# University of Nairobi

## School of Engineering

# Animal Habitat Suitability Analysis: Case of Grevy's Zebra in Laikipia, Kenya

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A project submitted in partial fulfilment of the requirements for the degree of Master of Science in Geographic Information Systems in the Department of Geospatial and Space Technology

**August 2018**

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I, **Timothy Onyango Otuoma**, hereby declare that this research project is my original work. To the best of my knowledge, this work has not been presented for a degree in any other Institution of Higher Learning.

Signature……………………………… Date………………………….

Name: Timothy Onyango Otuoma

This research project has been submitted for examination with my approval as university supervisor.

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# Dedication

This project is dedicated to all Kenyans working hard to preserve their environment and everyone else involved to make this a possibility.

# Acknowledgement

My Master's project would be impossible without the inexorable support and encouragement of many individuals- directly and indirectly.

Firstly, I would like to appreciate my sponsors- William's Chapel of North Carolina. I would also like to thank my family members for supporting me along the way. Sincere gratitude to my supervisor Dr. Siriba, for his immense support and understanding through this research journey.

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# Abstract

Habitat suitability maps have been used to provide information for environment resource planning and management. There are many causes of environmental degradation, natural and man-made. Wildlife has been especially affected by human interference. For instance, Grevy's zebras have become endangered. A number of efforts have been put forward by experts to understand the factors affecting their existence. There has been a number of conservation efforts put in place to manage the natural habitats for Grevy's Zebras. The Kenya government has not only banned the hunting of Grevy's zebras, but has also revised the conservation status of Grevy's zebras from 'Game animal' to 'Protected animal'. This study aimed at identifying and exploring habitat suitability for Grevy's zebra in Laikipia, Kenya using GIS. Vegetation cover, slope, proximity to water point, settlement and road were identified as the major Grevy's zebra habitat defining factors. Hence, their influences were analysed and reclassified for evaluating the suitable habitat. Implementing Geographic Information System (GIS) methods and tools such as weighted overlay and Analytical Hierarchy Process (AHP) would give a better understanding of the dynamics in nature and thereby allow better prediction and planning. The relative importance of the factors was determined through key informant interview and their weights were determined through AHP. The final suitable habitat map showed that suitable sites in Laikipia are not continuous and are in very close proximity to human settlements and human activities. Integrating this study into habitat conservation planning and management practices, would enhance decision making. More factors such as predation should be assessed with respect to their effect on Grevy's zebra habitat choice.

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# Abbreviations

**AHP**: Analytical Hierarchy Process

**AWF**: Africa Wildlife Foundation

**AWR**: Alledeghi Wildlife Reserve

**CI**: Consistency Index

**CITES**: Convention on International Trade of Endangered Species

**COV**: Covariance

**CQT**: Criteria

**CR**: Consistency Ratio

**DEM**: Digital Elevation Model

**ESRI**: Environmental Systems Research Institute

**GIS**: Geographic Information System

**GPS**: Global Positioning System

**IUCN**: International Union for Conservation of Nature

**KURA**: Kenya Urban Roads Authority

**KWS**: Kenya Wildlife Service

**LULC**: Land use land cover

**MCDM**: Multi-Criteria Decision Making

**RCMRD**: Regional Centre for Mapping of Resources for Development

**RI**: Random Index

**RS**: Remote Sensing

**UTM**: Universal Transverse Mercator

**WDFW:** Washington Department of Fish and Wildlife

**WGS**: World Geodetic System

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# CHAPTER 1 INTRODUCTION

## 1.1 Background

Grevy's zebra is listed in the International Union for Conservation of Nature (IUCN) red list as an endangered species. Between 1980 and 2000, their global population has reduced from 15,000 to about 2,500. Currently, they are only found in Ethiopia and Kenya. Kenya holds more than 90% of the world's population (Faith *et al*., 2013; Woodfins *et al*., 2009 & Kenya Wildlife Service, 2002). Unlike Plain zebras, Grevy's zebras do not share space with livestock. This makes them prone to habitat encroachment by nomadic communities. Their main threat is habitat loss mostly as a result of competition with cattle and human settlements. Other threats they face are habitat degradation, poaching, climate change and hybridization. There have been heavy resource investments in Grevy's zebras' conservation measures. Because large populations are found roaming freely within community owned land, conservation strategies have been designed in such a way that the community members are involved.

## 1.2 Problem Statement

Grevy's zebras changing population trends are directly linked to the changing potential of habitats to provide forage, water and safety from predators and humans activities. There are a couple of conservation strategies in place that have seen Grevy's zebras' population in Kenya slightly increase in the past two decades. In 1889 Grevy's zebras entered International Union for Conservation of Nature (IUCN) list as endangered species. More recently, these zebra species have been updated to the IUCN red list (Faith *et al*., 2013; IUCN. 2016). Having also entered Convention on International Trade of Endangered Species (CITES) according to Kenya Wildlife Service, (2012), Grevy's zebras have been offered the highest protection against trade. In Kenya, there is a ban against hunting Grevy's zebras. Further still, the Kenya government under the first schedule, Part II in CAP 376 of the Wildlife ACT, has revised the conservation status of Grevy's zebras from 'Game animal' to 'Protected (Kenya Wildlife Service, 2012). These measures have always aimed at having a sustainable population of Grevy's zebras within their natural habitat. In northern Kenya, communities have been directly involved in Grevy's zebras' conservation measures through monitoring of population trends in collaboration with conservation institution (African Wildlife Foundation, 2012). Other than the strategies in place, there is a need to come up with conservative strategies that are data-driven. Like aforementioned, most strategies in place are not data-driven (Kenya Wildlife Service, 2012; African Wildlife Foundation, 2012). Geographical Information System (GIS) and Remote Sensing (RS) have provided invaluable technologies necessary for gathering, processing and analysing spatial information for wildlife studies (Storea & Jokimakib, 2003). This study will incorporate GIS and RS technologies to map Grevy's zebras' habitat into classes that can better inform conservationists in their planning and decision making.

## 1.3 Objectives

The main objective of this research was to identify, explore and analyse suitable habitat for the Grevy's zebra in Laikipia County.

Specific Objectives

a) Identify the factors that influence habitat selection and preference of certain habitats by Grevy's zebras.
b) To establish the degree to which Grevy's zebras' distribution is affected by different levels of different factors.
c) Create a habitat suitability analysis model that incorporates different spatial parameters as input.
d) To map suitable habitats for Grevy's zebra in Laikipia Kenya.

## 1.4 Justification for the Study

As of the year 2012, 90% of Grevy's zebras in Kenya were hosted in private ranches and in community owned conservancies. It is for this reason that Kenya Wildlife Service (KWS), the main agency mandated to conserve wildlife in Kenya suggested the urgent need to replenish national parks with Zebra species. Consequently, it is important to develop a transparent and reproducible framework that can be used to identify potential suitable habitats for Grevy's zebras in Kenya. The study therefore contributes in designing a geospatial conceptual framework that can be used to map and identify suitable habitats and potential migration corridors between the current habitats and alternative sites for Grevy's zebra in Kenya.

## 1.5 Scope of work

The scope of this study was to come up with a weighted habitat suitability model that would primarily be used to determine the suitable habitat for Grevy's zebra in Laikipia and with parameter modification, this would be further used to come up with more suitable sites in other areas.

# CHAPTER 2 LITERATURE REVIEW

## 2.1 Zebra species in Africa

There are three species of Zebras found in Africa, namely, Burchell's zebra which is also referred to as the common or plain zebra, Mountain zebra and Grevy's zebra. Burchell's zebra are predominantly found in East Africa and are the most populous and widespread species. Their population spread from south of Ethiopia through to Botswana and Eastern parts of South Africa. The Mountain zebra are a threatened species largely found in south western Angola, Namibia and South Africa whereas Grevy's zebra are found in northern Kenya and Southern Ethiopia and are also considered endangered (Advani, 2013).

Grevy's zebra *(Equus grevyi)* was named after Jules Grevy's,the president of the French Third Republic, who received the first known specimen of the zebra in 1882 (Muoria and Oguge, 2011). Grevy's zebra are the largest equid in size with a potential weight of up to 450 kilograms and can stand five feet at the shoulder and 10 feet tall. Their mane runs from the top of their head to their upper back. Compared to other equids, Grevy's zebras have narrow and numerous stripes that do not extend to their stomach as can be seen in figure 2.1. They have a life expectancy of 22 years and are likely to be found in habitats that are dry, with low humidity and sparsely distributed food and water supplies. Notwithstanding the sparse distribution of water, its supply must be permanently available. Grevy's zebras do not develop lasting social bond and are perpetually on the move in search of green pasture. Their movement within the landscape is primarily driven by the search for water. Whereas mature adults can go up to five days without water, walking up to nine miles in search of the scanty watering holes, lactating females are able to camp near water bodies for daily supply but then can withstand 2 days without water (Hostens, 2009 and Advani, 2013). The difference in habitat needs between males, lactating females and non-lactating females is the reason for the weak social bond. For example, lactating females have to strike a balance between locations of water source, good forage and safety of their foal. When foals are below the age of four months, lactating females prefer to stay close to watering points unlike the other adult males and non-lactating females who can roam far and wide within their home range. However, if the primary needs (water, safety from predators and ideal forage) are available throughout the habitat, both the mare and the foal will stay together with the herd. The number of individuals within a herd varies regularly since social connections between members of a herd is non-existent. For this reason, Grevy’s zebras are considered one of the loneliest mammals (Hostens, 2009).

*Figure 2.1: Image of Grevy's zebra. Source: African Wildlife Foundation, (2013)*

Compared with other equid species like the plain zebras, Grevy’s zebras prefer short, green and tough grass (Hostens, 2009). It has been observed that they would rather go for quality forage rather than quantity with the exception of the mares during lactation. Even though they can resort to browsing in drier seasons, Grevy’s are passionate bulk grazers who spend two-thirds of their days grazing. During seasons of limited forage, they resort to bark and leaves. With changing environmental conditions, some individuals relocate in search of better habitats (Faith *et al*., 2013 and Advani, 2013).

The gestation period of Grevy’s zebras is 390 days. Within just an hour of birth, the foal is able to walk and even run. Until the foal is able to recognise the mother’s facade, voice and smell, it will be kept in isolation. This usually takes 2-3 days (Nunez and Daniel, 2011). A research conducted by Sundaresan *et al*. (2008) discovered that bachelors are often attracted to sites where the grass is green and short because these areas are commonly inhabited by lactating females, resulting in high chances of getting mates.

