abbott, R., Work, T., and Schuler, K., 2012. *Climate change and wildlife health: direct and indirect effects*. USGS Science for changing world. U.S. Geological survey National Wildlife Health Center, pp. 4.

Hofmeyr M., 2007. *Weather station moves to Pretorius*. Kruger Park Safaris. Siyabonga Africa.

Homer, C.G., Edwards, T. C., Ramsey, R.D., and Prince, K. P., 1993. Use of remote sensing methods in modelling sage grouse winter habitat. *Journal of Wildlife Management*, 57, pp.78–84.

Hounam, C.E., Burgos, J.J., Kalir, M.S., Palmer, W.C., and Rodda, J., 1975. *Drought and agriculture*. WMO Technical note no.138. World meteorological organisation. Geneva.

Hulme, M., Doherty, R., Ngara, T., New, M., and Lister, D., 2001. African climate change: 1900-2100. *Climate Research*, 17, pp.145-168.

Hydrology Project Training Module. 2002. How to analyse rainfall data. *Hydrology Project*. New Delhi.

Illius, A.W., and O'Connor, T.G., 2000. Resource heterogeneity and ungulate population dynamics. *Oikos*, 89, pp.283–294.

Ingram, J.C., and Dawson, T.P., 2005. *Climate change impacts and vegetation response on the Island of Madagascar*. Philosophical Transactions of the Royal Society. *Mathematical*, 363, pp.55–59.

Intergovernmental Panel on Climate Change. 2007. *Climate change 2007: Synthesis report: contribution of working groups I, II, and III to the fourth assessment report of*

the Intergovernmental Panel on Climate Change: Geneva, Switzerland, *Intergovernmental Panel on Climate Change*, pp.104.

International strategies for disaster reduction (ISDR). 2008. *Drought. Desertification and water scarcity*. ISDR-BIBLIO. United States.

International Strategies for Disaster Reduction (ISDR). 2002. *Living with Risk, A global Review of Disaster Reduction Initiatives, Preliminary version*, pp. 24-25. Geneva, Switzerland.

Justice, C.O., Townshend, J.R.G., Holben, B.N., and Tucker, C.J., 1985, Analysis of the phenology of global vegetation using meteorological satellite data. *International Journal of Remote Sensing*, 6, pp.1271–1318.

Kabanda, T.A., 2004. *Climatology of Long-term Drought in the Northern Region of the Limpopo Province of South Africa* (Doctoral dissertation, University of Venda).

Kaeslin, E., Redmond, I., and Dudley, N., 2012. *Wildlife in a changing climate*. FAO forestry part 167. Food and agriculture organisation of the United States. Rome.

Karabulut, M., 2003. An examination of relationships between vegetation and rainfall using maximum value composite AVHRR-NDVI data. *Turkey Journal of Botany*, 27, pp.93-101.

Karniel, A., Agam N., Pinker, R.T., Anderson, M., Imhoff, M.L., Gutman, G.G., Natalya, P., and Goldberg, A. (2009). Use of NDVI and land surface temperature for drought assessment: Merits and limitations. *Journal of climate*, 23, pp.618-633.

Kenya Projects Organisation (KENPRO). 2010. Effects of Drought in Kenya. *KENPRO Online Papers Portal*. Available online at [www.kenpro.org/papers](http://www.kenpro.org/papers).

Kenya Wildlife Service. 2009. *The impact of drought on wildlife, livestock and tourism in the Amboseli ecosystem: Recommendations for prompt action and ecosystem restoration*. African Conservation Centre.

King, S.R.B and Moehlman, P.D., 2016. *Equus quagga*. The IUCN Red List of Threatened Species.

King, T.L., Thornton, L.E., Bentley, R.J., and Kavanagh, A.M., 2015. The Use of Kernel Density Estimation to Examine Associations between Neighborhood Destination Intensity and Walking and Physical Activity. *Journal pone*, 10(9).

Kingdon, J., 1979. *East African Mammals: an Atlas of evolution in Africa*. The University of Chicago press, London, 3 (b).

Kloog, I., Haim, A., and Portnov, B.A., 2009). Using kernel density function as an urban analysis tool: Investigating the association between nightlight exposure and the incidence of breast cancer in Haifa, Israel. *Computers, Environment and Urban Systems*, 33, pp.55–63.

Kogan, F. N., 1987a. Vegetation index for areal analysis of crop conditions. Proceedings of 18th Conference on Agricultural and Forest Meteorology, AMS, W. Lafayette, Indiana, on 15–18 September 1987 (Indiana, USA), pp. 103–106.

Kogan, F. N., 1995, Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research*, 15, pp.91–100.

Kogan, F.N., 1990. Remote sensing of weather impacts on vegetation in non-homogeneous areas. *International Journal of Remote Sensing*, 11 (8), pp.1405–1419.

Kogan, F.N., 1995. Droughts of the Late 1980s in the United States as Derived from NOAA Polar Orbiting Satellite Data. *Bulletin of American Meteorological Society*, 76, pp.655-668.

Korner, C., 2003. Carbon limitation in trees. *Ecological journal*, 91, pp.4-17.

Kosmala, M., 2013. Rainfall patterns in the Serengeti. Snapshot Serengeti. A *Zooniverse project blog*.

*Kotzé, E., 2015. Response of soil properties to rangeland use in grassland and savanna biomes of South Africa (Doctoral dissertation, University of the Free State).*

Leilei, L., Jianrong, F., and Yang, C., 2012. The relationship analysis of vegetation cover, rainfall and land surface temperature based on remote sensing in Tibet, China. *Earth and Environmental Sciences*, 17.

