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SUITABLE HABITAT ZONE ANALYSIS IN ALLIDEGI WILDLIFE RESERVE, ETHIOPIA: A CASE STUDY FOR GREVY'S ZEBRA

YARED MESFIN

A Thesis submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Remote sensing and GIS

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN REMOTE SENSING AND GIS

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Suitable Habitat Zone Analysis in Allidegi Wildlife Reserve, Ethiopia: A Case Study for Grevy's Zebra

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Abstract

Currently natural and anthropogenic effects are causing changes in wildlife suitable habitat status and distribution. This resulted in heterogeneous habitat matrix of landscape. Meanwhile, limited range of methods for studying suitable habitat analysis leads to have limited information and knowledge. Application of GIS and remote sensing for wildlife suitable habitat analysis increases monitoring of suitable habitat distribution and assists in assessing suitable habitat variables and their respective influences. The GIS based multi-criteria evaluation for suitable habitat analysis presented in this study used to analyze Grevy's zebra suitable habitat distribution in Allidegi wildlife reserve through integrating habitat factors with expertise opinion. This enables to evaluate and characterize Grevy's zebra suitable habitat status and distribution across the study area. The objectives of this study were to contribute a better understanding of suitable habitat distribution of an endangered Grevy's zebra in Allidegi wildlife reserve by using GIS and remote sensing. Further, Grevy's zebra suitable habitat index had been developed through identifying and assessing the relative importance of Grevy's zebra suitable habitat parameters for an improved management in the study area. 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 analyzing and reclassified for evaluating the suitable habitat. The relative importances of the factors were determined through key informant interview and their weights were determined through analytical hierarchy process. GIS based multi-criteria evaluation was used to combine the factors map and their respective weight to produce final suitability map. Among the selected suitable habitat factors of Grevy's zebra grassland areas found to be the most important factor in the habitat suitability index with weight of 45%. The final suitable habitat map showed that 19% (272 km^2) are of the reserve found to be highly suitable habitat for Grevy's zebra and 25% (368 km^2) moderately suitable habitat and the rest 56% (820km^2) of areas found to be unsuitable. Integrating this study results into conservation planning and management practices of the reserve would enhance decision making utility.

Key words: Analytical hierarchy process; Geographical information system; Grevy's zebra; Habitat suitability index; Multi-criteria evaluation.

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Content **Page**

List of figures   Page

List of tables Page

Acronyms

AHP	Analytical Hierarchy Process
AWR	Allidegi Wildlife Reserve
DEM	Digital Elevation Model
EROS	Earth Resource Observation System
ESRI	Environmental Systems Research Institute
ETM+	Enhanced Thematic Mapper plus
EWCA	Ethiopia Wildlife Conservation Authority
EWCO	Ethiopia Wildlife Conservation Organization
GCP	Ground controlling Points
GIS	Geographical Information System
HIS	Habitat Suitability Index
IUCN	International Union for Conservation of Nature and Natural Resources
IBC	Institute of Biodiversity Conservation
KM	Kilometer
LULC	Land Use Land Cover
MCDM	Multi Criteria Decision Making
MCE	Multi Criteria Evaluation
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WLC	Weight Linear Combination

CHAPTER ONE

INTRODUCTION

1.1 Background

Different environmental predictors influence wild animals habitat preference such as habitat type, slope, water source, anthropogenic factors and these factors are essential in wildlife suitable habitat analysis (Barnard and Thuiller, 2008). Predicting the available suitable habitat distribution and status using habitat parameters is frequently perceived to be useful in conservation; for this matter geographical information system (GIS) and remote sensing have an application packages and the result helps to gain deeper understanding of the problems and bring more accurate information's and less guesswork to the table (G. Yohannes and Ekwa, 2012; Jacek, 2006; João *et al*., 2012; Suman, 2011).

Remote sensing and geographic information system (GIS) technologies have been used for gathering and analyzing of information regarding physical parameters for wildlife habitat evaluation and the results indicate definite advantage over conventional ground survey methods (G. Yohannes and Ekwa, 2012; Jacek, 2006; João, 2012; Kushwaha *et al*., 2012; Kushwaha and Roy, 2002; Ron and Jukka, 2003; Suman *et al*, 2011). Moreover, GIS provide means and aid to produce the data needed for different models and as platform to execute the models as well as to present the results of the analysis user friendly such as map (Daniel, 2014; Ron and Jukka, 2003; Sundaresan *et al*., 2007a).

The wide range of climates conditions resulted from its topography and latitudinal position results the variety of biological life in Ethiopia and makes the country rich in biodiversity abundance and endemism. However, due to natural and anthropogenic causes the original habitat matrix of the species had been changing, which lessens the distribution of suitable habitat (Institution of Biodiversity Conservation (IBC), 2009) and this significantly affects species far reaching survival and it is now the core of any conservation attempts.

Grevy's zebra is highly threatened species mainly from habitat loss (International Union for conservation of Nature and Natural Resources (IUCN), 2014). Historically, Grevy's zebra distribution range covers almost all of east African countries (Moehlman, 2002). However, the current distribution restricted to Ethiopia and Kenya, and Allidegi Wildlife

Reserve (AWR) is their strong hold in Ethiopia. The major threat of Grevy’s zebra in AWR is from the consequence of suitable habitat loss which is the outcome of increasing settlement, farmland and this diminishes the suitable habitat range of the species. Meanwhile, their suitable habitat distribution in the reserve is less addressed.

Thus, characterizing habitat choice and identifying Grevy’s zebra suitable habitat distribution in the reserve using GIS and remote sensing application grants an insight for decision support systems and assist for better conservation and ecology management. Consequently, this study identify the major Grevy’s zebra suitable habitat determining factors and analyze their influence to develop suitable habitat index for improved conservation of Grevy’s zebra and the reserve at large.

1.2 Problem Statement

Human activities such as agricultural development, deforestation, ground water exploration and urbanization have led to loss of the original wildlife habitat, reduction in suitable habitat patch size and increasing isolation of suitable habitat patches (Andrén, 1994). Consequentially, this results in heterogeneous landscapes with different suitability matrix which affects far reaching consequences of wildlife species survival.

To address the suitable habitat distributions of wildlife species GIS and remote sensing has a profound application packages that can deal through involving key suitable habitat factors (G. Yohannes and Imam, 2012; Jacke, 2006; João *et al*., 2012; Hassan *et al*., 2010; Ron and Jukka, 2003). However, unlike to other parts of the world in Ethiopia the application GIS and remote sensing in wildlife suitable habitat study is rare.

Grevy’s zebra habitat distribution in Allidegi wildlife reserve is affected from human and natural cause (Almaz, 2009; Fanuel *et al*., 2012). This distresses the suitable habitat distribution of Grevy’s zebra. Meanwhile, limited study approach leads to have limited information and knowledge gap on the functional suitable habitat landscape matrix of Grevy’s zebra in Allidegi wildlife reserve. Thus, addressing this problem is crucial for any conservation and management interventions.

Consequently, the GIS based suitable habitat model presented here used to analyze the suitable habitat distribution of Grevy’s zebra using multi-criteria evaluation approach. Accordingly, it devised to remedy the deficiency of information regarding Grevy’s zebra suitable habitat pattern in the study area as a result to conserve and protect the species.

And also the propose GIS based Grevy's zebra habitat suitability index enables to evaluate the habitat characteristics of the species in Allidegi wildlife reserve and identify the most important factors and critical areas for improved conservation of the species.

1.3 Objectives

1.3.1 General Objective

The main objective of this study is to analyzing Grevy's zebra suitable in Allidegi wildlife reserve using GIS based multi-criteria evaluation approach through identifying key Grevy's zebra habitat defining parameters and their influence, and to relate the information for improved conservation of Grevy's zebra in the study area.

1.3.2 Specific Objectives

- To identify key Grevy's zebra suitable habitat defining parameters.
- To assess the relative importance of habitat parameters for Grevy's zebra suitable habitat identification.
- To develop Grevy's zebra suitable habitat index and identify functional suitable habitat using GIS based multi-criteria evaluation for improved management in the study area.