The common zebra predators are lions and hyenas. Whenever a zebra is injured or weak, they get encircled during predation. Baby zebras also benefit from this arrangement. A buffer of strong adult zebras is thus created between the predator and the vulnerable zebras. According to Hostens (2009), successful lion attacks on solitary zebras stands at 35% compared to a paltry 22% when preying on a group of zebras living together. Zebra stripes further diminishes predation successes. When motionless in its natural habitat, it appears invisible to most predators, this is made possible by their camouflaging stripes. When moving fast, especially during an active hunt, the stripes makes the animal appear blurred and cumbersome for predators to lock on an individual prey (Advani, 2013).

## 2.2 Grevy’s zebras population and distribution

### 2.2.1 Geographic Distribution (past then present)

In the past, Grevy’s zebra population spread throughout the horn of Africa (Faith *et al*, 2013). The initial home range of Grevy’s zebras covered vast part of northern Kenya, western Somalia, northern Djibouti and southern Eritrea (Woodfins *et al*, 2009). Additionally, Grevy’s zebras have been sighted in Sudan (Kenya Wildlife Service, 2012). Kenya Wildlife Service (2012) further asserts that Grevy’s zebra is among the most affected by natural range reduction of all the African mammals and that the most dramatic habitat loss took place in the 1980s. Currently, Grevy’s zebras are found in only two former range states. They are found in discontinuous scanty patches of land in central to northern Kenya and in a few intermittent areas in Ethiopia (Faith *et al.*, 2013). The world’s largest contiguous population is found in central Kenya’s Lewa conservancy, the Laikipia Plateau, Samburu, Buffalo Springs, Shaba Shaba National Reserves and throughout Wamba area. Fragmented populations have been cited in the north of Sibiloi National park. (Woodfins *et al.*, 2009). Even though there is no clear evidence to ascertain the occurrence of Grevy’s zebras in the far north beyond Chalbi desert, Woodfins *et al., 2009),* further research claims that there have been sightings of herds of Grevy’s zebra in the north, near Kargi. Figure 2.2 shows the Historic and current distribution of Grevy's zebra based on Bauer et all., (1994).

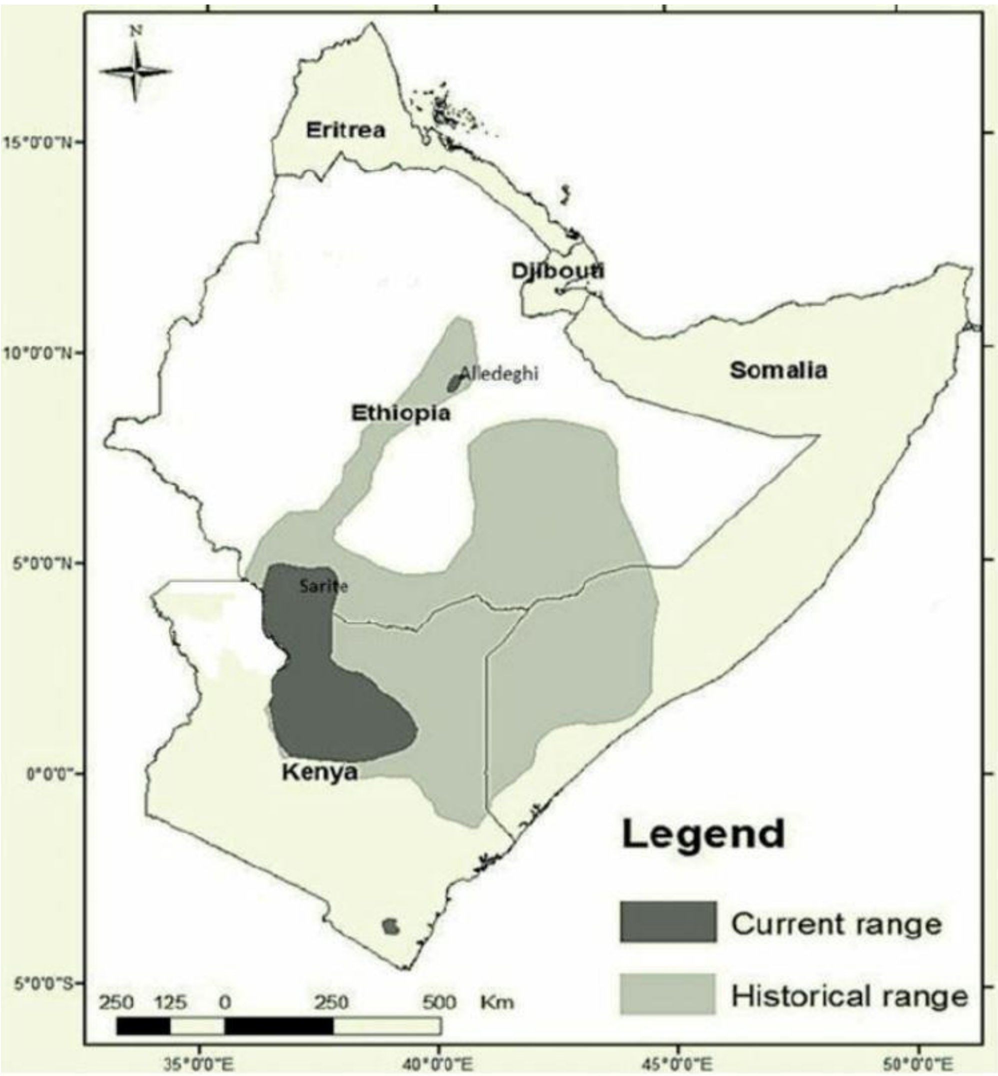


*Figure 2.2: Historic and current distribution of Grevy's zebra based on Bauer et all., (1994)*

### 2.2.2 Grevy's zebras' population statistics

Grevy's zebra population has massively reduced over the past several decades. From a study conducted by Faith *et al*. (2013) which examined the fossil history of Grevy's zebra in equatorial East Africa, it was found that the decline of Grevy's zebra population at the inception of the Holocene epoch was caused by increased precipitation and loss of arid grassland. Because Grevy's zebras thrive in arid and semi-arid areas, increased precipitation leads to loss of arid grassland rendering such areas uninhabitable.

From the late 1970s, the number of Grevy's zebras reduced at an alarming rate. From approximated 15,000 to 2,500 - 2,800 today which represents about 80% population fall. Kenya is home to roughly 90% of the remaining global population (Faith *et al*., 2013; Woodfins *et al*., 2009 & Kenya Wildlife Service, 2012). According to Roberts (2012), 20% of the current global population lives in captivity in zoos and sanctuaries. About 490 Grevy's zebras are in captivity in Europe (Kenya Wildlife Service, 2012). Of the countries currently with population of Grevy's zebra, namely Kenya and Ethiopia, Ethiopia's rate of population decline has been the highest at no less than 85% decline. It is estimated that the numbers were staggering at 1,900 animals in 1980s but then this population reduced to 281 in 2012 (Kenya Wildlife Service, 2012). In Kenya, the rate of Grevy's zebra population decline has not been as high as it was in Ethiopia. In 1977, the Kenya Grevy's zebra population was at 13,718. This population reduced to about 1,600 in 2004. Due to proper management, the country has witnessed a significant increase in Grevy's zebra population since 2005. Currently, the Kenya's Grevy's population is roughly 2,500 (Kenya Wildlife Service, 2012). During a survey conducted in 2008, 2,807 individuals were counted. This statistic further indicates potential upsurge in Grevy's zebra population in Kenya. There has not been much change however in Ethiopian Grevy's zebra population (Muoria and Oguge, 2011).

An estimated 281 and 2,546 Grevy's zebras were found in Ethiopia and Kenya by the end of 2011. This resulted from reversing the declining trends in the region. Now the population is either stable or increasing. These surviving populations are limited to a few protected areas in the world. In Ethiopia, they are found in small discontinuous populations. In Kenya, 322 individuals can be found in Lewa conservancy while others spread within the northern ranges (Parker *et al.*, 2010; Advani, 2013; Davidson, 2012).

### 2.2.3 Factors leading to population trends

The trend in Grevy's zebra populations is attributed to the changing capabilities of their habitats to provide quality forage, water and safety from predators and human activity. All these factors are linked to the extent that lack of one factor reduces the sufficiency or depletes another. Other than in the far northern Kenya and notable parts of Ethiopia where poaching for skin, meat, medical resources and sometimes for fun of it is the main cause of population decline, habitat degradation, and loss has been the leading threat to their populations (Parker *et al.*, 2010 and Kenya Wildlife Service, 2012). The elusive nature and high mobility of the Grevy's zebra of the Sibiloi National Park in the eastern Chalbi desert in Kenya renders them more vulnerable to hunting. Compared to plain zebras who freely interact with human and livestock populations, Grevy's zebra detest such interactions (Faith *et al.*, 2013). This could explain an additional dimension to their current range loss. With the increasing human population, interactions with the zebras are inevitable leading to competition for resources between man (and his livestock) on one hand and the Grevy's zebra on the other. There are times when Grevy's zebras are compelled to use water points at night when predation is highly likely just because it is the only time domestic animals are away from the water points. Most herders graze their cattle at the water points the entire day (Muoria and Oguge, 2011; African Wildlife Foundation, 2017). This renders man as the number one contributor to the habitat loss. Grevy's zebra are usually pushed out of these habitats for they will seldom compete.

Grevy's zebra compete with livestock for resources, and this presents another threat after habitat loss. Competition reduces water supply for the Grevy's zebra. Human and livestock presence has further accelerated habitat degradation. This is evident from large gullies caused by large herds of cattle that are driven by pastoralists especially in Maibae and Wamba conservancies in Kenya Muoria and Oguge (2011). Diseases cause sudden and unexpected population decline. In southern Samburu for instance, 53 Grevy's zebras precipitously died during an anthrax outbreak, as further asserted by Muoria and Oguge (2011).

Predation is yet another threat to the populations of the Grevy's zebra. Zebras are important prey for lions, hyenas, leopards, wild dogs and in rare cases cheetahs. Because these predators also avoid interactions with humans, they are similarly confined to the same uncontested land. This further increases the predation chances on Grevy's zebra. Kenya Wildlife Service, (2012).

On the other hand, precipitation dynamics affect the available land for the zebras. When there is too much precipitation, the habitat is no more arid or semi-arid – ideal habitat for Grevy's zebras. On the other hand, reduced precipitation reduces the size of arable land which eventually sparks competition among the animals for the remaining arable land. They compete for the access of water sources with other grazers and in many circumstances, they are constrained to sharing the same water points with predators (Faith *et al*., 2013).