Lewis, S.L., Brando, P.M., Phillips, O.L., van der Heijden, G.M. and Nepstad, D., 2011. The 2010 amazon drought. *Science*, 331(6017), pp.554-554.

Liu, H.Q., and Huete, A.R., 1995. A feedback based modification of the NDV I to minimize canopy background and atmospheric noise. *IEEE Transactions on Geoscience and Remote Sensing*, 33, pp.457-465.

Liu, W.T., and Ferreira, A., 1991. Monitoring crop production regions in the Sao Paulo State of Brazil using normalized difference vegetation index. *Remote Sensing of Environment*, 2, pp.447–455.

Lunetta, R.S., Knight, J.F., Ediriwickrema, J., Lyon, J.G., and Worthy, L.D, 2006. Land-cover change detection using multi-temporal MODIS NDVI data. *Remote Sensing of Environment*, 105 (2), pp.142-154.

Macandza, V.A., Owen-Smith, N. and Cain, J.W., 2012. Habitat and resource partitioning between abundant and relatively rare grazing ungulates. *Journal of Zoology*, 287(3), pp.175-185.

Maddock, L., 1979. *The 'migration' and grazing succession. Serengeti: Dynamics of an Ecosystem* (Sinclair, A.R.E. and Norton-Griffiths, M eds), pp.104-129. University of Chicago, Chicago, IL, USA.

Mahajan, D.R, Dodamani, B.M, and Mannina, G., 2016. Spatial and temporal drought analysis in the Krish river basin of Maharashtra, India. *Cogent Engineering*, 3(1)

Malek, M.A., Hossain, M.A., Saha, R., and Gatzweiler, F.W., 2013. Mapping marginality hotspots and agricultural potentials in Bangladesh. *Working paper* 114.

Malo, A. R., and Nicholson, S. E., 1990. A study of rainfall dynamics in the African Sahel using normalized difference vegetation index. *Journal of Arid Environments*, 19, pp.1–24.

Mansour, K., Mutanga, O. and Everson, T., 2012. Remote sensing based indicators of vegetation species for assessing rangeland degradation: opportunities and challenges. *African Journal of Agricultural Research*, 7(22), pp.3261-3270.

Marshal, J.P., Krausman, P.R. and Bleich, V.C., 2005. Rainfall, temperature, and forage dynamics affect nutritional quality of desert mule deer forage. *Rangeland Ecology & Management*, 58(4), pp.360-365.

Maselli, F., 2004. Monitoring forest conditions in a protected Mediterranean coastal area by the analysis of multiyear NDVI data. *Remote Sensing of Environment*, 89, pp.423-433.

Mashala, P., 2012. *Game on for Kruger Park Wildlife services*. Farmer's weekly magazine

Masih, L., Maskey, S., Mussa, F.E.F., and Trambauer, P., 2014. A review of drought on the African continent: a geospatial and long-term perspective. *Hydrology and Earth System Sciences*, 18, pp.3635-3649.

Mason, D.R., 1991. *Monitoring of the Ungulate population structure in the Kruger National Park*. Department of research KNP.

Mbogo, E., Inganga, F., and Maina, J.M., 2010. *Drought conditions and management strategies in KENYA*. Nairobi: Kenya

McDowell, N.G., 2011. Mechanisms linking drought, hydraulics, carbon metabolism, and vegetation. *Mortality plant physiology*, 155(3), pp.1057-1059.

McKee, T. B., Doesken, N. J., and Kleist, J., 1993. The relationship of drought frequency and duration to time scales. Proceedings of the 8th Conference on Applied Climatology. Boston. MA, Am. *Meteorology. Soc*, 17(22), pp.179–183.

Mduma, S.A., Sinclair, A.R.E. and Hilborn, R., 1999. Food regulates the Serengeti wildebeest: A 40-year record. *Journal of Animal Ecology*, 68(6), pp.1101-1122.

Mkundu, F.X., 1996. *Potential impacts of future climate change on Nyalatragelaphusangas in Lengwe National Park*, Malawi. Climate research.

Monacelli, G., 2005. *Drought assessment and forecasting*. Drought meteorological organization. Europe.

Montgomery, D.C., Peck, E.A., and Vining, G.G., 2012. *Introduction to linear regression analysis*. (5<sup>th</sup>.) John Wiley & sons. Canada.

Morais, C.D., 2014. *What is the difference between a heat map and hot spot map?* GIS lounge.

Narasimhan, B., and Srinivasan, R., 2005. Development and evaluation of soil moisture deficit index and evapotranspiration deficit index for agricultural drought monitoring. *Agricultural and Forest Meteorology*, 133, pp.69-88.

Nathali, P., 2013. *The normalised difference index*. Oxford University Press: United Kingdom.

Nekhavambe, T.D., 2012. *Assessment of Socio-economic and Institutional Factors that Affect the Performance of Irrigation Schemes in Vhembe District of Limpopo Province, South Africa* (Doctoral dissertation, University of Venda).

Nicholls, N., 2004. The changing nature of Australian droughts. *Climatic change*, 63(3), pp.323-336.

Odum, E.P., 1971. *Fundamentals of ecology 1971*. Philadelphia: WB Saunders Company.

Ogutu, J.O., & Owen-Smith, N., 2003. ENSO, rainfall and temperature influences on extreme population declines among African savanna ungulates. *Ecology letters*, 6, pp.412.

Ogutu, J.O., and Owen-Smith, N., 2003. Rainfall influences on ungulates population dynamics', in J.T. Du Toit, K.H. Rogers and H.C. Biggs (eds.), *the Kruger experience: ecology and management of savanna heterogeneity*, Island press: Washington, DC. Pp.310-331.