1.4 Significance of the study

GIS based approach for suitable habitat analysis increases monitoring of suitable habitat distribution and assists in assessing suitable habitat variables and their respective influences. Therefore, GIS based multi-criteria suitable habitat modeling approach presented in this study provides another means of insight in wildlife suitable habitat analysis through integrating habitat factors with expertise opinion. The approach presented in this study enables to evaluate Grevy's zebra suitable habitat as well as to bring suitable habitat status and distribution into being.

The information regarding Grevy's zebra suitable habitat distribution developed by this study would assist to craft sound planning and to prioritize conservation approach. Further, the study provides background information to exercise right judgment in functional landscapes, suitable habitat utilization and conservation in the study area Allidegi wildlife reserve.

In the mean time this study produces suitable areas map of Grevy's zebra and characterize the study area into different ranges of suitability. This helps to understand the status and distribution of habitat matrix in the study area. Further, the result from this study provides an insight to divulge the habitat characteristics of the landscapes for the newly proposed boundary of the reserve.

1.5 Organization of the thesis

This thesis involves using of GIS and remote sensing for Grevy's zebra suitable habitat study. Chapter one of the thesis involves background information of the study regarding the application of GIS based multi criteria evaluation and remote sensing in wildlife habitat study and Grevy's zebra habitat factors. Mean while problems had been identified and objectives for the identified problems had been developed. This had been also enhanced in the literature review part in chapter two. Chapter three covers the method part of this study regarding data used, procedure followed and software's used to develop the model. Chapter four covers the result of the study, which involves all findings of the analysis in maps and numeric's and their implications. The findings of the study had been also discussed in the discussion part. Finally, based on the findings conclusion and recommendation had been drawn that would aid the decision making and policy formulation process.

1.6 Limitations of the study

The distribution of the species varies in dry and wet season accordingly the selected variables exhibit seasonal variability. However, this study did not address the seasonal variability of the identified factors. Due to time constraint and absence of concrete data and understanding some variables such as the effect of ground water exploration and resource competition from livestock did not involve in the analysis of Grevy's zebra suitable habitat in the study area Allidegi wildlife reserve.

CHAPTER TWO

LITERATURE REVIEW

2.1 Application of remote sensing and GIS in wildlife suitable habitat study

Remote sensing satellite and earthbound sensors are providing us with vast amounts of data about our planet (Environmental Science Research Institute (ESRI), 2014) and the availability of different GIS software's makes the application of GIS and remote sensing common and visible in wildlife suitable habitat study (Asfaq *et al*, 2008; Chambers, 2006; Daniel, 2006; Douglas and Sanga-Ngoie, 2004; G. Yohannes and Imam, 2012; Hassan *et al*., 2010; Imam *et al*., 2012; João *et al*., 2012; Leyequien *et al*., 2007).

Remote sensing and geographic information system (GIS) technologies have been used for gathering information regarding physical parameters of wildlife habitats and geospatial modeling of wildlife habitat (G. Yohannes and Ekwa, 2012; Jacek, 2006; João *et al*, 2012; Kushwaha and Roy, 2002; Kushwaha *et al*., 2012; Suman *et al*, 2011). Moreover using GIS the data needed for different models can be processed and as well as serve as platform to execute the models and present the results of the analysis user friendly (Daniel, 2014; Ron and Jukka, 2003; Sundaresan *et al*., 2007a). Therefore, the application GIS in wildlife suitable habitat study improves decision making utility (Jacek, 2006; Ron and Jukka, 2003).

2.1.1 GIS based wildlife habitat modeling

With the development of geographic information tools, it has become easier to represent the spatial distribution of environmental variables and produce visual presentation of spatial models such as maps of species habitat suitability and probability of the species occurrence. Geographically explicit models have become extremely powerful tools for representing the species-habitat relationship and they are extensively used in applied contexts of wildlife management. And also the variety of statistical and mathematical models that have been developed in the last decades for the representation of species habitat relationships had made wildlife habitat study easier (Antoine and Zimmerman, 2000). Further, wildlife habitat suitability modeling has been advanced by the application of Geographic Information Systems (GIS) and remote sensing. GIS is an admirable tool for identifying areas of conservation significance areas and assessing the habitat potential of unstudied sites.

There are several GIS based approaches for wildlife suitable habitat modeling based on deductive and inductive logics using environmental variables such as type of ecological, topographical, or management surface. The deductive habitat models use previous works and expert value judgments (G. Yohannes and Imam, 2012; João *et al*, 2012; Ron and Jukka, 2003). The deductive model is a descriptive model based on the suitability or unsuitability of the individual attributes of each environmental variable.

Inductive habitat models use species occurrence records to drill through environmental variables (Asfaq *et al*., 2008; Fanuel *et al*, 2012; Hassan *et al*., 2010). This modeling approach associations through mathematical algorithms and species presence. Recently, several algorithms (e.g. Maximum Entropy) have been created that use presence-only occurrence datasets.

However, in a case of no data of the species presence multi-criteria evaluation has been an effective approach in studying wildlife species suitable habitat distribution and factors analysis (G. Yohannes and Imam, 2012; Ron and Jukka, 2003; Suman *et al*., 2011).

2.1.2 Wildlife suitable habitat analysis

For many species habitat requirements are related to the structure of the habitat and relating factors which affect the habitat status (Barnard and Thuiller, 2008). Past approaches for locating suitable habitat sites for species have used either aerial or ground-monitoring of radio marked which is expensive and time consuming as well as unfeasible with some environmental limitations such as forest cover and in wider areas (Norton-Griffiths, 1998). However, in recent time the development of GIS technology and the availability of remote sensing data and the capability of integrating for wildlife suitable habitat study makes the approach appropriate as a result it is becoming common (Antoine and Zimmermann, 2000; Daniel *et al*., 2006; Douglas and Sanga-Ngoie, 2004; G. Yohannes and Imam, 2012; Hassan *et al*., 2010; Imam *et al*., 2012; Ron and Jukka, 2003).

The spatial and thematic aspects of GIS and remote sensing enable users to overlay various data to delineate and predict the future of resources such as land, agriculture and wildlife habitat (Jacek, 2006). This enables decision makers to gain a deeper understanding of the problems and brings more accurate information and less guesswork to the table. This leads to implement laws and programs that will protect and sustain the environment and its resources. Thus, GIS are well suited for habitat suitable modeling through representing environmental variables.

The GIS application in wildlife study extends from water ecosystem (Daniel, 2006) to terrestrial land (Kushwaha *et al.*, 2012; João *et al.*, 2012; Hassan et al. 2010; Kushwaha and Roy 2002; Daniel, 2014; Suman *et al*., 2011). However, to apply GIS in wildlife suitable habitat study exploring and identifying the habitat factors is the crucial step. This can be through reviwing of previous works, existed statistical data, expert opinions and field survey (G. Yohannes and Imam, 2012; João *et al*., 2012; Ron and Jukka 2003; Suman *et al*., 2011).

Models for wildlife habitat selection patterns are based on the investigation of the relationship between the collected occurrence data and the appropriate background variables. Depending on the available data there are different approaches of exploring relationships. Multiple Logistic regression analysis applied in cases when presence/absence data are collected (Asfaq *et al*., 2008; Josk and Robert, 1991), whereas multiple regression analysis in case of abundance data are available (Jane and John, 2009; Ron and Jyrki, 2001; Ron and Jukka, 2003) and Maxent modeling approach would used in a case that the presence data of the dependent variable are available (Fanuel *et al*., 2012; Phillips and Dudik. 2008). However, in the case of no presence data multi criteria evaluation (MCE) modeling approach used; which uses previous works, existing statistical data, expert opinions and field survey for evaluating the species habitat factors and their influences for suitable habitat distribution analysis (G. Yohannes and Imam, 2012; Ron and Jukka, 2003; Suman *et al*., 2011).