Recent climatic changes have caused drought. Even though this has not been of major threat, the foals have been especially affected. There has been a contention not to include hybridization in this list owing to its natural nature, but then arguments are still that hybridization could cause a significant reduction in Grevy's zebras population. Between closely related species, hybridization is a natural phenomenon and operates as a natural evolution force.

This however does not make up for the fact that it has rendered many species extinct Hill (2009). Plain Zebras and Grevy's zebra are closely related. As a result, there are high chances of interspecies mating which often results to intermediate traits (Cordingley, *et all*., 2009). Cordingley, *et al*. (2009) further observes that chances of hybridization are higher when small herds of Grevy's zebras stray into predominantly plain zebra habitat. When animals get isolated, as would be the case with many Grevy's zebras, there is an increased chance for hybridization which would potentially cause genetic drift leading to population diversity erosion. (Hill, 2009).

## 2.3 **Grevy's zebras' conservation measures**

Of all the zebras, Grevy's zebras became the last to gain recognition as a stand-alone sub species Advani (2013). Their population trends in the recent years has sparked concern among conservationists. As a result, it has been listed as endangered since 1986 and recently entered the IUCN red list (Faith *et al*., 2013; IUCN. 2016). Grevy's zebras are listed by the CITES, offering them the highest protection against trade. In Ethiopia, they have been legally protected since 1977. There is a ban against hunting Grevy's zebras in Kenya. Furthermore, the Kenya government is revising the conservation status of Grevy's zebras under the first schedule, Part II in CAP 376 of the Wildlife Act from 'Game Animal' to 'Protected Animal' (Kenya Wildlife Service, 2012).

Other than Ethiopia and Kenya where Grevy's zebras still persist in their natural habitats, in other countries they can only be found in zoos. Grevy's zebras' population decline would only mean need for conservation measures. In northern Ethiopia for instance, the largest population of Grevy's zebras is found within Alledeghi Wildlife Reserve (AWR) (Firehiwot *et al*., 2014). In 2006, Ethiopia took the initial steps of initiating the community conservation models (Trust, 2006). According to Grevy's zebra trust, the model being implemented in Ethiopia was adopted after its success in Kenya.

In the recent past, communities have not been sufficiently inspired to conserve their wildlife for they do not see any direct benefit (Louis, 2005). In Ethiopia, for instance, pastoralist communities hang on livestock for survival. Livestock to them is a sign of wealth and well-being. As such, livestock and wildlife interaction is inevitable. When these communities share habitat with Grevy's zebra, the habitat area available for the zebras is reduced. Unlike the past, when the pastoralist communities would move from place to place in search of water, today they have boreholes and have become increasingly permanent, thereby freeing the zebras' habitat (Firehiwot *et al*., 2014). These communities nonetheless hunt zebras occasionally for food and medicine worsening the situation. Because 95% of Grevy's zebra population is found within community owned lands, it is proper to involve the locals as stakeholders when designing and executing the conservation management strategies for the Grevy's zebras. In this sense both the community and the wildlife can extract direct benefit from a properly designed co-existence (Trust, 2006). Faith *et al*., (2013) stresses the need to reinforce conservation programs run by local communities. This assertion takes into thought the fact that the largest portion of Grevy's zebras' habitat stretch is shared with people.

The conservation measures aim is to have a sustainable population on Grevy's zebras within their natural habitat. These populations should exist within a healthy ecosystem. With a healthy population of the Grevy's zebras, communities would directly benefit from tourism. There have been interdisciplinary approaches to achieve the overall goal for the Grevy's zebras' conservation. Programs have been designed in such a way that scientists in the field work together with local communities. In the past 15 years, conservation measures have increased, and a lot of money and resources has been allocated towards developing conservation strategies and a way forward in Grevy's zebra population management within their natural habitat. With the realisation that fates of both the pastoralist communities and the Grevy's zebras are tied together to the delicate habitat, there are notable results of these conservation investments. Trends in population of the zebras have changed in the recent years as a result of successful conservation measures. As of 2011, the population of Grevy's zebra in Kenya and Ethiopia has increased to 2,546 and 281 respectively (Kenya Wildlife Service, 2012). According to Advani (2013), in 1991 the Grevy's zebras' population in Lewa was 259. Today the population in Lewa stands at between 400 and 500, thanks to the reduction in hunting and livestock populations within the reserve. It is foreseen that the Lewa population could be used in the future to recharge the national parks, further explains Advani (2013). In northern Kenya, communities are involved in the Grevy's zebras' conservation measures. They benefit from consistent assessments of the populations of Grevy's zebras. It is in this part of Kenya where wildlife roam freely. In northern Kenya, large areas are protected, making it possible for wildlife to shift location within their natural range. Their movement is monitored, and they are accorded protection (Parker *et al*., 2010; Hostens, 2009). Monitoring on the other hand provides data that enables stakeholders to secure crucial habitat for the conservation of Grevy's zebra African Wildlife Foundation (2017).

## 2.4 Factors affecting Grevy's Zebra distribution patterns

### 2.4.1 Vegetation cover

Grevy's zebras are herbivorous and depend on vegetation for their survival. The distribution pattern would be influenced by availability and vegetation cover. These zebras are more adapted to dry habitats compared to other wild equids found in East Africa (Parker *et al*., 2010). According to (Hostens, 2009), Grevy's zebras continue to exist in arid and semi-arid grassland. They prefer areas with short grass or scattered acacia bush. Northern Kenya is a stretch of land characterised by short grass and open savannah (Low *et al*., 2009). Just like livestock, Grevy's zebra prefer green grass, often categorised as plains and flats. This is the habitat where most of the Grevy's zebras are found (Younan, 2015).

### 2.4.2 Availability of water

Grevy's zebras mostly rely on permanent water sources (Low *et al.*, 2009) and prefer grazing at night when water points are clear of herders and livestock (Hostens, 2009). However, their preferred watering hours come with the increased risk of predation. As a result, Grevy's zebras have easily developed a compromise survival pattern, and make use of watering points during the day when the herders are in the vicinity as this is an assurance of safety from other wild predators. (Low *et al*., 2009)

### 2.4.3 Slope

Slope is the general nature of landscape, otherwise referred to as the gradient or topography. The topography of a habitat influences its vegetation cover type, susceptibility to flooding, roaming/grazing and extinction. Furthermore, steep slopes facilitate soil erosion which leads to washing away of vegetation cover, consequently reducing the foraging resources for Grevy's zebras. Very steep areas would deter animals from grazing as manoeuvring is difficult. On the other hand, plain slopes may facilitate flooding forcing the Grevy's zebras to migrate to safer places. Characteristics of topography therefore have a bearing on the distribution patterns of Grevy's zebra (Lindberg, 2013).

### 2.4.4 Human settlements

Human settlements are the major driver of habitat loss for Grevy‘s zebras population (Mesfin and Berhan, 2016). Increasing growth of human population has therefore become a limiting factor for wildlife habitats (Khalatbari, 2013). Other than overgrazing and farming, most of the natural lands have been converted into agricultural lands and human settlements (Ceballos and Ehrlich, 2002). Human indirect and direct activities have also contributed to climate change. In recent years, climate change has been a major contributor to animal extinction (Diamond et all, 1989). Animal habitat encroachment leads to population decline, relocation of animals and sometimes loss of genetic diversity (Travis, 2003). Additionally, human settlements often in close proximity to habitats of wildlife encourage poaching and increase the risk of human-wildlife conflict (Mesfin and Berhan, 2016).

### 2.4.5 Proximity to roads

Construction of roads increase habitat loss, habitat fragmentation and habitat degradation; thereby affecting wildlife. Roads have barrier effect to larger mammals and in some cases smaller animals (Gunther and Wyman, 2008). Disturbances arising from roads can also affect the spatial distribution of individual animals in habitats adjacent to the roads (Adams and Geis, 1983). Roads have a barrier effect for crossing animals. Automobiles using the roads also have the potential of running over and killing animals using the roads (Underhill J., 2002). Passing vehicles produce noise and animals tend to move away from such disturbances. Road constructions contribute to removal of vegetation cover resulting to relocation of animals in the search of greener pastures. Roads have increased accessibility to wildlife leading to increased human and wildlife conflicts (Underhill and Angold, 2000).

## 2.5 Application of GIS in Animal Habitat Suitability Analysis

Geographical Information Systems (GIS) and Remote Sensing (RS) have been invaluable technologies in gathering, processing and analysing spatial information for wildlife habitat studies. GIS and RS have generated superior results compared to other conventional ground survey methods (Storea and Jokimakib, 2003). Measurements and analysis show how the current variation of different factors on animal habitat are important in guiding the formulation of wildlife management policies and decision making (Kushwaha and Roy, 2002). Even though ground survey methods are and still will be useful (Lamprey, 1963), RS techniques have improved on the tiresome ground survey methods that have posed various challenges related to accessibility and inaccurate data (Kushwaha and Roy, 2002). GIS utilities in data production have provided a platform to run the models, and Graphic User Interphase for rendering maps as well as hard copy maps (Letoiye, 2014). GIS as a tool can be used by managers to understand far better both animal and human habitats.

### 2.5.1 Habitat Evaluation Procedures (HEP)

HEP was developed as a result of the need to standardize habitat evaluation procedures (Kushwaha and Roy, 2002). The purpose of HEP was to study habitats and analyse their suitability for certain animal species. The following are the basic steps for HEP according to (Kushwaha & Roy, 2002):

1. The area under study is divided into strands using RS and ground truthing methods.
2. The animal species, its habitat and range requirements are assessed.
3. Habitat Suitability Index (HSI) value is calculated for each one of the species using ecological parameters.

In cases where there is a need to combine different criteria, Saaty's scale of relative importance and its application in multicriteria evaluations can possibly be of use (Saaty, 1977).

Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision Making (MCDM) analysis. It was used to rank into levels of suitability different classes within the criteria. AHP was developed by Thomas L. Saaty in 1977 and is based on his experience. It is basically a method used to derive ratio scales from paired comparisons. There is always a minimal inconsistency due to human error. Due to its simplicity, AHP has been invaluable in multiple sectors to managers and decision makers. AHP is theoretically sound and accepted methodology leading to its universal adoption tool for decision making (Bhushan N., 2004). Table 2.1 outlines the pairwise comparison ranking criteria.