Ogutu, J.O., Piepho, H.P., Dublin, H.T., Bhola, N. and Reid, R.S., 2008. Rainfall influences on ungulate population abundance in the Mara-Serengeti ecosystem. *Journal of Animal Ecology*, 77(4), pp.814-829.

Ogutu, J.O., Piepho, H.-P., Dublin, H.T., Bhola, N., and Reid, R.S., 2009. Dynamics of Mara Serengeti ungulates in relation to land use changes. *Journal of Zoology*, 278, pp.1–14.

Ogutu, J.O., Piepho, H.P., Dublin, H.T., Bhola, N., and Reid, R.S., 2007. ENSO, rainfall and temperature fluctuations in the Mara-Serengeti ecosystem. *African Journal of Ecology*.

Osborne, P., Alonso, J., and Bryant, R., 2001. Modelling landscape-scale habitat use using GIS and remote sensing: a case study with great bustards. *Journal of Applied Ecology*, 38, pp.458-471.

Osborne, P.E., and Tigar, B.J., 1992. Interpreting bird atlas data using logistic models: an example from Lesotho, Southern Africa. *Journal of Applied Ecology*, 29, pp.55–62.

Ottichilo, W.K., De Leeuw, J., Skidmore, A.K., Prins, H.H. and Said, M.Y., 2000. Population trends of large non-migratory wild herbivores and livestock in the Masai Mara ecosystem, Kenya, between 1977 and 1997. *African journal of Ecology*, 38(3), pp.202-216.

Owen-Smith, N, and Mills, G.L.M., 2006. Manifold interactive influences on the population dynamics of multispecies ungulates assemblage. *Ecological Monographs*, 76, pp.73-92.

Owen-Smith, N., 2005. *Adaptive herbivore ecology*. Cambridge University Press. Johannesburg.

Owen-Smith, N. and Ogutu, J.O., 2003. Rainfall influences on ungulate population dynamics. *The Kruger experience: Ecology and management of savanna heterogeneity*, pp.310-331.

Owen-Smith, N., le Roux, E., and Macandza, V., 2013. Are relatively rare antelope narrowly selective feeders? A sable antelope and zebra comparison. *Journal of Zoology*, 293, pp.181-191.

Owen-Smith, N., Mason, D.R., and Ogutu, J.O., 2005. Correlates of survival rates for 10 African ungulate populations: density, rainfall and predation. *Journal of Animal Ecology*, 74, pp.774–788.

Packer, C., Altizer, A., Appel, M., et al., 1999. Viruses of the Serengeti: patterns of infections and mortality in African lions. *Journal of Animal Ecology*, 68, pp.1161-1178.

Palma, L., Beja, P., and Rodrigues, M., 1999. The use of sighting data to analyse Iberian lynx habitat and distribution. *Journal of Applied Ecology*, 36, pp.812–824.

Palmer, W. C., 1965. *Meteorological drought*. US Department of Commerce. Weather Bureau. Washington: D.C, 45, pp.1–58.

Parker, H., 2011. *The importance of Kruger National Park: Preserving South Africa's big five*. South Africa study abroad. WordPress

Pascual, M.A., and Hilborn, R., 1995. Conservation of harvested populations in fluctuating environments: the case of the Serengeti wildebeest. *Journal of Applied Ecology*, 32, pp.468–480.

Peters, A.J., Walter-Shea, E.A., Ji, L., Vina, A., Hayes, M., and Svoboda, M.D., 2002. *Photogrammetric Engineering & Remote Sensing*, 68(1), pp.71-75.

Pettorelli, N., Vik, J., Mysterud, A., Gaillard, J., Tucker, C., and Stenseth, N., 2005. Using the satellite derived NDVI to assess ecological responses to environmental change. *TRENDS in Ecology and Evolution*, 20(9), pp.503-510.

Petty, A.M., Merner, P.A., Lehmann, C.G.R., Banfai, D.S., and Elliott, L.R., 2007. Savannah responses to feral buffalo in Kakadu National Park. Ecological monographs: *Ecological society of America*, 77(3), pp.441-463.

Pioneer, U de V., 1963. The large mammals of the Kruger National Park - Their distribution and present-day status. *Koedoe* 6, pp. 1-37.

Pienaar, U de V., 1990. *Neem uit die verlede*. Pretoria: Sigma Press.

- Pinaud, D., 2008. Quantifying search effort of moving animals at several spatial scales using first-passage time analysis: effect of the structure of environment and tracking systems. *Journal of Applied Ecology*, 45(1), pp.91-99.
- Redfern, J.V., Grant, C.C., Gaylard, A. and Getz, W.M., 2005. Surface water availability and the management of herbivore distributions in an African savanna ecosystem. *Journal of Arid Environments*, 63(2), pp.406-424.
- Regassa, R., and Yirga, S., 2013. Distribution, abundance and population status of Burchell's zebra (*Equus quagga*) in Yabello Wildlife Sanctuary, Southern Ethiopia. *Journal of Ecology and the Natural Environment*, 5(3), pp.40-49.
- Rogers, D.J., Hay, S.I., Packer, M.J., and Wint, G.R.W., 1997. Mapping land-cover over large areas using multispectral data derived from the NOAA-AVHRR: a case study of Nigeria. *International Journal of Remote Sensing*, 18, pp.3297– 3303.
- Rojas, O. Li, Y. and Cumani, R., 2014. *Understanding the drought impact of El Niño on the global agricultural areas*. Food and Agriculture Organization of the United Nations, Rome.
- Ropelewski, C.F; and Halpert, M.S., 1987. Global and regional scale precipitation patterns associated with the El-Nino-Southern Oscillation (ENSO). *Monthly weather review*, 114, pp.1606-1626.
- Rouse, J.W., Haas, R.H., Deering, D.W., and Sehell, J.A., 1974. Monitoring the vernal advancement and retro gradation (Green wave effect) of natural vegetation. Final Rep. RSC 1978–4, *Remote Sensing Centre*, Texas A&M Univ., College Station.
- Rushton, S. P., Ormerod, S. J., and Kerby, G., 2004. New paradigms for modelling species distributions. *Journal of Applied Ecology*, 41, pp.193–200.
- SADC climate Service Centre., 2011. *Drought Risk Management in Southern African*. African-Asia Drought Adaptation Forum.
- Sanchez, D., 2016. *Crocs, Lions could be biggest drought beneficiaries as weak prey makes for fast food*.AFKInsider.