2.1.3 Multi-criteria decision making

Spatial decision problems typically involve a large set of feasible alternatives and multiple conflicting and incommensurate evaluation criteria. The alternatives are often evaluated by a number of individuals (decision-makers, managers, stakeholders, interest groups). The individuals are typically characterized by unique preferences with respect to the relative importance of criteria on the basis of which the alternatives are evaluated. Accordingly, many spatial decision problems give rise to the GIS-based multi-criteria decision making (GIS-MCDM) (Jacek, 2006).

GIS techniques and procedures have an important role to play in analyzing decision problems. Indeed, GIS is often recognized ‘as a decision support system involving the integration of spatially referenced data in a problem solving environment. On the other hand, MCDM provides a rich collection of techniques and procedures for structuring decision problems, and designing, evaluating and prioritizing alternative decisions. At the most rudimentary level, GIS-MCDM can be thought of as a process that transforms and combines geographical data and value judgments (the decision-makers preferences) to obtain information for decision making. It is in the context of the synergetic capabilities of GIS and MCDM that one can see the benefit for advancing theoretical and applied research on GIS-MCDM (Jacek, 2006).

Multi criteria decision making (MCDM) is GIS-based index models that combined several factors and the factors specific weights values to come up with suitable habitat map. This approach is used to study suitability in different fields (Jacek, 2006) and in wildlife suitable habitat study (G. Yohannes and Ekwal, 2012; Douglas and Sanga-Ngoie, 2004; João *et al*., 2012; Josk and Robert, 1991; Kushwaha *et al.*, 2012; Suman *et al.*, 2011).

The proliferation phase of MCDM was characterized by the development of the user-oriented GIS technology, which has stimulated a wide range of GIS applications including the GIS-based approaches for tackling spatial decision problems. According to Jacek (2006) the integration of GIS and multi criteria decision analysis has attracted significant interest over the last 15 years or so in several fields. The main application areas are on environment and wildlife suitable habitat modeling.

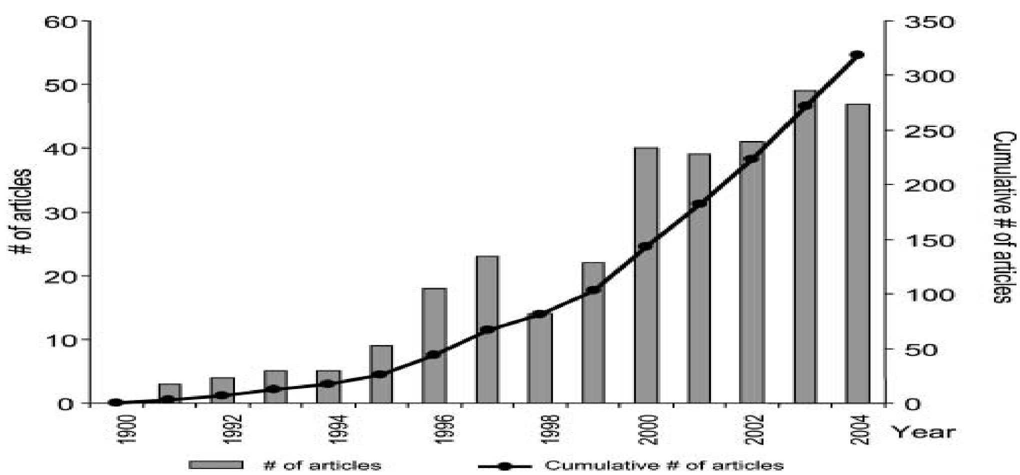

Figure 1: Total number of GIS-MCDM articles for the period 1990–2004 (Jacek, 2006).

The rapid increase of the volume of the GIS-MCDM research can be attributed to a number of factors. In particular, the availability of fully fledged decision support GIS software's such as ESRI software's of ArcGIS, ERDAS imagine and Clark software of IDRISI. They have been instrumental for stimulating applied research in GIS-MCDM (G.Yohannes and Imam, 2012; Jacek, 2006; Ron and Jukka, 2003; Ron and Jyrki, 2001).

2.1.4 GIS based multi-criteria evaluation for wildlife suitable habitat analysis

Multi-criteria evaluation in a GIS environment is the additive technique whereby the criterions scores are standardize and the total score for each alternative is calculated by multiplying each criterion score by its weight factor and then adding the result in weighted linear summation which is the best known and applied (G. Yohannes and Imam, 2012; João *et al*., 2012; Ron and Jukka, 2003). To do so identifying key habitat controlling factors affecting wildlife species suitable habitat distribution have to be analyze foremost.

Habitat suitability analysis through MCE helps to know the quantity and quality of the species suitable habitat status and distribution (G.Yohannes and Imam, 2012; João *et al*., 2012; Ron and Jyrki, 2001). Suitable habitat map created with the use of suitable habitat controlling parameters shows the available and quality of different habitat matrix as well. Therefore, the use of GIS base MCE approach is fundamental to obtain a better combination and interpretation of the factors involved in habitat evaluation for decision making and conservation strategies. MCE approach has also used to develop species suitable habitat index.

Environmental variable such as vegetation cover, slope, water, disturbance have different role on species habitat selection (Barnard and Thuiller, 2008; G.Yohannes and Imam, 2012; João *et al*., 2012; Mudasir, 2014; Suman *et al*., 2011). Consequently, assigning the relative importance and weight of each factor is necessary in multi-criteria habitat analysis.

Analytical hierarchy process (AHP) developed by (Saaty, 1977) is used to identify the relative weight of suitability habitat determining factors. G.Yohannes and Imam (2012), Ron and Jukka (2003) and João *et al*., (2012) applied AHP to weight different habitat controlling parameters in suitable habitat analysis of wildlife. AHP provides a way to rank the landscape matrix based on area attributes. The relative importance of the factors can be determined via expert opinions through key informant interview or focused group discussions.

In the process of AHP, the prime task of calculation is the eigenvector corresponding to the largest eigen value of the matrix. Each element in the eigenvector indicates the relative priority of corresponding factor (Saaty, 1977). During examining the rationality of AHP, it is necessary to determine the degree of consistency that has been used in developing the judgments. In AHP, an index of consistency, known as the consistency ratio (CR), is used to indicate the probability that the matrix judgments were randomly generated (Jacek, 2006).

Generally, GIS-MCDA is a significant and relevant approach for wildlife suitable habitat analysis. This integrated geospatial techniques to provide accurate, cost-effective as well it is time-effective method for habitat evaluation and use to develop species suitable habitat index.

2.1.5 Habitat Suitability Index

In the last decades there has been a considerable amount of work done towards the identification of relationships that would express how species relate to the environment, thus guiding towards the conservation of particularly valuable areas. One approach used extensively for this purpose is the development of Habitat Suitability Indices (HSI). They were developed by the U.S. Fish and Wildlife Service (USFWS) in the attempt to establish linear relationships between species and environmental variables in a standardized way across all the United States (USFWS, 1981). HSI are models that incorporate a number of environmental variables considered to be important for the presence of a given species. They are related to the species presence in a quantitative way using data from field studies and combined spatially in a GIS. The HSI contain a great deal of expertise value judgment in various steps of their development. The selection of significant variables is left to subjective decision by scientists and experts who have prior knowledge (G.Yohannes and Imam, 2012; Jacek, 2006; João *et al*., 2012; Ron and Jukka 2003).

2.2 Wildlife diversity of Ethiopia

The wide range of climates conditions resulted from its topography and latitudinal position results the variety of biological life in Ethiopia and makes the country rich in biodiversity abundance and endemism (IBC, 2009; John, 1968). For conservation and management of wildlife's and associated ecosystem Ethiopia has established nine protected areas, three wildlife sanctuaries, eight wildlife reserves, and 18 controlled hunting areas onward of 1960s (Fanuel *et al*., 2012; IBC, 2009; John, 1968). These are a home for a wide variety of wild species including endemic mammals such as Walia Ibex, Mountain Nyala, Starck's Hare, Ethiopian Wolf and Gelada Baboon (IBC, 2009).