*Table 2.1: Pairwise comparison ranking criteria*

| Pairwise comparison ranking criteria | |
|---|---|
| 1 | criteria A and B are equally important |
| 3 | A is thought to be moderately more important than B |
| 5 | A is thought to be strongly important than B |
| 7 | A is thought to be, or has been demonstrated to be much more important than B |
| 9 | A has been demonstrated to have much more importance than B |

### 2.5.2 GIS Suitability Modelling and Sensitivity Analysis

Modelling species habitat relationships using GIS tools is a form of Habitat Suitability Analysis (HSA). Approaches adopted in habitat suitability analysis usually depend on the objective of the analysis and the availability of data. If more than a single criterion is in question, data layers are usually combined to come up with suitability map. In combining the layers, the analyst has the option of using either arithmetic or logic map overlay operations. The resulting map depicts levels of habitat suitability (Davis and Goetz, 1990).

Multi-Criteria Decision Making (MCDM) analysis and overlay analysis have successfully been used to establish different habitat suitability models in multiple projects. Due to an alarming reduction in the habitat range of Gray Wolf in Washington State, Cleland, (2013) developed a habitat suitability model using MCDM process and overlay analysis. The model was meant to demonstrate how geographically-explicit data can be efficacious in management decisions. Similarly, Mesfin and Berhan, (2016) incorporated similar methodology to analyse the distribution of Grevy's zebra's suitable habitat in Allidegi Wildlife Reserve (AWR) in Ethiopia. This project was influenced by the effects of the current natural and anthropogenic trends that are causing alteration in suitable status and distribution of wildlife in their natural habitats. Finally, a study by Buruso, (2017) conducted a habitat suitability analysis for hippopotamus using similar aforementioned tools and processes to come up with a habitat suitable model. Buruso's objective was to identify suitable habitat sites within Lake Tana and its surroundings that can be utilised by hippopotamus.

# CHAPTER 3 MATERIALS AND METHODS

## 3.1 Study area description

All the Grevy‘s zebra data was collected  in Laikipia county. Laikipia county is one of the 47 counties in the Republic of Kenya. Laikipia borders 7 other counties, namely: Nakuru, Samburu, Meru, Isiolo, Nyandarua, Nyeri and Baringo and traverses 9,700 square kilometres. The average annual temperature in the county varies between 16°C and 26°C (Butynski & Jong, 2015). The average mean annual rainfall received falls between 400mm and 500mm. The dominant vegetation cover types in Laikipia are grassland, bushland, woodland and dry forest. Human population in Laikipia is approximately 399,000 according to the most recent census and has a population density of 42 people per square kilometre. Livestock farming is the principal economic activity in Laikipia (County Government of Laikipia, 2014). Residents of Laikipia North are nomadic pastoralists. (County Government of Laikipia, 2014). Almost every ranch in Laikipia is privately owned and the majority of these embrace conservation measures, support wildlife and tourism. The highest density of large mammals in Kenya is sustained in Laikipia (Guide, 2013). Figure 3.1 below shows the map of the study area.

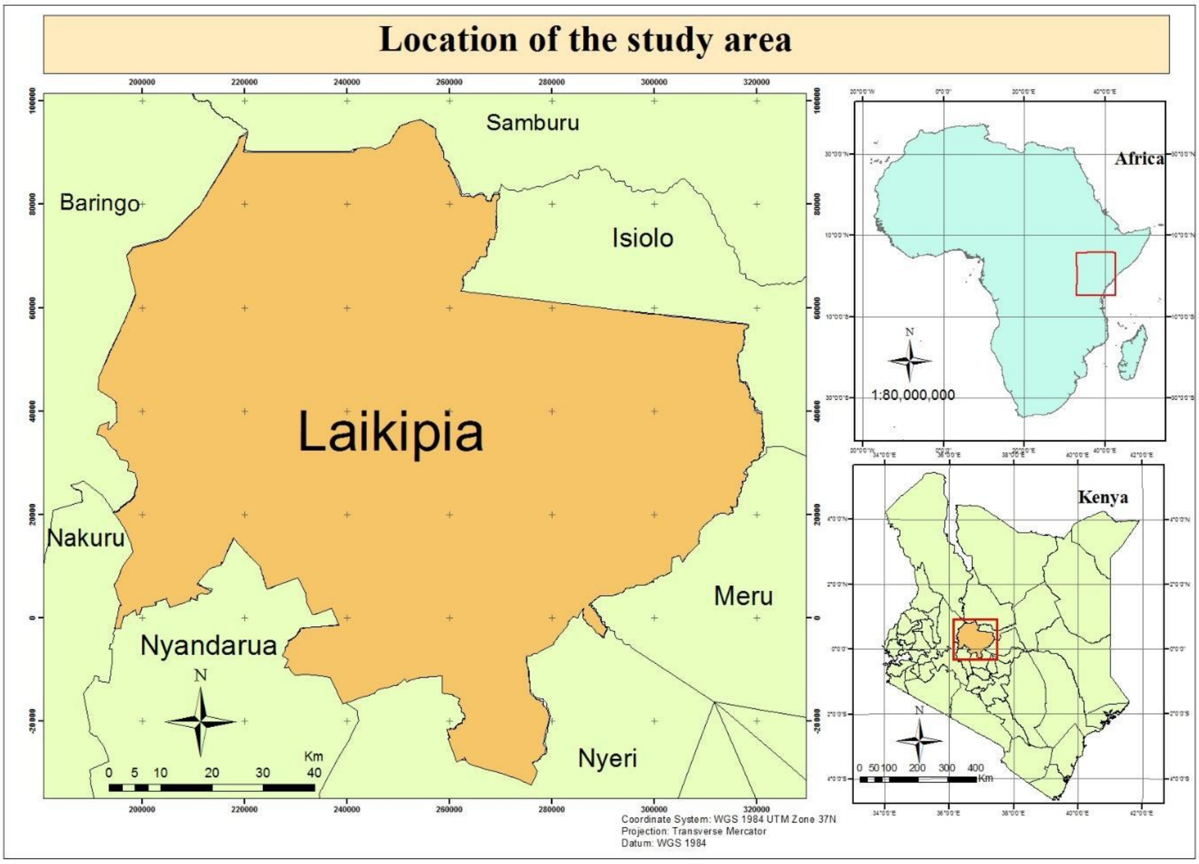

*Figure 3.1: Map of area of study, Laikipia county in Kenya.*

## 3.2 Methodology

### 3.2.1 Data collection and preparation

Data in both vector and raster formats from different sources was used in this study. Digital Elevation Model (DEM) at 30 meters. Spatial resolution was used as the basis for describing topographic characteristics of the area of study. Other datasets were retrieved in vector (Environmental Systems Research Institute -ESRI shapefile) formats and included: land use/cover data, movement trajectories of Grevy's zebra in the area of study, centroids of town centres, road and rivers. Table 3.1 outlines the main datasets, their formats and the respective sources of the data. In Universal Transverse Mercator (UTM) map projection with World Geodetic System 1984 (WGS84) geodetic datum, Laikipia lies within zone 37N. All the data was converted to UTM Zone 37N to ensure uniformity in map projection.

*Table 3.1: Table showing data type, source and content that was used in the suitability modelling*

| Layer Name | Type | Source | Description |
|---|---|---|---|
| Road network | Vector Shapefile - network | http://kura.go.ke/ | Contains spatial information related to the different classes of roads found within Laikipia county, as well as the surface type. |
| Towns | Vector Shapefile - point | http://kura.go.ke/ | Contains information related to towns. Sizes, names, locations and population are provided. |
| Water bodies | Vector Shapefile - network | www.kws.go.ke/ | Contains information pertaining to locations of rivers and lakes within Laikipia. Sizes of lakes are also defined. |
| DEM SRTM | Raster Dataset (DEM) | www.ramani.co.ke | 30m elevation model. |
| Land cover | Raster | www.geoportal.rcmrd.org | Contains information on land use and land cover for Kenya. Defined in 10 classes. |

### 3.2.2 Methodological workflow

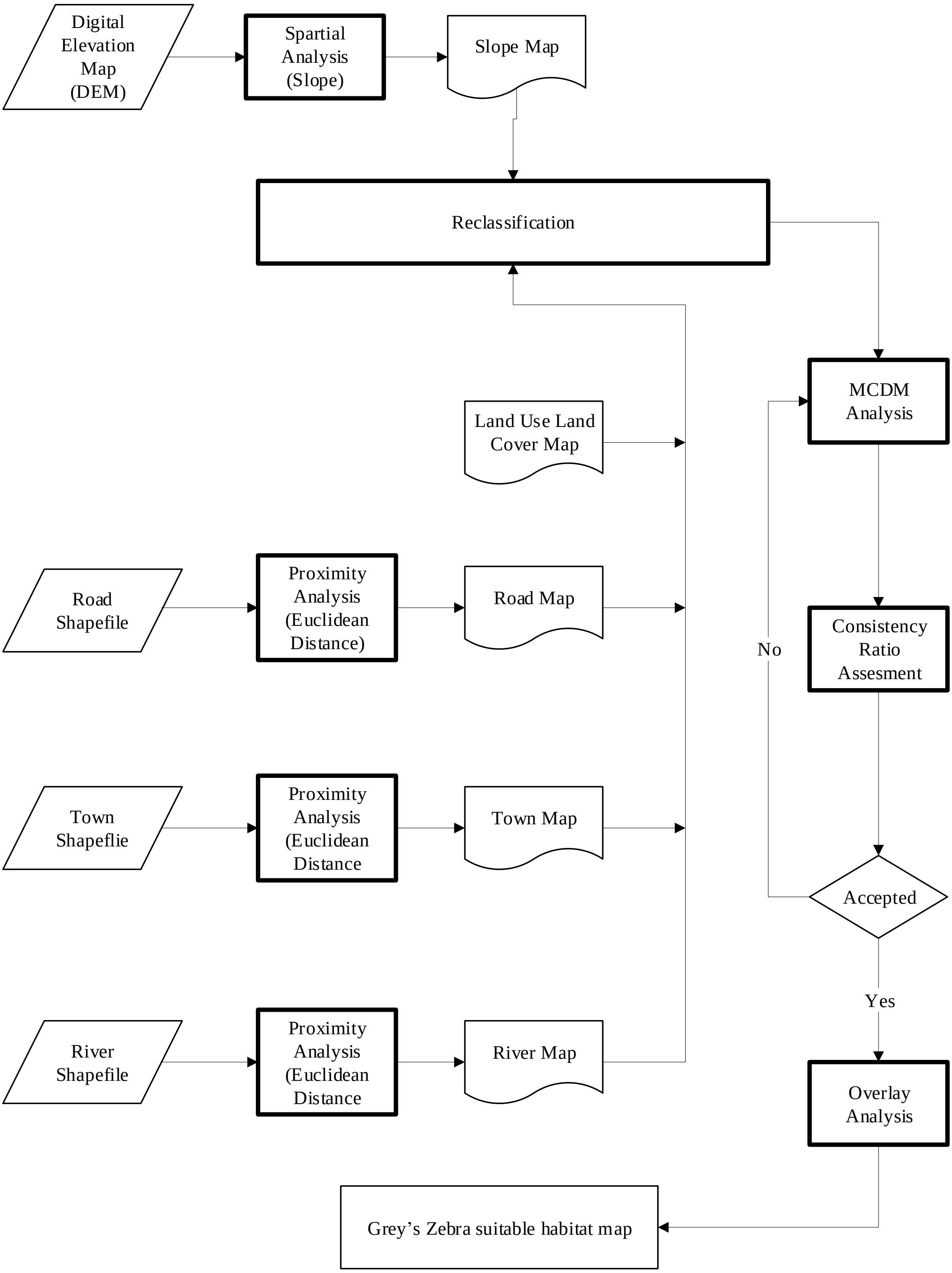


*Figure 3.2: A methodological workflow for habitat suitability modelling. Source: Author (June, 2018)*