Saveraid, E. H., Debinski, D. M., Kindscher, K., and Jakubauskas, M. E., 2001. A comparison of satellite data and landscape variables in predicting bird species occurrences in the Greater Yellowstone Ecosystem, USA. *Landscape Ecology*, 16, pp.71–83.

Savides, M., 2015. *Drought stalks KZN wildlife*. Profile data.

Schneider, A., Hommel, G., and Blettner, M., 2010. Linear regression analysis part 14 of a series evaluation of scientific publications. *DtschArztebl International*, 107(44),pp.776-82.

Schutte, I.C., 1986. The general geology of the Kruger National Park. *Koedoe*, 29(1), pp.13-37.

Sellke, T., Bayarri, M.J., and Berger, J.O., 2001. Calibration of p Values for Testing Precise Null Hypotheses. *The American Statistician*, 55(1).

Senzota, R.B.M., 1988. Further evidence of exogenous processes regulating the population of zebra in the Serengeti. *African Journal of Ecology*, 26,pp.11–16.

Shewmake, S., 2008. *Vulnerability and the impact of climate change in South Africans Limpopo river basin*. International food policy research institute: environment and production technology division.

Simonetti, E., Simonetti, D., and Preatoni, D., 2014. *Phenology based land cover classification using Landsat 8 time series*. JRC Technical reports. Joint research centre.

Singh, R. P., Singh, N., Singh, S., and Mukherjee, S., 2016. Normalized Difference Vegetation Index (NDVI) Based Classification to Assess the Change in Land Use/Land Cover (LULC) in Lower Assam, India. *International Journal of Advanced Remote Sensing and GIS*, 5(10),pp.1963-1970.

Sitati, N., Lekishon, K., Bakari, S., Warinwa, F., Mwiu, S.N., Gichohi, N., Bitok, E., Mwita, M., Ija, H.K., and Mukeka, J. (2014). Wildebeest (*Connochaetestaaurinus*) Population Densities and Distribution in Dry and Wet Season in the Kilimanjaro Landscape. *Natural Resources*, 5(8).

Skinner, J. D., and Chimimba, C. T., 2005. "Equidae". The Mammals of the Southern African Subregion (3rd ed.). *Cambridge University Press*, pp. 537–546. ISBN 0-521-84418-5.

Smit, I.P.J., Riddell, E.S., Cullum, C., and Peterson, R., 2013. Kruger National Park research supersites: Establishing long-term research sites for cross-disciplinary, multiscaled learning. *Koedoe*, 55(1).

Smuts, G.L., 1975. Home range sizes of Burchell's zebra *Equusburchelliantiquorum* from Kruger National Park. *Koedoe*, 18, pp.139-146.

South African National Parks. 2008. *Management plan of SANParks: recommended to Department of Environmental Affairs and Tourism*. South African National Parks.

Stuart, C., and T. Stuart., 1997. *Field Guide to the Larger Mammals of Africa*. Struik Publisher's Pvt. Ltd., Cape Town.

Sun. J., Ai. T., Zhao. C. and Yan. H., 2007. Assessing vegetation degradation in loess plateau by using potential vegetation index. *IEEE*, pp.1794- 1797.

Svoboda, M., 2016. *ENSO and drought forecasting*. The National drought mitigation center. University of Nebraska Lincoln, Pp.10-821.

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F., De Siqueira, M.F., Grainger, A., Hannah, L. and Hughes, L. (2004). Extinction risk from climate change. *Nature*, 427(6970), pp.145.

Thornton, L., Pearce, J.R., and Kavanagh, A., 2011. Using geographic information systems (GIS) to assess the role of the built environment in influencing obesity: a glossary. *International Journal of Behavioural Nutrition and Physical Activity*, 8, pp.71–79.

Torchia, C., 2016. *Drought hits South Africa's biggest wildlife park*. The associated press.

Trambauer, P., Maskey, S., Werner, M., Pappenberger, F., van Beek, L.P.H., and Uhlenbrook, S., 2014. Identification and simulation of space–time variability of past hydrological drought events in the Limpopo River basin, southern Africa. *Hydrology and Earth System Sciences*, 18, pp.2925-2942.

Tucker C.J., 1979. Red and Photographic infrared linear combinations for monitoring vegetation. *Remote sensing of Environment*, 8, pp.125-150.

Tucker, C. J., and Choudhury, B.J., 1987. Satellite remote sensing of drought conditions. *Remote Sens. Environ*, 23, pp.243–251.

Tucker, C.J., Gatlin, J., Schnieder, S.R., and Kunginos, M.A., 1982. *Monitoring large scale vegetation dynamics in the Nile delta and river valley from NOAA AVHRR data: Proceedings of the conference on remote sensing of arid and semi-arid lands*. Cairo, Egypt, pp.973-977.