Before the establishment of protected areas legally in 1960s, Emperor Menilik II declared the first wildlife conservation law in 1909. This law prohibited killing of wildlife without the permission of hunting authorities who were appointed by the Emperor. However, it only includes larger mammals such as Elephant, Lion and Buffalo. Thirty-five years later, the Ethiopian Ministry of Agriculture passed a wildlife conservation proclamation in 1944 to regulate wildlife hunting through a division in the Ministry of Agriculture (Almaz, 2009). However, there was no institution established to conserve and manage the wildlife resources of the country until the establishment of Ethiopian Wildlife Conservation Organization (EWCO) by the year 1964.

The first legally gazzeted parks are Awash National park which is adjacent to Allidegi Wildlife Reserve (AWR) and Semine Mountains National park in 1966 (John, 1968). Eventually, EWCO legally declared in 1970 with order number 65/70 to manage all protected areas in the country (Almaz, 2009) and become the sole responsible organization to conserve and manage the parks constitutes.

2.2.1 Allidegi Wildlife Reserve

Allidegi wildlife reserve established in 1960s where most parks were established (Almaz 2009; EWCA, 2013; Fanuel *et al*., 2012), with the main objective of serving as a buffer zone for neighboring Awash National Park (Almaz, 2009). Based on the IUCN protected-area management categories (IUCN, 2010), AWR falls under category six (i.e., a managed resource protected area). This defined as "an area containing predominantly unmodified natural systems, managed to ensure long-term protection and maintenance of biological diversity, while providing at the same time a sustainable flow of natural products and services to meet community needs". This category allows some level of human activity (grazing, collecting wild plant foods, etc).

So far 33 species of mammals and 140 bird species have been recorded in the reserve (EWCA, 2013). Among them AWR supports highly threatened Grevy's zebra of Ethiopian eastern most population and other grasslands dependent wildlife (EWCA, 2013, Almaz, 2009; Fanuel *et al*., 2012; Guy *et al*., 2010; Williams, 2002) which undeniably makes the reserve to have international significance.

The habitats type in and around the reserve include grasslands, wooded grassland, bush land, shrub land, shrub grassland, gallery /riverine forest and highland forest (Almaz, 2009; Fanuel *et al*., 2012; EWCA, 2013) mean while its plain lands are attractive for plain grazing animals such as Wild Ass (*Equus africanus*), Soemmering gazzel, Basin Oryx and others (EWCA, 2013; Fanuel *et al*., 2012). However, Almaz (2009) confirms that the African Wild Ass (*Equus africanus*) which is very rare in the reserve, while Swayne's Hartebeest (*Alcelaphus buselaphus swaynei*), and Defassa Water Buck (*Kobus defassa*) once present in the area are now locally extinct, and now the turn seems to be Grevy's zebra (Almaz, 2009; Schulz and Kaiser, 2013).

2.2.2 Grevy's Zebra Habitat Range

Historically, Grevy's zebra were believed to be found in semi-arid areas of Djibouti, Eritrea, Ethiopia, Kenya, Somalia, and Sudan; however their current distribution has restricted to the semi-arid zones of Ethiopia and Kenya and possibly Sudan (Williams, 2002). According, to Almaz (2009) Grevy's zebra were found in Awash National Park however it was locally extinct from the Park and now AWR is the only area were Grevy's zebra found in high number in Ethiopia.

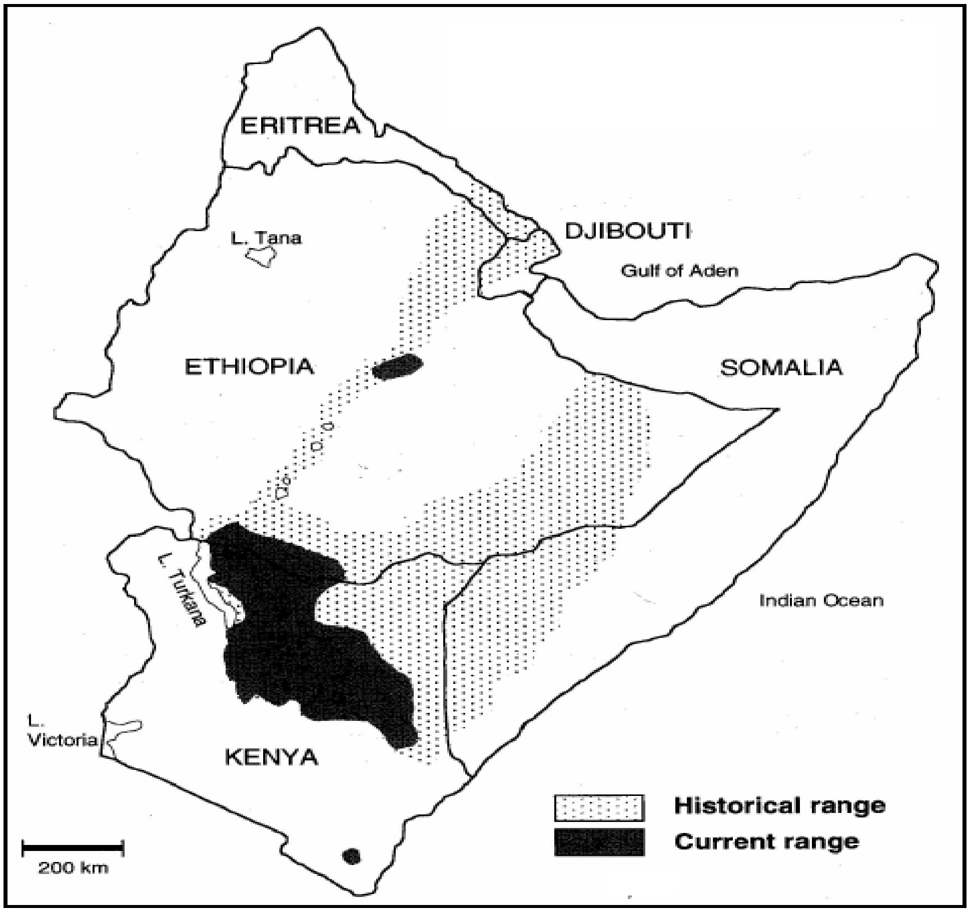

Figure 2: Historical and current habitat distribution of Grevy's zebras (Moehlman, 2002).

Currently the populations of Grevy's zebra are distributed over an area of 85,000 square kilometers of savannah grassland in Northern Kenya and Eastern Ethiopia (Guy *et al*., 2010).

Towards the end of the 1970s, the global population of Grevy's zebra was estimated to be approximately 15,000 bur present-day estimates lie between 1,964 and 2,445 (Mwasi and Mwangi, 2007). This represents an 84-87% decline in global numbers over the past three decades. Meanwhile, Williams (2002) estimates that the species numbers of Grevy's zebra were around 3000 globally, and has undergone a 75% decline since the 1970s. Grevy's zebra's last remaining stronghold is in the Laikipia Samburu Ecosystems of central Kenya and Allidegi plain in Ethiopia (Williams, 2002) where 90% of the population founds in Kenya (KWS, 2008).

Allidegi plain supports about 126 individuals of Grevy's zebras (Fanuel *et al*., 2012); whereas the most recent survey by EWCA (2013) estimated their number up to 173.

Further they reported that they also found in Yabello Sanctuary and surrounding areas including the Borana Controlled Hunting area and Chew Bahir (Chalbi Wildlife Reserve) with more abundant than Allidegi wildlife reserve but have also facing drastic decline (William, 2002). Beside of this Williams *et al*., (2002) hints that the decline of Grevy's zebra populations in Ethiopia was by at least 90% throughout the country, with an estimated 1,900 animals in 1980 to 577 animals in 1995 and 110 in 2003. Rate of decline has been slower in Kenya than in Ethiopia. Hence, largest population almost 90% of Grevy's zebra founds in Kenya (KWS, 2008).