In order to analyse the suitable habitat for the Grevy's zebra, the following criteria datasets were reclassified into varied suitable ranges: Slope map derived from a 30 meters DEM; Classified LU/LC; and road, town and river surfaces developed from road, town and river maps using a proximity analysis tool called Euclidean distance in ArcMap environment. The criteria datasets were then overlayed using raster calculator putting into consideration the criteria weights derived using AHP, a multi-criteria decision making tool. Figure 3.2 above shows the methodological workflow of the entire process. A detailed description of the main analysis are as follows:

#### 3.2.2.1 Spatial and Proximity Analysis

To conduct habitat suitability analysis, all the input datasets were converted to raster format. The slope function (spatial analysis tool) in ArcGIS was used to convert DEM to slope map. Road, town and river vector maps were converted to raster using Euclidean distance tool under proximity analysis also within the ArcGIS environment. Euclidean distance was used. Euclidean distance tool describes the relationship of adjacent cells based on a straight line distance. Euclidean distance constitutes the straight line distance between two points in a Euclidean space. Euclidean distance is computed from the centre of a cell that is considered to be the source to the centre of the surrounding cells. The resulting raster has within it the distance measured from every cell to the nearest source. The tool assigns to each output raster cell the value of the closest cell as established by Euclidean distance algorithm. Equation 3-1 gives the Euclidean distance formula.

*Equation 3-1: Euclidean distance formula*

$$dist\big((x,y)\big),(a,b) = \sqrt{}(2-(x-a)^2+(\mathrm{y}-\mathrm{b})^2$$

where the distances are between points in a plane that has coordinates $(x, y)$ and $(a, b)$ (Bogomolny, 2009). LULC map was acquired in raster format. All the raster maps were then clipped to Laikipia county boundary.

The criteria raster maps were then classified reclassified into four classes each. The classes used were derived from related literature, statistical data - from field surveys, and suggestions - from conservation experts.

#### 3.2.2.2 Reclassification

The process of assigning new output values to a value, range of values or list of values, is referred to as reclassification. Coming up with the new classes is among the most important processes when conducting weighted habitat suitability analysis. The assumption is that species distribution is affected differently by different levels of each factor. The reason for reclassification in this study was to change the precious class values to be in line with the new classification scheme developed from the study. Usually these classes are derived from field surveys, statistical data, related literature and consultation with conservation experts. When represented in maps, the output shows criteria's independent influence on species distribution, in this case Gravy's zebra. Table 3.2 below shows the established suitability ranges for the criteria in question.

*Table 3.2: Grevy's zebra habitat suitability factor classes*

| Variables | Suitability range | | | |
|---|---|---|---|---|
| | Highly suitable | Moderately suitable | Slightly suitable | Unsuitable |
| Vegetation cover type | Open grassland | Wooden grassland | Open forest | Others |
| Proximity to water source | <3km | 3-11km | 11-20km | >20km |
| Slope in degrees | <3° | 3°-6° | 6°-10° | >10° |
| Proximity to human settlements | 3-10km | 10-30km | >30km | <3km |
| Proximity to roads | >20km | 11-20km | 5-11km | 0-5km |

#### 3.2.2.3 Multi-Criteria Decision Making Analysis

One of the most challenging processes is factor prioritization. Different factors affect species differently and studies show that these factors correlate. Establishing conservation measures requires identification of issues which require the most of attention (Low, Sundarresan, Fischhof, & Daniel, 2009). In order to prioritise the different criteria in question, Analytic Hierarchy Process (AHP), a Multi-Criteria Decision Making Analysis (MCDA) was incorporated. It was used to rank into levels of suitability different classes within the criteria.

AHP was developed by Thomas L. Saaty in 1977 and is based on his experience. It is basically a method used to derive ratio scales from paired comparisons. There is always a minimal inconsistency due to human error. Due to its simplicity, AHP has been invaluable in multiple sectors to managers and decision makers. AHP is theoretically sound and accepted methodology leading to its universal adoption tool for decision making (Bhushan N., 2004). Table 3.3 shows the pairwise comparison ranking criteria that was used. Table 3.4 shows the criteria comparison matrix $[C]$ a resultant of comparing the criteria.

*Table 3.3: Pairwise comparison ranking criteria*

| Pairwise comparison ranking criteria (ctq) | |
|---|---|
| 1 | criteria A and B are equally important |
| 3 | A is thought to be moderately more important than B |
| 5 | A is thought to be strongly important than B |
| 7 | A is thought to be, or has been demonstrated to be much more important than B |
| 9 | A has been demonstrated to have much more importance than B |

*Table 3.4: Criteria comparison matrix*

| Criteria Comparison Matrix (CCM) | | | | | |
|---|---|---|---|---|---|
| | Vegetation Cover | Water | Slope | Towns | Roads |
| Vegetation Cover | 1 | 3 | 4 | 4 | 7 |
| Water | 0.33333 | 1 | 2 | 3 | 4 |
| Slope | 0.25 | 0.5 | 1 | 3 | 3 |
| Towns | 0.25 | 0.33333 | 0.33333 | 1 | 4 |
| Roads | 0.14286 | 0.25 | 0.33333 | 0.25 | 1 |

Weights were computed as the average of the raw values derived from the normalised comparison matrix$[C]$. Table 3.5 shows the normalised criteria comparison matrix with criteria weights appended at the end.

*Table 3.5: Normalized Criteria Comparison Matrix with criteria weights*

| Criteria | Vegetation Cover | Water | Slope | Towns | Roads | Criteria Weights (W) |
|---|---|---|---|---|---|---|
| Vegetation Cover | 0.5060241 | 0.5901639 | 0.5217391 | 0.3555556 | 0.3684211 | 0.4683808 |
| Water source | 0.1686747 | 0.1967213 | 0.2608696 | 0.2666667 | 0.2105263 | 0.2206917 |
| Slope | 0.126506 | 0.0983607 | 0.1304348 | 0.2666667 | 0.1578947 | 0.1559726 |
| Towns | 0.126506 | 0.0655738 | 0.0434783 | 0.0888889 | 0.2105263 | 0.1069947 |
| Roads | 0.0722892 | 0.0491803 | 0.0434783 | 0.0222222 | 0.0526316 | 0.0479603 |

#### 3.2.2.4 Consistency ratio assessment

The results from AHP process were tested for validity using consistency ratio assessment test. Below are steps that were followed to validate the consistency of the results developed from the APH process.

**Step 1**. Determined the weight sum vector $W_s$ given by:

$$\{W_s\} = [C]\{W\}$$

**Step 2.** Determined the consistency vector:

$$-Dot\ \ product\ \{consis\} = \{W_s\}.\{\frac{1}{W}\}$$

**Step 3.** Established λ given by the average of elements in $\{consis\}$

**Step 4.** Determined the consistency index, $CI$ given by:

$CI\ = (\lambda - n)/(n - 1)$

**Step 5.** Determined Consistency Ratio, $CR$ given by:

$$CR = CI/RI$$

$n$: number of criteria

$C$: criteria comparison matrix

$W$: vector extracted from the weights

According to (Bhushan N., 2004), Thomas L. Saaty argues that, if CR is greater than 1, the comparisons in the CCM are inconsistent and should be computed again. Here, CR was **0.0673** meaning the CCM was consistent.

#### 3.2.2.5 Overlay Analysis

With the incorporated classes and weight, the criteria were combined using map algebra to produce the Grevy's zebra habitat suitability map. Map algebra is a tool used in raster analysis to combine and or compare several layers of criteria in order to unearth a trend valuable in answering a problem. Map algebra uses math to compute and is possible that three suitability model types can be created. In this case, a weighted suitability model was created. In weighted suitability model unlike the binary and ranked, the output values are ranged from bad to good (ESRI, A quick tour of using Map Algebra, 2010). Equation 3-1 shows the weighted habitat suitability model equation that was used to combine the study criteria.

*Equation 3-2: Weighted HSM equation*

$$
\begin{aligned}
Wighted\ HSM \\
&= (\text{"}\%Reclass\_Slop6\%\text{"} * 15.5) + (\text{"}\%Reclass\_Rive3\%\text{"} * 22) \\
&+ (\text{"}\%Reclass\_Town3\%\text{"} * 11) + (\text{"}\%Reclass\_Road3\%\text{"} * 4.5) \\
&+ (\text{"}\%Reclass\_LULC2\%\text{"} * 47)
\end{aligned}
$$

# CHAPTER 4 RESULTS AND DISCUSSIONS

## 4.1 Weight Assignment for Thematic Maps

The assumption here is that different variables have different weights of effect on a species distribution. Table 4.2 below shows the criteria weights derived using AHP.