Tucker, C.J., Townshend, J.R.G., and Goff, T.E., 1985. African land covers classification using satellite data. *Science*, 227, pp.4685

Tuqa, J.H., Funston, P., Musyoki, C., Ojwang, G.O., Ginchuki, N.N., Bauer, H., Tamis, W., Dolrenry, S., van'tzeldde, M., de Snoo, G.R., and de Longh, H.H., 2014. Impact of severe climate vulnerability on lion home range and movement patterns in the Amoboseli ecosystem, Kenya. *Global ecology and conservation*, 2, pp.1-10.

Tyson, P. D., and Preston-Whyte, R. A., 2000. *The Weather and Climate of Southern Africa*. Oxford University Press: Cape Town.

Van Bommel, F., Heitkonig, I., Epema, G., Ringrose, S., Bonyongo, C., and Veenendaal, E., 2006. Remotely sensed habitat indicators for predicting distribution of impala (*Aepyceros melampus*) in the Okavango Delta, Botswana. *Journal of Tropical Ecology*, 22, pp.101-110.

Van der Linden, P. and Mitchell, J.E., 2009. ENSEMBLES: Climate change and its impacts-Summary of research and results from the ENSEMBLES project.

Van Soest, P.J., 1994. *Nutritional ecology of the ruminant*. Cornell university press.

van Wilgen, B.W. and Richardson, D.M., 2012. Three centuries of managing introduced conifers in South Africa: benefits, impacts, changing perceptions and conflict resolution. *Journal of environmental management*, 106, pp.56-68.

Verlinden, A. and Masogo, R., 1997. Satellite remote sensing of habitat suitability for ungulates and ostrich in the Kalahari of Botswana. *Journal of Arid Environments*, 35(3), pp.563-574.

Vina, A., Bearer, S., Zhang, H., Ouyang, Z., and Liu, J., 2008. Evaluating MODIS data for mapping wildlife habitat distribution. *Remote Sensing of Environment*, 112, pp.2160-2169.

Vogel, C., 1994. (Mis) management of drought in South Africa: past, present and future. *South African journal of sciences*, 90, pp.4-6.

Vogt, J. V., Niemeyer, S., Somma, F., Beaudin, I., and Viau, A. A., 2000. *Drought monitoring from space*. In: Drought and drought mitigation in Europe, pp.167–183.

Warburton, L.S., and Perrin, M.R., 2005. Conservation implications of the drinking habits of black-cheeked lovebirds *Agapornis nigrigenis* in Zambia. *Bird Conservation International*, 15, pp.383–396.

Wardlow, T., 2015. *Posts Tagged With: Kruger National Park*. *The adventure journal theme*. WordPress.

Water Research Commission. 2015. *Background to current drought situation in South Africa*. WRC Drought Factsheet 1.

Wessels, k.J., and Dwyer, P.C., 2011. *Impact of ENSO events on the Kruger National Park's vegetation*. In *Observations on Environmental Change in South Africa*. Ed. Larry Zietsman, Sun Press: Stellenbosch, pp.92-97.

Western, D., 1975. Water availability and its influence on the structure and dynamics of a savannah large mammal community. *African Journal of Ecology*, 13(3-4), pp.265-286.

Wetmore, S.P., and Townsend, G.H., 1975. *A geographical mode for storage identification: Analysis of Ecological data*. KREMU, Nairobi, Kenya. Technical report, 1.

Welman, C., Kruger, F. and Mitchell, B., 2005. Research methods.

Wildlife ranching. (2009). *Plain zebra (Equus quagga)*. Wildlife ranging.com.

Wiley, J and Sons. (2011). Drought under global warming: a review. *Wires climate change*, 2,pp.45-65.

Wilhite, D.A., 2002. *Defining drought: the challenge for early warning system*. University of Nebraska, Lincoln.

Wilhite, D.A., 2000. *Drought as a Natural Hazard: Concepts and Definitions*. Routledge Publishers: London.

Williams, P., Humphries, C., Vanewright, D., and Gaston, K., 1997. Descriptive and predictive approaches to biodiversity measurement. *Trends in Ecology and Evolution*, 12,pp.444–445.

Winsor, M., 2015. *El Niño In Africa 2015: Weather Phenomenon May Devastate East African Farmers, Herders With Drought, Floods*. International business times.

Wisconsin Initiative on Climate Change Impacts (WICCI)., 2011. *Wisconsin's changing climate; impacts and adaptation*. WCCI report. University of Wisconsin

Woodcock, C.E., Macomber, S.A., and Kumar, L., 2002. Vegetation Mapping and Monitoring. In: Skidmore, A.K. Environmental Modelling with GIS and Remote Sensing. London, UK: Taylor and Francis.

World health organization., 2015. *Drought- technical hazards sheet- natural disaster profile*. WHO. Humanitarian health action.

World Meteorological Organization., 2006. *Drought monitoring and early warning: concepts, progress and future challenges*. World Meteorological Organisation.

Yohe, G., Malone, E., Brenkert, A., Schlesinger, M., Meij, H., and Xing, X., 2006). Global Distributions of Vulnerability to Climate Change. *Integrated Assessment Journal*, 6(3), pp.35-44.

Young, M. V., 1994. Back to basics: Depressions and anticyclones: Part 1- introduction. *Weather*, 49, pp.306-311

Zambatis, N., and Biggs, H.C., 1995. Rainfall and temperature during the 1991/92 drought in Kruger National Park. *Koedoe*, 38(1), pp.1-6. Pretoria. ISSN 0075-6458

Zargar, A., Sadiq, R., Naser, B., and Khan, F.I., 2011. A review of drought indices. *Environmental review*, 19, pp.333-349.