The main cause for Grevy's zebra habitat diminishing in Ethiopia and Kenya are reduction of water resource duet to unsustainable extraction and exclusion of wildlife, habitat loss and destruction, competition for resource, tourism, hunting, and live animal trade (Williams, 2002). Additionally, AWR is also prone to drought and expansion of exotic invasive species *P. juliflora*t lead to inadequate forage for wildlife as well as competition from livestock and ground water exploration and expansion of settlements (Almaz, 2009, Fanuel *et al*., 2012). The intensive competition from livestock and agricultural activities end up in most cases by displacing Grevy's zebra from their preferable habitat (Almaz, 2009; Daniel, 2014; Fanuel *et al*., 2012). The cause for conflict would be inadequate space to harmonize people, livestock and wildlife (Daniel, 2014). Large cattle are mostly kept in grasslands nearby water, thereby making the water unreachable for the zebras during daytime, and forcing them to drink during the night, when they are more vulnerable to predation. Competitions for resource and hunting have a direct relation with human settlement, where in AWR there are around 30 permanent settlements and water source used by both livestock and wildlife area outside the park (Almaz, 2009, Fanuel *et al*., 2012) and this make the species vulnerable for threats.

In order to conserve Grevy's zebra correct and up to date information on distribution of suitable habitat status provides necessary input in any decision support system for effective wildlife management. Such information may include habitat matrix and characterization, habitat distribution and influence of habitat factors.

2.2.3 Grevy's zebra suitable habitat determining factors

Grevy's (*E. grevyi)* zebra are large-bodied (about 350–450 kg) grazing ungulates living in rangelands of central-northern Kenya and Ethiopia (Sundaresan *et al*., 2007a). Habitat of Grevy's zebra is characterized by short grass savannah, offering good visibility so that the animals are able to detect both one another and the predators at a distance (Guy *et al*., 2010; Sundaresan *et al*., 2007b).

Vegetation features important to zebras include forage quantity and quality, and habitat openness; further it varies in reproductive status (Schulz and Kaiser, 2013; Sundaresan *et al*., 2007b). Grevy's zebra also avoid areas close to humans, road and livestock because of disturbance and competition with domestic animals over forage (Almaz, 2009; Fanuel *et al*., 2012; Sundaresan *et al*., 2007a,).

Habitat use of wildlife is highly affected by shape by the availability of water resources (Holecheck, 1988). Water is crucial to maintain body condition and reproductive success (Daniel, 1998). Grevy's zebra is mainly dependent in standing water and adult Grevy's zebra drinks at least once in a day where lactating female drinks once in a day (Sundaresan *et al*., 2007b).

2.2.4 Threats of Grevy's zebra

Today more than ever before we must manage, preserve, and restore our natural resources; mean while decision makers are charged with this task need a complete picture of the issues. As of most protected areas AWR is under a lot of troubles (Almaz, 2009; Fanuel *et al*., 2012). According to Williams (2002) the major treats to Grevy's zebra are reduction of water resource and foraging resources due to unsustainable extraction and competition of resource by livestock's.

Allidegi wildlife reserve is also prone to drought and expansion of exotic invasive species *P. juliflora*t lead to inadequate forage for wildlife as well as competition from livestock and ground water exploration (Almaz, 2009) which potentially influence the resource distribution and availability. The intensive competition from livestock and human end up in most cases by displacing Grevy's avoiding them from their preferable habitat (Daniel, 2014). The cause for conflict would be inadequate space to harmonize people, livestock and wildlife (Daniel, 2014). Large cattle are mostly kept in grasslands nearby water, thereby making the water unreachable for the zebras during daytime, and forcing them to drink during the night, when they are more vulnerable to predation. Competitions for resource and hunting have a direct relation with human settlement, where in AWR there are around 30 permanent settlements and water source used by both livestock and wildlife area outside the park (Almaz, 2009; Fanuel *et al*., 2012) and this make the species vulnerable.

The species was declared protected by the Kenyan and Ethiopian governments about 20 years ago (Moehlman, 2002). However, despite the laws, the animals are still in threat. Thus, to minimize conflict and protect wildlife from any danger through better management plan and decision making characterizing habitat choice is essential; especially for endangered species (Norton-Griffiths, 1998).

Thus, correct and up to date information on wildlife population and suitable habitat status provides necessary input in any decision support system for effective wildlife management. Such information may include species abundance, functional relationship between species distribution and environmental factors, or change in biodiversity and should be derived through effective study approach technique (Alan, 1997; Mccarthy *et al*., 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

Allidegi wildlife reserve lies in the Great Rift Valley (approximately $8^{0}30'$ to $9^{0}30'$ N and $39^{0}30'$ to $40^{0}30'$ E) of Amibara and Mieso woreda of Afar and Oromiya regional state, respectively, 280 km east of Addis Ababa covering an area of 1,832 km^2. The elevation ranges between 800 m to 2400 m above sea level.

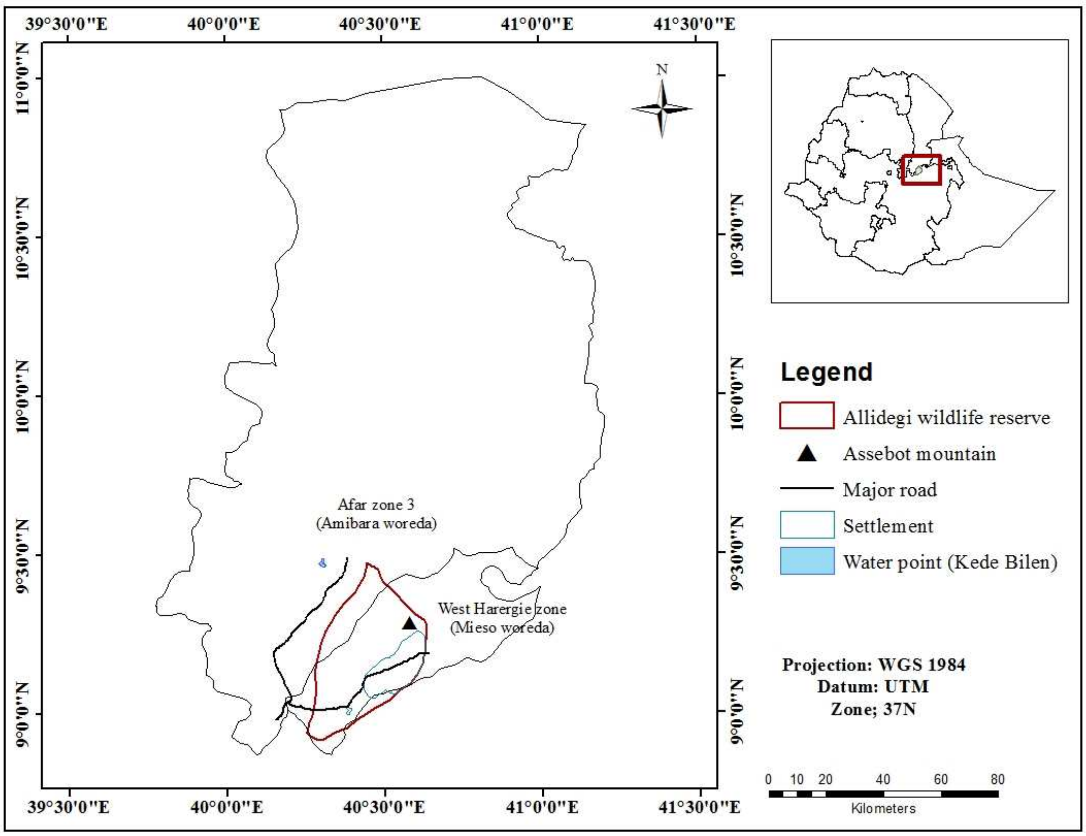

Figure 3: Location map of the study area Allidegi wildlife reserve.

3.1.2 Drainage

The Awash River is about 2.5 km (in a straight line) from the boundary of the Allideghi Plain. However, the major sources of natural permanent water for wild animals and livestock are the Big Bilen (Kede Bilen) and Small Bilen (Undo Bilen) hot springs, which are about 6.5 and 6.0 km (in a straight line) from the nearest side of boundary of the Allideghi Plain, respectively. Big Bile is the most frequently accessed by wild animals and livestock (Almaz, 2009; Fanuel *et al*., 2012).