*Table 4.1: Grevy's zebra habitat suitability factor weights*

| Criteria | Vegetation Cover | Water | Slope | Towns | Roads |
|---|---|---|---|---|---|
| Criteria Weights (W) | 0.47 | 0.22 | 0.155 | 0.11 | 0.045 |

## 4.2 Slopes Suitability

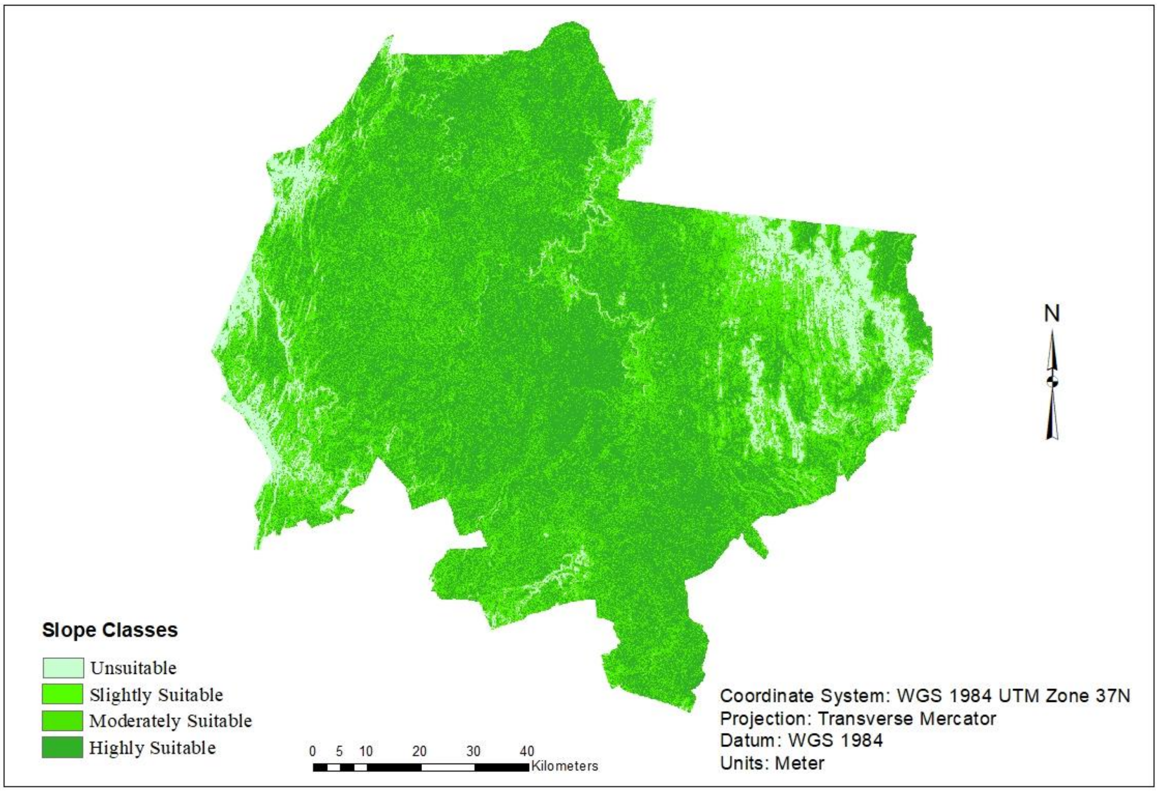


*Figure 4.1: Slopes Suitability Classes in Laikipia County*

Grevy‘s Zebra distribution is affected by slope. In this study, slope was measured in degrees. The classes were derived from literature review. Slope has influence on vegetation cover. Where the slope is too steep, there are high chances of soil erosion which washes away vegetation and in many instances depletes the land of nutrients. This adversely affects the vegetation cover potentially reducing the availability of forage for Grevy‘s zebras. Steep areas pose challenge to movement and grazing for the animals. Low lands are also susceptible to flooding. These two extremes are not preferred by Grevy‘s zebras. Gentle slope of 0 °to 3° is the most preferred slope profile.

When the slope surface of Laikipia was mapped and classified, 19 percent of the land mass was found unsuitable. The rest of the land surface can be used, with 35% highly suitable. This means that 35% constitutes a gentle slope within the range of 0° to 3°. If Slope was a parameter with 100% weight, Laikipia would be perfectly suitable for Grevy‘s zebra.

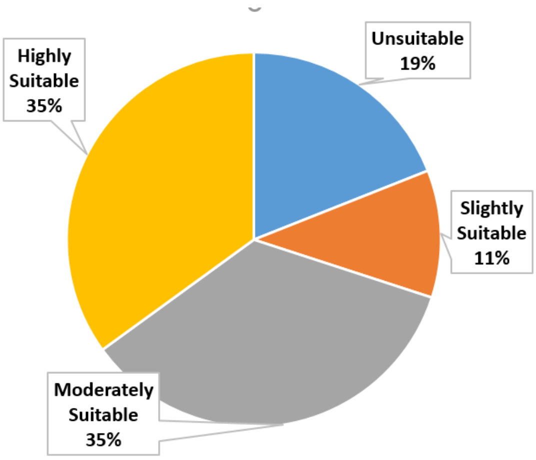


*Figure 4.2: Slope suitability chart*

## 4.3 **Water Source Proximity Suitability**

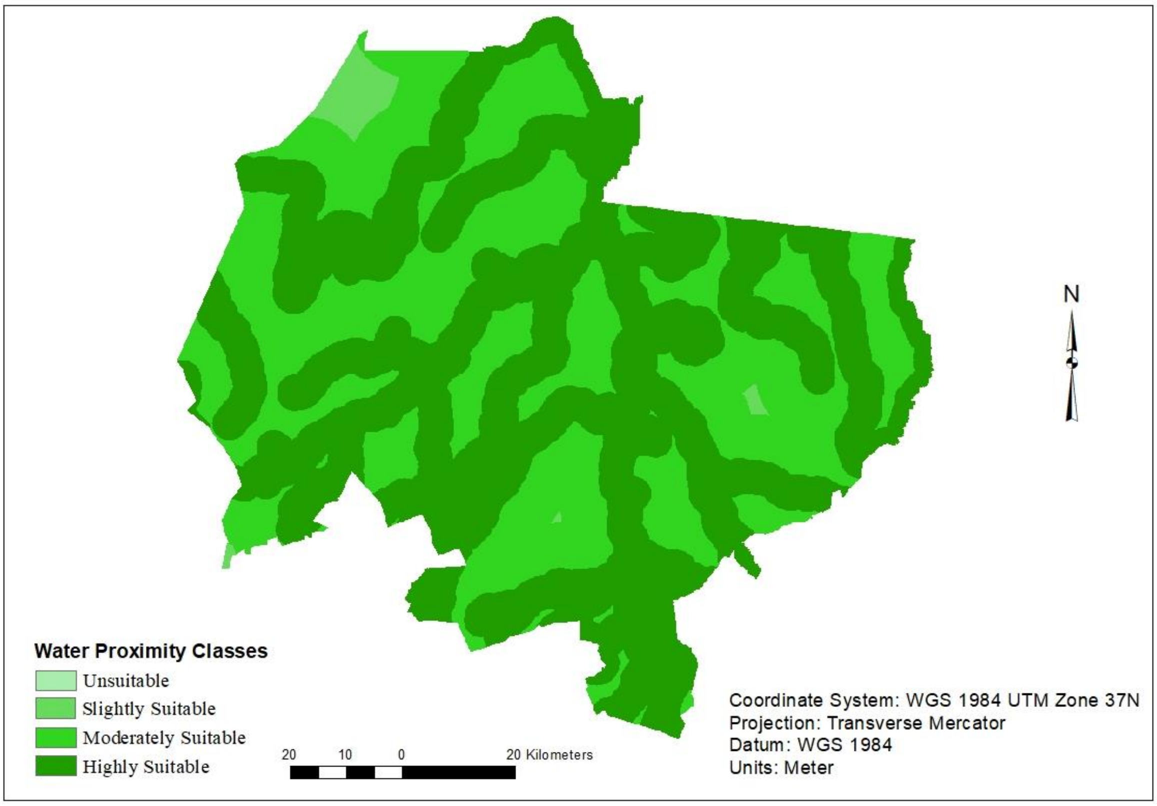


*Figure 4.3: Water Source Proximity Classes*

Grevy's zebras rely heavily on water. Sources of water therefore influence their distribution. According to (Low, Sundarresan, Fischhof, & Daniel, 2009), Grevy's zebras prefer more stable sources of water. This means, they will rather depend on lakes and permanent rivers unlike seasonal rivers. There will be high density of Grevy's zebras between 0 and 15 kilometres from the water sources. Accessing water resources during the day also poses a grave challenge to the zebras who avoid the water sources to elude herders and their cattle. This makes them prone to predators (mostly lions and hyenas) during the night. Similarly, because water points are shared with other animals, which pose danger, it is observed that Grevy's zebra will avoid such locations (below 2 km), mainly to avoid dangerous conflicts. According to the established proximity classes in Figure 3, at least all Laikipia water (river networks) can be accessed by Grevy's zebra. The highly suitable sites cover up to 12%, with 85% of the land mass passing as moderately suitable. This is evidence that water sources are not a problem for the Grevy's zebra except for the fact that they are shared with livestock population. Even though this research does not cover the extent to which herders and their livestock hinder Grevy's zebras from accessing water points, Advani (2013) claims that livestock and human interference are a major hindrance to Grevy's zebras access to water points. Advani (2013) further mentions that Grevy's zebras' movement within their habitat is majorly influenced by the availability and access to water. Adults Grevy's zebras can stand going without water for up to five days while lactating female only two days.