Zinn, A.D., 2013. *Can MODIS NDVI measurements be used to predict zebra (*Equus burchelli*) foraging patterns?* University of the Witwatersrand, Johannesburg.

Zinner, D., Pelaez, F., and Torkler, F., 2002. Distribution and habitat of ' grivet monkeys (*Cercopithecus aethiops aethiops*) in eastern and central Eritrea. *African Journal of Ecology*, 40, pp.151–158.

## 7. APPENDICES

### Appendix I: Rainfall stations of the Kruger National Park and their location point as received from Kruger National Park

ID	CODE	STATION NAME	LAT	LONG
1	BDL	Berg-en-D	-25.42	31.45122
2	BOE	Bushman	-25.41	31.36042
3	KRO	Crocodile	-25.3584	31.89236
4	GIR	Giriyondo	-23.6501	31.69134
5	HOU	Houtbosch	-24.1049	31.66733
6	JOC	Jock Safar	-25.2098	31.56277
7	KFI	Kingfisher	-24.4629	31.44153
8	LET	Letaba	-23.851	31.57673
9	OSA	Lower Sab	-25.1211	31.91727
10	MAH	Mahlange	-23.6478	31.14744
11	MAK	Makhadzi	-23.6913	31.62064
12	MCP	Makuleke Concession		
13	MAL	Malelane	-25.4724	31.5089
14	BYA	Mbyamiti	-25.3212	31.69903
15	MOO	Mooiplaas	-23.5193	31.40373
16	NAP	Napi Trails	-25.1617	31.43792
17	NHL	Nhlangule	-24.7096	31.65563
18	NKU	Nkuhlu	-24.9995	31.76654
19	NWA	Nwanetsi	-24.4715	31.97667
20	NYA	Nyalaland	-22.5129	31.0856
21	OLI	Olifants	-24.0057	31.74022
22	PAP	Pafuri (Bo	-22.4492	31.31553
23	PHA	Phabeni	-25.0214	31.24272
24	PHA	Phalaborv	-23.94	31.18
25	PRE	Pretoriusk	-25.1723	31.26928
26	PUN	Punda Ma	-22.6955	31.01611
27	SAT	Satara	-24.3977	31.77778
28	SHA	Shangoni	-23.1675	30.94262
29	SHM	Shimuwin	-23.71	31.31
30	SHI	Shingwed	31.43238	31.43238
31	SKZ	Skukuza	-24.9954	31.59287
32	STO	Stolznec	-25.3214	31.39262
33	TAL	Talamati	-24.5574	31.55513
34	TIM	Timbavati	-24.2604	31.64154
35	TSH	Tshokwan	-24.7882	31.85594
36	VLA	Vlaktepla	-22.868	31.22733
37	WOL	Wolhuter	-25.372	31.39292
38	WOO	Woodlanc	-23.2197	31.21203

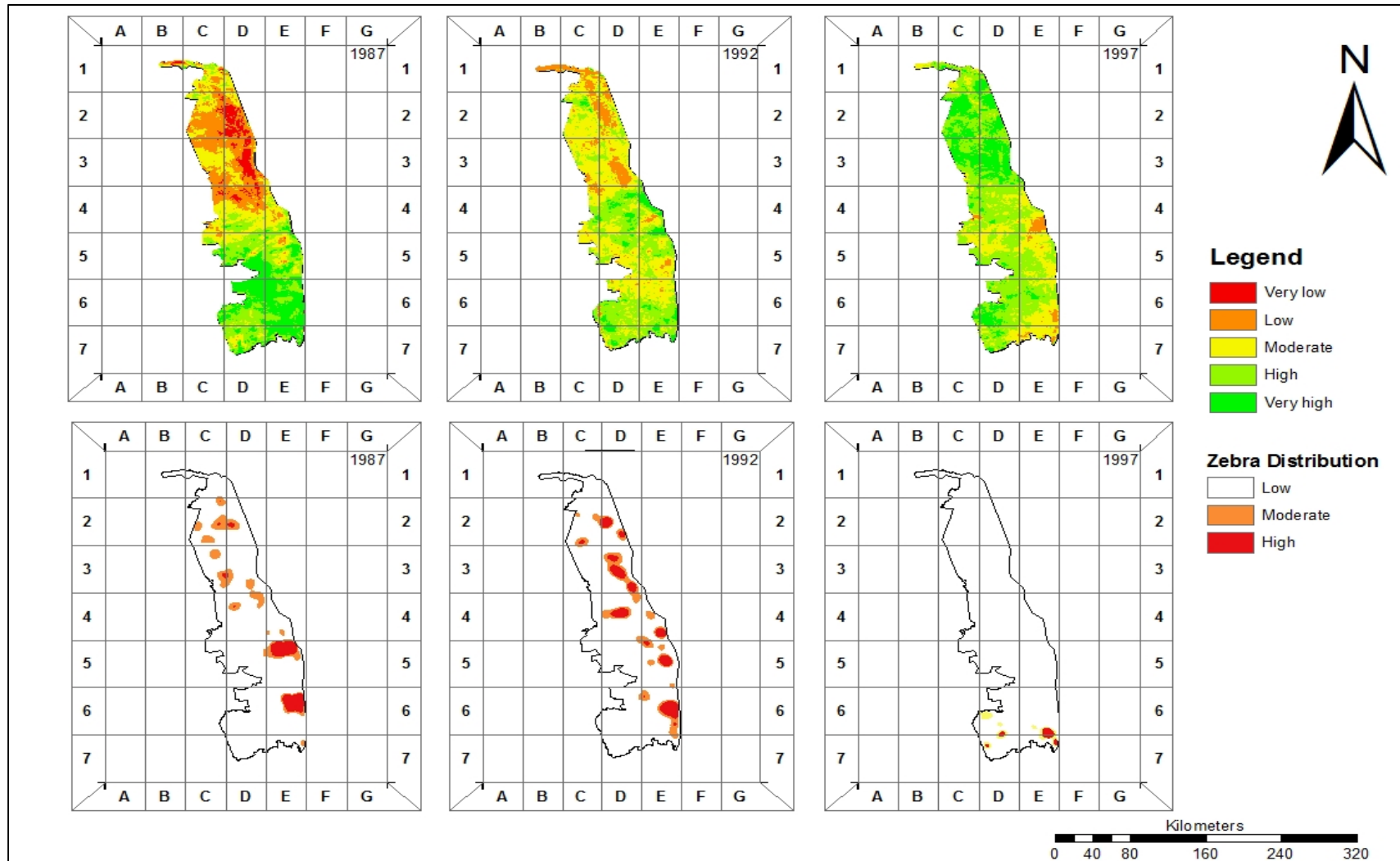
## Appendix II: Rainfall and zebra distribution data from 1983-2012 in the Kruger National Park