3.1.3 Climate

3.1.3.1 Temperature

The climate of the area exhibits short wet season in February and March and short dry season in December. The long dry and wet seasons are in June and, July and August respectively. In general wet season of the area are February, March, April, July, August, part of September, while the rest months are dry season (Fanuel *et al*., 2012).

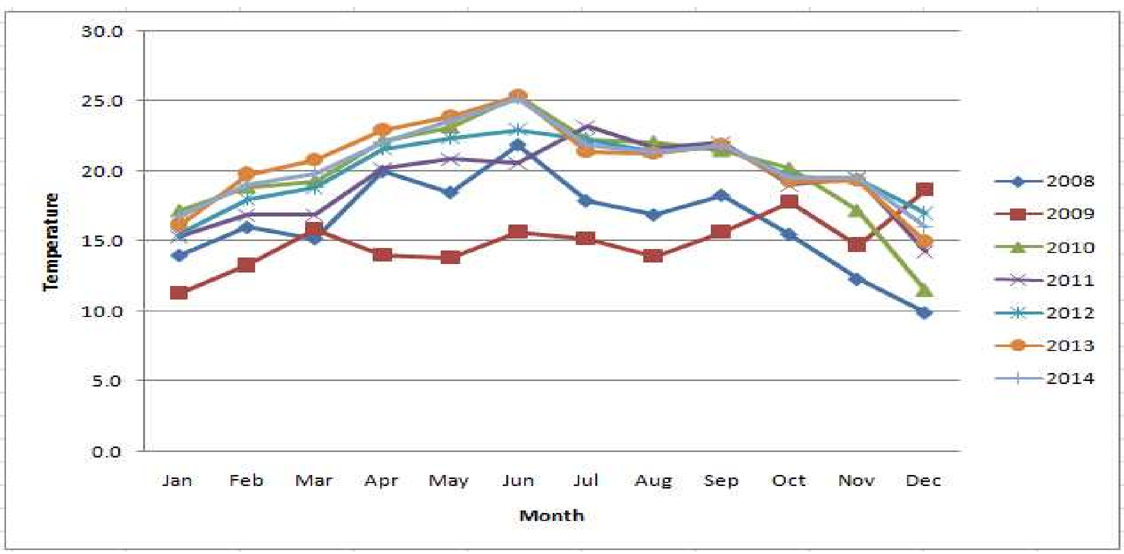

Figure 4: Monthly minimum temperature (Source: Melka werer agricultural research center).

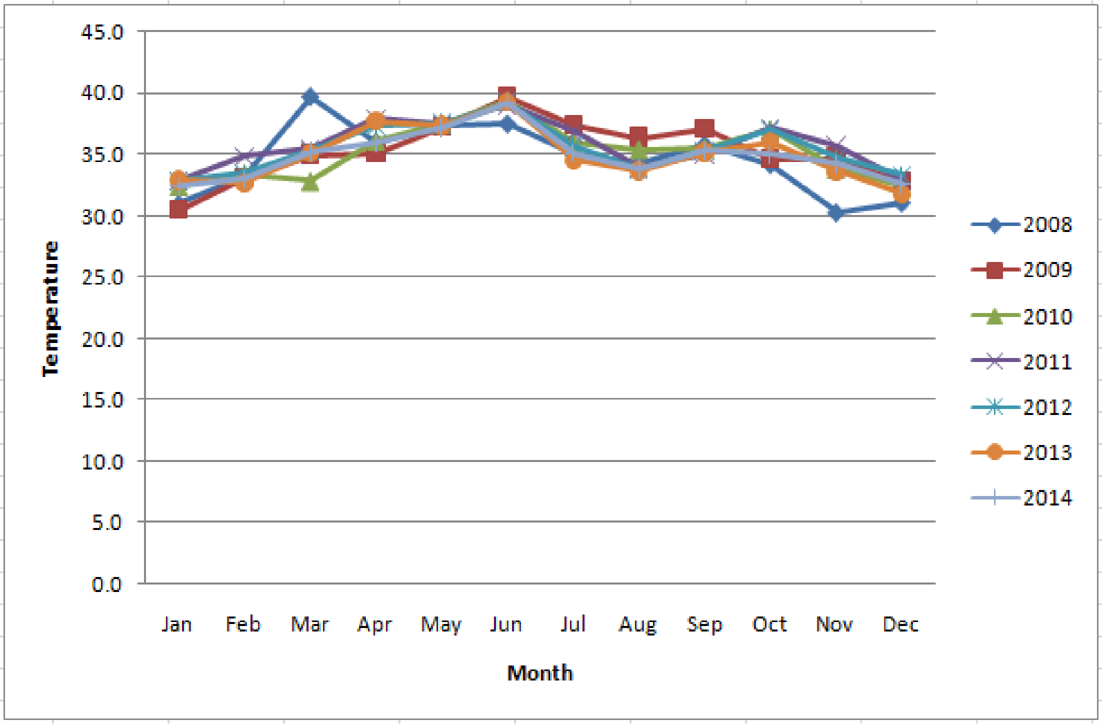

Figure 5 : Monthly maximum temperature (Source: Melka werer agricultural research center).

3.1.3.2 Rainfall

The Alledeghi wildlife reserve is located in a semi-arid ecosystem with bimodal rainfall patterns. Annual rain fall ranging between 400 and 700mm. High rainfall season is in July and August with above 150 mm while low mean monthly rainfall with below 20 mm exhibits in December (Almaz, 2009; Faunel *et al*., 2012).

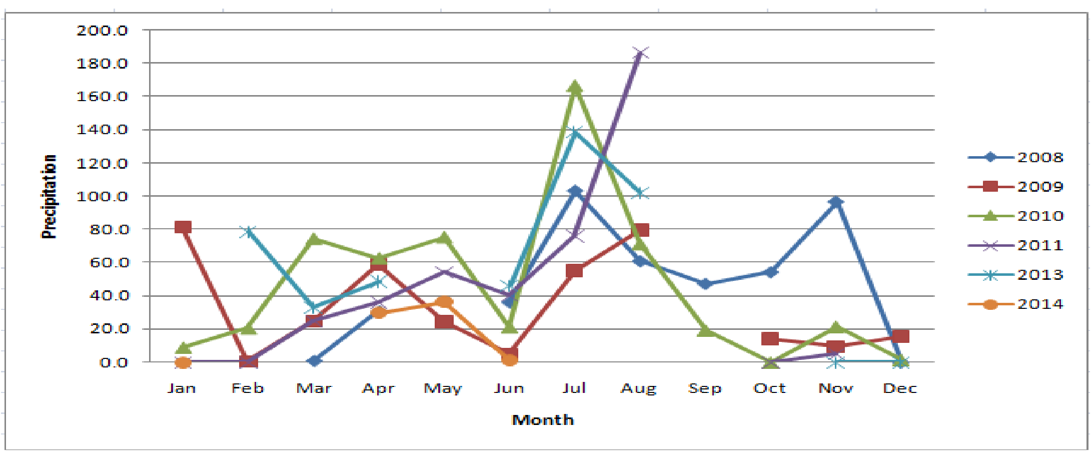

Figure 6 : Monthly rainfall of the study area (Source: Melka werer agricultural research center).

3.1.4 Vegetation cover type

The major vegetation types in and around the reserve includes grassland, bush land, shrub land, wooded grassland, shrub grassland, gallery /riverine forest and highland forest. About 70 plant species have been identified in the previous studies (Almaz, 2009). *Chrysopogon plumulosus* and *Sporobulus iocladus* comprise a relatively high percentage of herbaceous vegetation on the plains. The southern, northern, and western edges of the reserve are bush-grasslands or shrub lands, with *Acacia senegal* being the dominant species. In some parts of the grassland, *P.juliflora* is becoming the dominant woody species. The woody plant species in the plains of this reserve include Acacia senegal, Acacia tortilis, Acacia mellifera, Balanitis aegyptiaca, Cadaba species., and Grewia species. The highland forest of Mount Asebot include *Cordia africana*, *Croton macrostachyus*, *Erythrina abyssinica*, *Juniperus procera*, *Olea europaea*, *Podocarpus falcatus*, *Pouteria altissima*, *Rhus vulgaris* and many others (Almaz, 2009).