## 4.4 Human Settlements Proximity Suitability

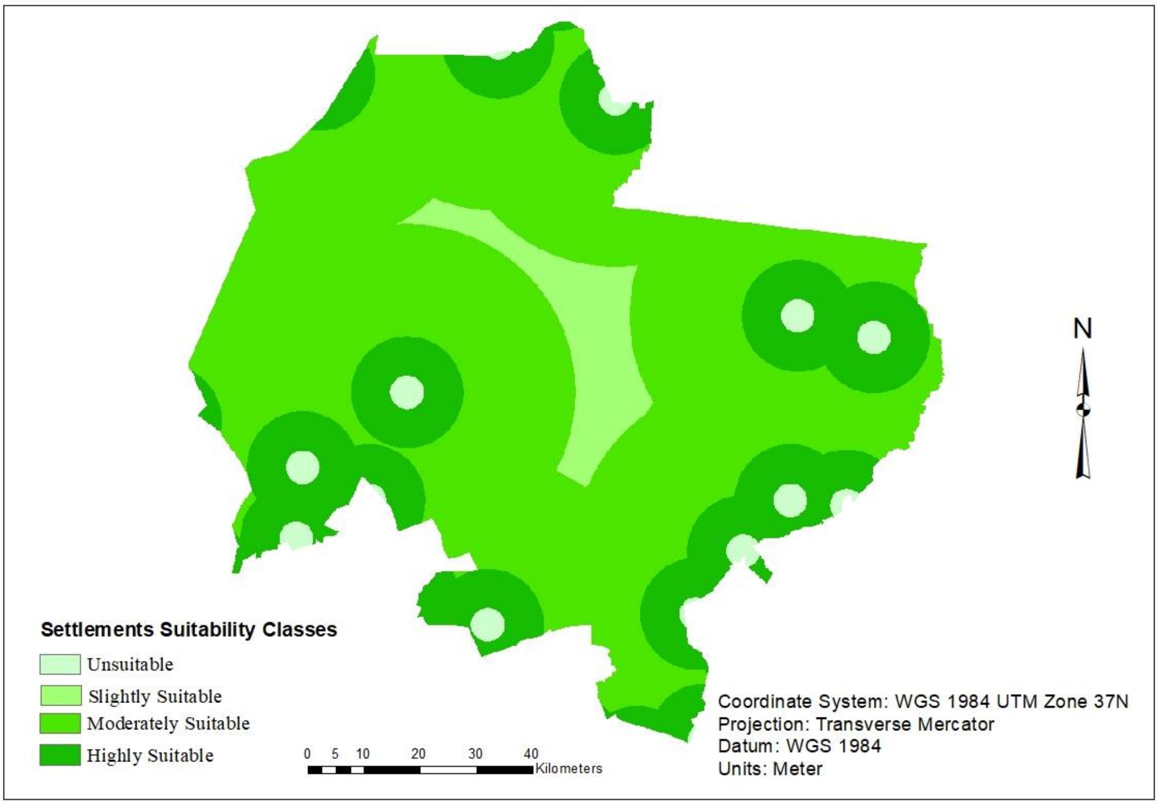


*Figure 4.4: Human Settlements Proximity Classes*

Human settlements are the main causes of wildlife habitat loss. Most of the land is usually converted to agricultural land or settlements. In this project, towns have been used to define area inhabited by human. As a result, the accuracy of the classes is based on the points and not the town's polygon. Human settlements increase overgrazing on habitats shared with Grevy's zebras. This results in reduction of viable forage and the end result is Grevy's zebras are compelled to relocate. Encroachment into Grevy's zebras' habitat further leads to population reduction. Usually the kind of space occupied by man is equally suitable for Grevy's zebra. Even though Grevy's zebra prefer to stay away from human settlements, they are drawn closer due to shared habitat needs. They typically avoid three kilometers of human settlement. This space is not suitable due to human and wildlife conflict. Based on the suitability classes, 63% of Laikipia landmass is highly suitable for Grevy‘s zebra habitation. This is possible because of close proximity of the entire land to towns inhabited by man. Six percent of the land is not suitable. 15% is slightly suitable while 16% is moderately suitable.

## 4.5 Proximity to Roads Suitability


*Figure 4.5: Proximity to Roads Classes*

Construction of roads lead directly to animal habitat loss. Roads occupy spaces apt for wildlife habitation. Further still, roads fragment animal habitat, restricting their movements. Large animals are in danger of crossing the roads for they are prone to being knocked over by moving cars (Underhill, 2002). The proximity to road suitability map above indicates clearly that there is no place that is highly suitable for the Grevy‘s zebras. 66% of the habitat is slightly suitable and 33% is unsuitable. A smaller percentage of 9 is moderately suitable. Increased roads mean increased access as such, more encroachment.

## 4.6 Land Use Land Cover Suitability

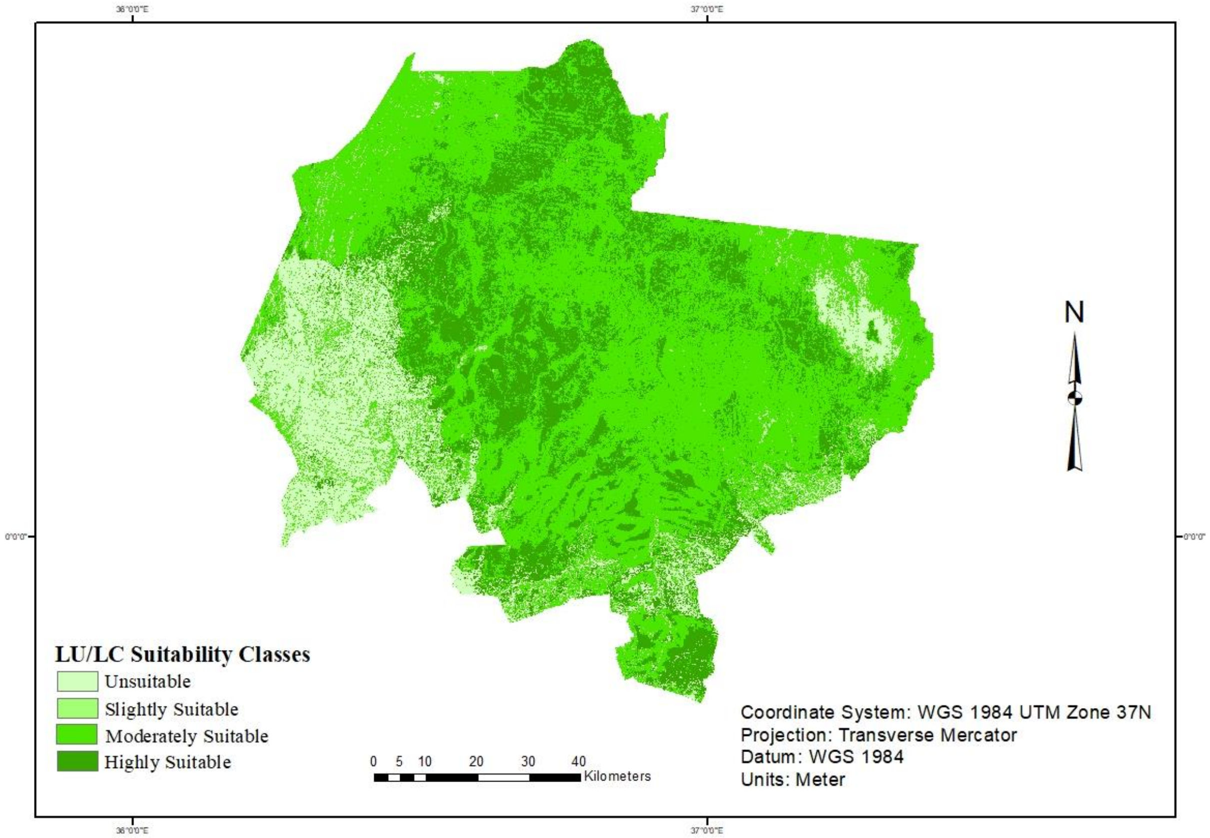


*Figure 4.6: Land Use Land Cover Suitability Classes*

Laikipia receives low and erratic rainfall and has a high evaporation demand. The vegetation types are grassland, bushland, wooden forest and dry forest. The rain season is sort, leaving a long dry spell. Rainfall received falls between 400 mm and 599 mm. Grevy‘s zebras are bulk grazers and prefer open grasslands. They spend up to 2/3 of their day grazing. Wooden grassland is moderately suitable for the zebras. With 29% of the vegetation cover highly suitable and 61% moderately suitable, Laikipia vegetation cover has potential of supporting the population of Grevy‘s zebras. During the dry seasons, when the amounts of forage is not sufficient, Grevy‘s zebras will opt for bark and leaves (Faith, Tryon, Peppe, & Fox, 2013).

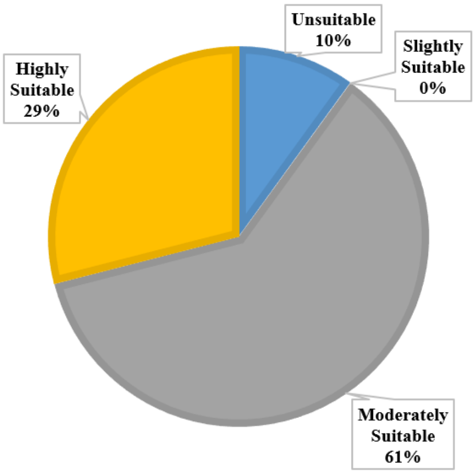


*Figure 4.7: LU/LC Suitability Chart*

## 4.7 **Weighted Overlay Analysis**

After reclassification and weighting of the factors, a weighted overlay analysis followed for the factors affecting Grevy‘s zebra distribution. Raster calculator analysis tool within ArcMap spatial analysis tools was used to combine the factors and their weights. The result identified suitable sites for Grevy‘s zebras in Laikipia county in Kenya and this was categorised from worst to best habitat using natural breaks classifier. The classifier placed usable habitat at 47% and the worst habitat at 53%. Of the 47% suitable area, 12% is highly suitable. Figure 7 and Figure 8 show the Grevy‘s zebra habitat suitability model and the model result.

The highly suitable habitat for Grevy’s zebras is limited and discontinuous. Most of it is found where there is open and wooded grassland. Settlements appear to be the main indicators for the Grevy‘s zebras suitable site. With the scattered settlements, Grevy‘s zebras are mostly confined in Northern part of Laikipia where there is continuous favourable habitat. In as much as the other factors such as vegetation cover and water resources weigh much in defining the population of Grevy‘s zebra, human settlements affect the other factors more directly. Herders, for instance, will occupy areas with similar quality of vegetation as would be preferred by Grevy‘s zebra.