Years	Rainfall	Zebra
1983	378.959	25909
1984	595.9	30252
1985	639.361	29942
1986	370.4	33164
1987	536.27	32819
1988	448.874	30733
1989	478.991	32458
1990	508.991	32244
1991	296.575	33249
1992	409.621	31462
1993	447.207	29420
1994	335.707	22712
1995	531.582	22701
1996	687.607	25969
1997	477.332	22588
1998	530.503	22425
1999	768.472	14296
2000	1122.26	19620
2001	651.766	29016
2002	275.966	21598
2003	354.175	17797
2004	738.814	12177
2005	361.719	21102
2006	595.659	32879
2007	482.924	25565
2008	341.11	26337
2009	467.385	27786
2010	446.135	28938
2011	372.472	32986
2012	430.895	35630

### Appendix III: generalised rainfall pattern of Kruger National Park from 1983-2012 in all the rainfall stations.

YEAR	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012		
BDL									235.5	378.6	377.5	321	641.1	817.8	553.6	767.9	880.7	1484	610.9	903.7	1921	806.4	488.4	838	466	647.7	527.6	577.5	53.69	745.1		
BOE																										561.9	320.7	302.1	165	360.6	516.7	
BVA									168.2	451.5	556.2	340.8	592.4	438.8	716	701.7	817.8	1263.7	663.8	486.6	3362	640.8	452.3	677.7	343.962	308.4	271.3	0	0	0		
GR																										632.5	345	348	555.1	294.4	312	
HOU	345.5	380.4	678.8	213.5	488.8	332	445.4	882.2	185	372.8	322.4	276.2	485.5	569.6	359.6	468.3	661.3	756.8	502.3	163	357.2	873.7	263.6	515	458.8	333.3	415.1	437.8	381.3	582.4		
KR	364	659.3	533.4	233.9	711.3	488.7	472.2	814.2	345	324.1	554.9	359.9	537.3	671.5	530.4	610	625.6	1111.3	782	368.4	1887	786	289.5	734.2	465.2	421.4	542.4	575.2	595.8	385.8		
KRO	515.5	590	569.3	490.8	596.7	674.1	852.6	381.6	497.9	529.9	544.2	391.9	688.7	517.3	713.3	832.5	773.6	1150.4	738.3	308.6	369	716.9	488.1	703.6	484	425.33	418.82	425.56	554.15	748.16		
LET	362.7	504.7	427.6	279.6	489.7	380.8	363.5	580.5	345.7	238.4	388	292.1	365.6	690.7	310.7	567.1	504.7	952.9	651.1	135.3	374.5	816.9	240.9	583.5	478.9	262.6	338.1	388	355.9	625.15		
MAH	268.3	521.9	588.4	192.2	385.8	340.9	244.7	308.4	283.5	346.4	456.8	217.3	318.8	531.6	353.5	333.5	765.9	1081.8	640.2	258.4	302.7	765	311.9	383	493.5	244.5	386.2	486.7	305.9	385.6		
MAL	673	793.5	678	585	578	501.8	706.4	439.6	507.8	486.7	452.3	274.8	506.3	697.5	492	684.3	812.7	1353	534.3	393.4	282.2	754.5	390.4	866.2	225.4	324.6	688.4	757.4	537.7	770.2		
MWZ																											444.5	324	300.6	553	320	0
MOD	321.5	427.8	639.3	309.9	462.1	467.9	370.1	284.4	284	331.8	396.9	291	314.6	830.7	261	449.3	736.8	1826.8	583.6	265.4	449.3	733.1	212	647.5	434.5	355.9	1111.6	501.5	496.7	472.9		
MOP									59.1	342.4	328.6	296.7	350.2	752.9	259.3	428.3	690	1265.6	371.6	0												
NHL																										430.5	319.5	319.5	280.51	216	0	
NVA	530.5	771.8	633.5	302.7	584.5	344.1	477	655.4	314.1	380.7	400.8	431.4	622.1	648.4	454.2	473.8	817.4	824.5	657.5	246.4	300.3	520	323.6	554.9	489.3	177.1	356.8	388.2	250.7	510.7		
NVA																											388.8	229.5	441.4	310.3	316.7	371.2
OU	362.7	515.9	686.5	284.5	528	265.5	180	640	316.3	362.1	386.6	336.6	379.8	607.8	400.1	536.6	705.6	774	632.9	291.4	460.6	1031.5	394.6	574.6	498.7	522.9	460	595.5	383.1	695.2		
OIT																											271.9	214.6	0	34	167.8	168.4
OSA	537.2	765.2	688.4	609.3	547.3	388.4	648.4	474	232.7	455.2	614	485	554.7	528.4	684.1	716.1	698.4	1044.5	851.7	436.3	468.4	1022.1	407.9	690.9	517.5	217.5	628.1	592.8	600.3	825.8		