3.1.5 Fauna

Thirty-one species of mammals have been observed at AWR and the surrounding areas. A species list is provided in the most common large herbivores in the AWR include Grevy's zebra, Oryx, Soemmering's Gazelle, Gerenuk, Cheetah, Leopard, Lion, Lesser Kudu, Ostrich and many others (Almaz, 2009).

3.2 Materials

For this study the following software's were used ArcGIS 10, ERDAS IMAGINE 10, IDRIS Selav 17.0 and DNRGarmin for geo-spatial and image analysis. The materials that used in this study were GPS, digital camera, computer, range finder and binocular. The input data for this study were taken from different internet sources and from offices where relevant information was available. Accordingly, the following data showed in table 1 were used.

Table 1: Data used and source

No	Data type	Source	Resolution	Software used for processing and analysis
1	Landsat 8 ETM+ image Year of 2014	USGS (EROS) (http://earthexplorer.usgs.gov)	30 meter	ERDAS IMAGINE 10
2	DEM	ASTER DEM (http://gdem.ersdac.jspacesystems.or.jp)	30 meter	ArcGIS 10
3	GPS data	Field survey/Google earth		
4	Factors relative importance	Key informant interview		
5	Study area shape file	Ethiopia Wildlife Conservation Authority (EWCA)		

3.3 Methods

3.3.1 Data collection and organization

This study is aimed to identify functional suitable habitat of Grevy's zebra in Allidegi wildlife reserve using GIS and remote sensing. Accordingly, to model Grevy's zebra suitable habitat distribution five Grevy's zebra suitable habitat determining factors namely settlements, slope, vegetation cover, water point and road had been identified from related literatures and interviewing expertise.

The selected parameters were prepared to integrate to the GIS environment and for the analysis each factors were converted to raster format and reclassified based on the responses of key informant interview and previous works. Then the analysis was undertaken in GIS environment.

The modeling approach used to integrate Grevy's zebra habitat defining parameters by this study was GIS based multi-criteria evaluation (MCE). The relative importance had been evaluated through key informant interview and the weight of the factors for the habitat suitability index of Grevy's zebra had been generated via analytical hierarchy process (AHP) using IDRISI software. The overly analysis to combine the habitat factors layer map with their respective weight were conducted using ArcGIS 10 software spatial analyst extension.

3.3.2 Factors influencing Grevy's zebra habitat suitability

Almaz (2009); Daniel (2014); Fanuel *et al*. (2012); Sanderson and Pascual-Hortal (2007), Sundaresan *et al*., (2007a and 2007b) mentioned that vegetation cover, proximity to water point, proximity to road, proximity to settlement/farmland and slope are the major factors governing Grevy's zebra suitable habitat use. Therefore, in this study these factors were analyzed for modeling Grevy's zebra suitable habitat in the study area Allidegi wildlife reserve.

Table 2: Suitable habitat parameters and their relevance for the analysis

Suitable habitat parameters	Relevance for the analysis
Vegetation cover	For identifying the species preferable habitat type.
Slope	For identifying the plain areas.
Distance from water point	In order to identify proximity to the permanent water point.
Proximity to road	In order to minimize visual, noise, habitat fragmentation impacts on the wildlife.
Proximity to settlement	In order to minimize visual, noise, and land use impacts on the wildlife.

3.3.2.1 Vegetation type

The vegetation cover type in and around the study area includes grasslands, bush land, shrub land, wooded grassland, gallery /riverine forest and highland forest (Almaz, 2009; Fanuel *et al*., 2012). Grevy's zebra highly prefers grassland area (Almaz, 2009, Fanuel *et al*., 2012, Daniel, 1998). Therefore, the vegetation cover/land use land cover of the study area was ranked according to the availability of grasslands.

Vegetation cover of the study area was derived by employing supervised method of image classification using the maximum likelihood algorithm. The supervise classification was applied with ground truthing on preprocessed Landsat 8 ETM+ (path 167 and row 54) image of the year 2014 which was obtained from United State Geological Survey (USGS) Earth Resources Observation Systems (EROS) (Figure 8). Then the classified image was reclassified according to suitability ranges as highly suitable habitat (grassland), moderately suitable habitat (wooded grassland) and unsuitable habitat (other types of vegetation cover/land cover) (Table 3, Figure 9).

There are always errors in classification thus it is essential to evaluate the accuracy, and whether that level of accuracy is sufficient for the ways we want to use the classification (Awotwi, 2009). Thus to evaluate the representation of the classifications to the ground vegetation/land use land cover type the accuracy of the classification had been assessed.

The accuracy is essentially a measure of how many ground truth pixels were classified correctly. To perform quantitative classification accuracy assessment, it is necessary to compare two sources of information: first, the remote sensing derived classification data and second, the reference test information data obtained from field observation. The relationship between these two sets of information is summarized in cell array. The Cell array is a list of class values for the pixels in the classified image and the corresponding reference image (Leica Geosystems, 2003) where the class values for the reference are based on ground truth data and the cell array data is retrieved from the image file.

From the cell array assessment, two reports were derived: the error matrix comparing reference points to classified points, and the accuracy report. The result of an accuracy assessment provides us with an overall accuracy of the map based on an average of the accuracies for each class in the map. The error matrix is a square array of numbers laid out in rows and columns that express the number of sample units assigned to a particular category relative to the actual category as verified in the field. The columns usually represent the reference data, while the rows indicate the classification generated from the remotely sensed data.

Over all accuracy = (Total Number of pixels correctly classified)/ (Total number of pixels (cells))…………………………………………………….Equation 1

Producer's accuracy is the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data (column total). This statistics indicates the probability of a reference pixel being correctly classified and is a measure of omission error.

The other accuracy evaluation of the image classification is Kappa. Kappa were used to measure the agreement or accuracy between the remote sensing derived classification map and the reference data as indicated by the major diagonals and the chance agreement, which is indicated by the row and column totals (Jensen, 2003). It is a discrete multivariate technique that used in accuracy assessments. Kappa analysis yields a Khat statistics (an estimation of Kappa) which measures the difference between actual agreement in the error matrix (i.e., the agreement between the remotely sensed classification and the reference data), and the chance agreement between the reference data and a random classifier (Lillesand *et al.*, 2008).

The Kappa factor is given by the formula:

Kappa = $(p_0+p_e)/(1-p_e)$……………………………………Equation 2

Where: Po = is the proportion of correctly classified cases

Pe = is the proportion of correctly classified cases expected by chance.

Such formula statistic serves as an indicator of the extent to which the percentage correct values of an error matrix are due to true agreement versus the chance agreement. As the true agreement or the observed agreement approaches 1 and chance agreement approaches 0, kappa approaches 1 which is considered the ideal case. In actual classification, usually kappa ranges between 0 and 1. A Kappa of 0 indicates that a given classification is no better than random classification or assignment of pixels while if Kappa takes negative values, then it is an indication of very poor classification and had to be reconsidered.

3.3.1.3 Slope

Concerning slope the steeper the slope the more difficult for movement and grazing of the species accordingly slope range to 5^o is highly visible by plain animals for grazing (Holecheck, 1988). This is because steep slope will require more grading and earth movement than gentle slope. Grevy's zebra prefers plain land ranging less than 5 degree (Fanuel *et al*., 2012; Daniel, 1998).

Thus, slope for this study had been generated from 30 meter of ASTER DEM (Figure 10) and reclassified accordingly from plain slope (highly suitable habitat) to steeper slope (unsuitable habitat) (Table 3, Figure 11).