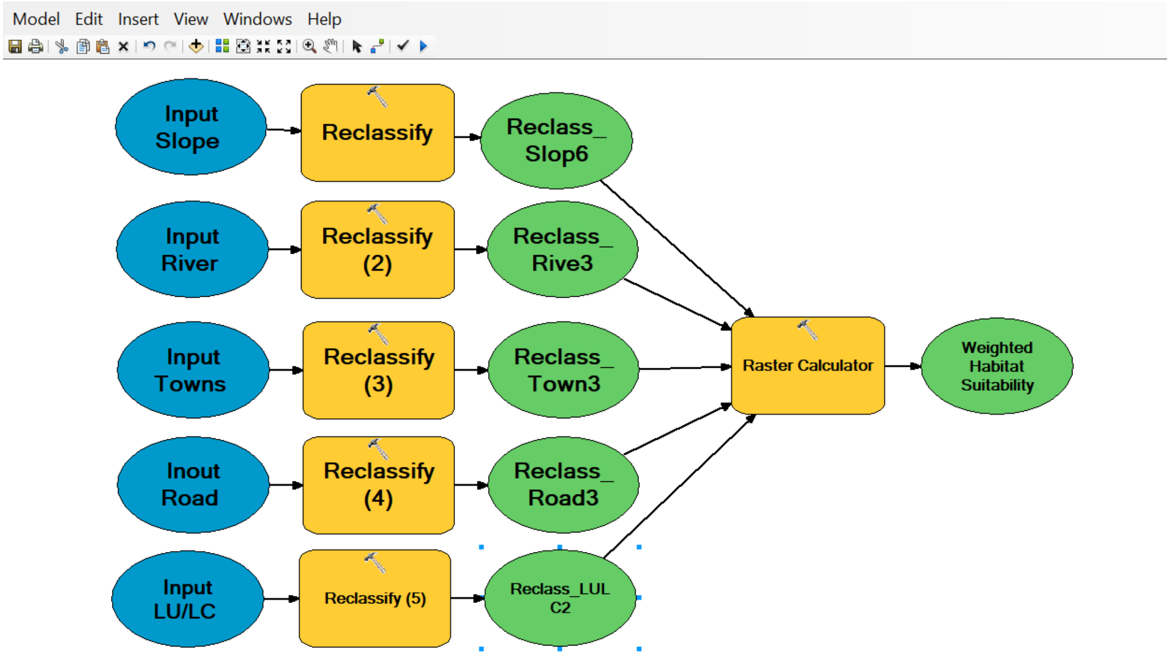


*Figure 4.8: Grevy's Zebra Habitat Suitability Model*

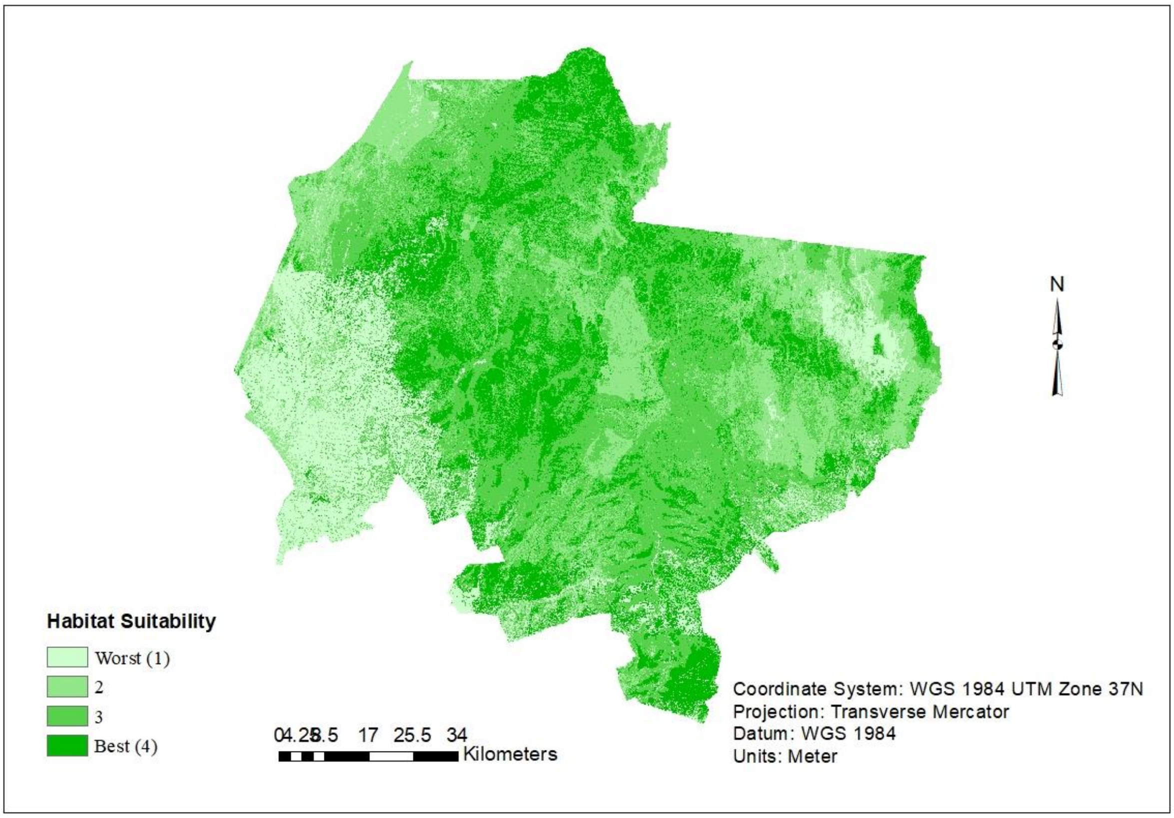


*Figure 4.9: Model Result for Grevy's Zebras habitat in Laikipia County*

# CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

Grevy's zebras are highly endangered and have been listed in the IUCN red list. Their survival and distribution highly depends on the availability of forage, water and security. It is invaluable to know as much as possible their migration pattern and how they utilise the resources available within their habitat. Even though recent conservation measures have been designed to involve the community members, the communities have not been sufficiently inspired to conserve their wildlife for they do not see any direct benefits. Successful conservation measures must in the long run be geared towards conserving the natural habitat of Grevy's zebras. GIS and RS have in the recent past gained popularity in animal habitat management. This study aimed at finding out and exploring suitable sites for Grevy's zebra in Laikipia County by consolidating Multi-Criteria Decision Analysis with Remote Sensing and GIS techniques. To achieve this, factors that can possibly influence Grevy's zebra habitat choice such as vegetation cover, human settlements, proximity to roads, slope and proximity to rivers were examined.

Individual factor analysis shows a variation in output and land size. Slope had a percentage influence weight of 15. This influence of slope has significance especially in Grevy's zebra habitat choice. The study found out that moderately and highly suitable land in relation so slope accounts for up 70 percent of Laikipia land mass. The steep part of Laikipia are towards the border with Baringo County in the west and Isiolo County in the north-eastern side of Laikipia. This can be attributed to the existence of Lake Bogoria that lie between 1000 and 6000 metres above the sea level surrounded by 600 meters high Ngendelel Escarpment behind the border with Baringo county and Buffalo Springs lying 1230 meters above the sea level behind Laikipia borders with Isiolo county. Given the relatively gentle slope in Laikipia, there is high chances of having less soil erosion with potential of washing away vegetation cover. Based on this, the vegetation cover of Laikipia would be sufficiently suitable for Grevy's zebras. This study found out that 29% of the land cover is open grassland which is considered to be highly suitable for Grevy's zebra. Wooden grassland constitutes moderately suitable land and this lies on 61% of the land cover. Having an influence weight of 47% on Grevy's zebra distribution and owing to the fact that 90% of the vegetation cover is suitable for Grevy's zebra.

Even though vegetation cover type accounts for the highest percentage influence on Grevy's zebra habitat choice, water supply weighs at 22 percent which is ranking second in Grevy's zebra's criteria significance identified in this study. Within Laikipia, all the land is within favourable proximity to water sources for the Gravy's zebras with 12 percent and 85 percent highly and moderately suitable for Grevy's zebra respectively.

Unlike vegetation cover, slope and water sources, there is a high density of roads and towns. Even though road network has the least weight of 4.5%, the presence of roads is so high and has been caused mainly by the presence of towns in Laikipia county. Towns means human settlements. The more the towns, the more the population of human settling in this area. It is indeed plausible to conclude that conflict between Grevy's zebras and human activities mainly farming and cattle keeping are inevitable.

This study demonstrated that Multi-Criteria Decision Analysis can be relied on in assessing the variations by which different variables affect the distribution of Grevy's zebras. In as much as there are many MCDA methods and models, there is none that can be considered to be appropriate to provide all solutions. It is usually up to the analyst to be conscious of the limitations and assumptions of the MCDA method of choice. In this study, AHP was the MCDA method of choice primarily because it is intuitive and easy to use. AHP also allows one to take into account all criteria under study and organise them into a hierarchy.

All the Grevy's zebra habitat factors were combined using map algebra and factoring in the MCDA criteria rankings established using the aforementioned methods. The result was the final habitat suitability map for Grevy's zebra in Laikipia.

According to the study, the amount of suitable areas for Grevy's zebra within Laikipia is sufficient but lies largely within the areas with the presence of human settlements and their activities. Other than overgrazing and farming, most of the Grevy's zebras potential natural land are used for agriculture and cattle raring given the countless number of ranched in Laikipia. Further still, the shared habitat means chances of increased competition for available resources. Even though Laikipia has suitable habitat for Grevy's zebra, it appears that Grevy's zebras would avoid most pastures and other resources such as water points due to their proximity to human settlement. Other rich pasture lands, lie within the areas occupied by human and are not accessible to Grevy's zebra, hence this can potentially cause further fragmentation of the Grevy's zebras habitat.

## 5.2 Recommendations

Even though this study achieved its objective of exploring and analysis the suitable habitat for Grevy's zebra in Laikipia, there is still room for future work in this area. Firstly, more study should integrate actual Grevy's zebra GPS tracking data that would be used to map the actual habitat range for Grevy's zebra. With this information, there would be possibility of analysing the potential habitat for Grevy's zebras that falls within the Grevy's zebra habitat range.

Secondly, predation, not only affects the population of Grev's zebra, but also their distribution within the habitat. This study did not explore the effect of predation in determining the suitable habitat for the Grevy's zebra. Laikipia is home to top predators. Lions, hyenas, Leopards and in some rare cases cheaters predate on Grevy's zebras and are found within Laikipia County. Mapping the distribution of these predators and exploring their relationship with Grevy's zebra would add more value to the study.

Thirdly, this study was limited in terms of factoring in different variations in roads, rivers and settlement criteria. There are different geographic sizes of towns for instance. No matter the town size, this study considered all the town as points. Using the actual size of towns would add more accuracy to the result of the study. The same case applies for rivers and roads. In addition, there are seasonal rivers and permanent rivers in Laikipia. Factoring this information in the study would be invaluable.

Finally, more research should be done to give more information on people's attitude towards reintroduction of Grevy's zebras into suitable areas but in close proximity to human settlements. Habitat suitability models usually advise the possibility of availing more potential habitat for animal species, in this case Grevy's zebra. Understanding human attitude towards these animals is very vital and would reveal potential human-animal conflicts.

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