PAP	189	363.4	523.9	301.3	357.5	485	131.5											131.5	631.3	1007.6	629.9	217.5	283.1	768.8								
PAP	136.5	338.5	636.8	314.6	447	347.8	382.2	544.1	269.5	355.4	426.9	302.2	321.5	596	280.7	372.4	636.4	891.8	629.2	367.5	344.7	662.6	476.7	309	517.5	217.5	294.3	428.7	348.6	222.5		
PHA	375.6	589.1	639.2	280.7	485	428	545.8	542.4	315.4	348.6	568.1	315.2	545.8	755.2	374	505.4	638.3	1067.9	694.7	362.7	307.4	715.7	178.6	547.4	518.9	216.6	280.5	635.6	386.4	461.6		
PRE	633.9	734.4	749	647.8	811.8	643.4	728.9	597.6	502.8	655.7	551.1	281.4	857.8	1039.2	878.9	636.3	874.4	1620.8	628.8	460.3	364.2	912	438.4	669.4	416.8	92.8	1030.7	775.3	753.8	852.3		
PUN	205.1	416.4	834.3	487.3	401.7	620.2	463.7	334.3	459.4	316.2	394.2	413.1	491.5	798	439.1	389.7	922.1	1132.9	880.3	397.2	400.1	600.6	362.3	673.7	685.3	358.1	481.8	325.9	48	45.9		
SAT	466	739.5	577.4	234.4	678.2	295.1	551.6	754.8	352.9	426	472	383.6	561.2	622.7	591	558.5	770.2	885.5	588.7	116.5	292.4	849.1	257.6	528.5	546.5	316.1	1071.8	629	402.2	539.6		
SHA	276.9	482.4	638.2	302.1	538.7	454.7	378.3	416.3	385.7	424	422.7	269.8	529.4	770.7	479.4	380.1	785.9	1229.9	721.8	295.6	306.9	512.6	364.9	633.8	610.4	372	541.1	544	322.9	156.6		
SHI	286.6	532.4	520	397.5	304	385.6	285.6	488.9	221.2	459.4	355.4	327.2	476.7	854.5	343.9	430.3	913.1	1149.9	503.6	164.1	525.1	358.2	259.7	319.4	609.2	335.2	517	610.1	468	264.5		
SHW									86.4	297.8	284.5	242	415.9	528.9	329.1	490.5	770	1068.6	623.5	225.7	333.8	623.7	128.1	240.7								
SIR									17.7	525.7	453.8	390.2	470.5	743.5	426.1	406.9	1026.5	1152.5	670.2	182.1	473	301.7	342.4	229								
SKZ	480.4	727.2	607.4	445.2	621.5	555.6	695.3	463.2	315	434.5	470.9	321.9	886.7	701.7	689.8	640.9	651.6	1115.4	719.6	318.9	280	596	560.7	807.3	393.9	581.9	454.9	569.3	545.4	847.32		
STO	566.2	882.1	747.3	561.4	702.6	547.1	807.6	610.6	496	507.7	451.2	338.6	625.1	750.5	681.1	722.6	882.4	1590.4	686.8	379.2	309.3	789.8	611.8	785.6	587.4	610	661.2	521.1	665.8	695.6		
TAL									173.1	334.6	506.8	380.7	880.6	769.3	588.8	553.5	657.9	1125.9	815	270.2	245	769.8	367.2	485.3	454.1	367.5	465.9	165	326.4	86.5		
TSH		652.3	748	338.4	693.7	575.4	497.8	802.1	354.5	430.2	388.9	521.6	612.1	673.4	593.8	739.9	767	1099.6	717.1	103.7	230.5	819.5	426.1	533.7	569.6	188.4	670.2	496.7	272.5	854.8		
VLA	134.1	504.5	788.3	309.9	450.6	489.5	461.5	371.1	330.7	545.8	467.1	360.3	469	736.1	278.4	421.3	889.5	1044.4	603.9	218.9	528.9	507.1	287.3	640.7	689	301.4	415.9	538.3	419.9	330.1		
WDL																											314.9	563.1	373.8	300	243.7	250
WOO	286.9	493	621.3	269.2	475.7	381.5	315.7	411.1	245	428.2	521	247.3	422.4	710.3	323.4	459.4	978.6	984	587.9	166	317.3	522.7	471.4	617.2	414.2	390.4	307.6	619.4	414	243.9		
AVERAGE	378.9181	596.9	628.3628	370.4	536.2186	448.1798	478.9813	518.9808	296.575	429.6214	447.3271	335.7271	521.5821	607.6271	471.3221	510.5284	758.4714	1122.265	621.2625	275.9625	364.175	73.83143	361.7185	595.6289	482.8238	341.1129	467.3825	445.1385	372.4734	42.08848		

**Appendix IV: Change in the abundance of zebra over change in vegetation cover from period 1987-1997 within a 5 year interval.**



**Appendix IV: Change in the abundance of zebra over change in vegetation cover from period 2022-2012 within a 5 year interval**