3.3.1.4 Settlement and Road

To escape from the disturbance caused by human and associated activities Grevy's zebra significantly avoid areas of human intervention mainly from settlement and farmland (Almaz, 2009; Daniel, 2014; Williams, 2002). Roads act as barriers for wildlife species (Andes, 1994). Generally, landscapes fragmentation and habitat loss caused by developmental activities restrict wildlife mobility. Consequentially, settlement/farmland and road effect on Grevy's zebra habitat had been analyzed and reclassified based on expertise value judgments and previous works and the distant area from these factors were classified as highly suitable habitat (Table 3, Figure 12 and 13).

The spatial data for settlement/farmland and road had been extracted and digitized from existing dataset, field survey and Google earth. As of other parameters to integrate in the GIS environment they were converted to raster format.

3.3.2.2 Water point

The movements of Grevy's zebra shape by the availability of water resources to maintain body condition and reproductive success. Therefore, Grevy's zebra keep their distance close to the permanent water point (Almaz, 2009; Fanuel *et al*., 2012; Daniel, 1998; Williams, 2002,).

The major sources of natural permanent water for wild animals and livestock in the study area are the Big Bilen (Kede Bilen) and Small Bilen (Undo Bilen) hot springs (Almaz, 2009, Fanuel *et al*., 2012), which are about 6.5 and 6.0 km (in a straight line) from the nearest side (west side) of boundary of the Allideghi wildlife reserve, respectively. Big Bile is most frequently accessed by wild animals (Almaz, 2009; Fanuel *et al*., 2012).

Therefore, the water point mostly used by Grevy's zebra and other wildlife species (Big Bilen) spatial location had been collected from field survey. Then based on expertise opinions the closer area less than 10 km inside the reserve were classified as highly suitable habitat, the area ranges between 10 km to 20 km were classified as moderately suitable habitat and the far area classified as unsuitable habitat (Table 3, Figure 14).

Generally, based on the response from the key informant interviews and review of previous studies on Grevy's zebra the factors identified as the defining parameters of Grevy's zebra suitable habitat use and distribution had been classified as highly suitable habitat, moderately suitable habitat and unsuitable habitat (Table 3).

Table 3: Classification of factors in relation to Grevy's zebra suitable habitat.

Factor	**Property considered**	**Range of suitability**		
		Highly Suitable	**Moderately suitable**	**Not suitable**
Vegetation cover	Type	Grassland	Wooded Grassland	Bus/shrub land/settlement/farmland and other
Slope	Degree	0^o-5^o	5^o-10^o	>10^o
Settlement	Proximity	>16Km	8.5 – 16Km	<8.5Km
Road	Proximity	>17Km	11 – 17Km	<11Km
Water point	Proximity	<10Km	10 – 20Km	>20Km

Note: Source from the response of expertise and previous works.

3.3.3 Determining the relative importance of suitable habitat for the suitability analysis

3.3.3.1 Analytical Hierarchy Process (AHP)

The technique described here and implemented in GIS environment using IDRISI software is Pair-wise comparisons developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). By using this comparison matrix inconsistence in decision making is minimized (Jacek, 2006).

A pairwise comparison was used to derive the weight of the factors in Grevy's zebra habitat suitability index through evaluating the relative importance of the factors obtained from the responses of expertise. Which was done by applying a scale developed by Saaty (1977) using 9-point rating scale ranging from 1 (equal importance) to 9 (strongly more important) and reciprocal values, where the middle number 1/8, 1/6, 1/4, 1/2, 2, 4, 6, and 8 are the intermediates.

Table 4: Pairwise comparison 9 point continuous rating.

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very strongly	Extremely
Less important				More important				

Source: (Saaty, 1977)

In Saaty's technique, weights of this nature derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between the criteria's. The purpose of weighting was to express the importance or preference of each factor relative to other affecting factors. Then, the factors weight in the index was calculated and it used to derive consistency ratio (CR) of the Pair-wise comparisons which determines the inconsistency in defining of the comparison among the factors. If the CR > 0.10, then some Pair-wise values needs to be reconsidered and the process is repeated till the desired value of CR reached < 0.10 (Jacek, 2006, João *et al*., 2012, Suman *et al*., 2011, Imam and G. Yohannes, 2012). The more CR is approaching to zero the comparison is more consistence.

$CR = CI/RI$ ……………………………………………………Equation 3

Where: RI is the average of the resulting consistency index depending on the order of the matrix and consistency index (CI) is defined as:

CI = $\frac{\lambda_{max} - n}{n-1}$…………………………………………………...Equation 4

Where: $\lambda_{max} - n$ is the principal Eigen value of the matrix, n is the order of the matrix (Saaty, 1977).

In this study the relative importance of the identified Grevy's zebra suitability habitat defining factors had been derived from interviewing expertise. The selected informants were from Ethiopian Wildlife Conservation Authority (EWCA) staffs who are currently involved on Allidegi wildlife reserve conservation works and those carry out study on Grevy's zebra and the reserve. Further, staffs from Allidegi wildlife reserve were also questioned.

3.3.4 Suitable habitat analysis

GIS in habitat suitability analysis improves delineation and characterization of habitat extent (G. Yohannes and Imam, 2012; Ron and Jukka, 2003; Suman *et al*., 2011,). For this matter multi criteria evaluation is a good approach and helps to address problems by relating the key habitat factors and expertise opinion. Consequentially, the GIS based multi criteria evaluation (MCE) facilitates for identifying the functional suitable habitat of Grevy's zebra suitable habitat in the study area by relating the identified key suitable habitat defining factors.

3.3.4.1 Multi-Criteria Evaluation

Multi-criteria evaluation (MCE) is most commonly achieved by one of two procedures. The first involves Boolean overlay whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as intersection (AND) and union (OR). The second is known as Weighted Linear Combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average. The result is a continuous mapping of suitability.

While these two procedures are well established in GIS, they frequently lead to different results, as they make very different statements about how criteria should be evaluated. In the case of Boolean evaluation, a very extreme form of decision making is used. If the criteria are combined with a logical AND (the intersection operator), a location must meet every criterion for it to be included in the decision set. If even a single criterion fails to be met, the location will be excluded. Such a procedure is essentially risk-averse, and selects locations based on the most cautious strategy possible location succeeds in being chosen only if its worst quality (and therefore all qualities) passes the test. On the other hand, if a logical OR (union) is used, the opposite apply, and location will be included in the decision set even if only a single criterion passes the test. This is thus a very gambling strategy, with (presumably) substantial risk involved (Ron and Jukka, 2003).

However, weight linear combination (WLC) used in this study, criteria are permitted to tradeoff their qualities. A very poor quality can be compensated for by having a number of very favorable qualities. This operator represents neither an AND nor an OR rather it lies somewhere in between these extremes. It is neither risk averse nor risk taking. As indicated earlier, the primary issue in multi-criteria evaluation is concerned with how to combine the information from several criteria to form a single index of evaluation (Jacke, 2006).

In multi-criteria evaluation weight is developed for group of factors and the weight explains the relative importance of the factors (G.Yohannes and Imam, 2012, João *et al*., 2012). The weights for the factors determining Grevy's zebra suitable habitat distribution were developed by providing a series of pairwise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. The pairwise comparisons matrix is produce set of weights for each factor that sum to **1**.

The weighted linear combination (WLC) aggregation method multiply each standardized Grevy's zebra suitable habitat factor maps (i.e., each raster cell within each map) by its factor weight derived through pairwise comparison and then sums the results. Since the set of factor weights for an evaluation must sum to one, the resulting suitability map will have the same range of values as the standardized factor maps that were used.

Habitat suitability index (HIS) was then calculated as the sum of habitat suitability factors multiplied by corresponding weights (Eastman *et al*., 1995, Suman *et al*., 2011, USFWS 1981, Wang *et al*., 2008). The weight of the factors were derived via analytical hierarchy process using IDRIS software and ArcGIS 10 software had been used to multiply the reclassified factors with their respective factors weight (coefficient) and this results suitable habitat distribution map of Grevy's zebra.

$$\mathbf{HSI} = \Sigma\,(w_i x_i) \quad \text{……………………………………………Equation 5}$$

Where: HSI is the habitat suitability index, $\mathbf{W}i$ the weight of factor i and $\mathbf{X}i$ is the rating factor of *i*.

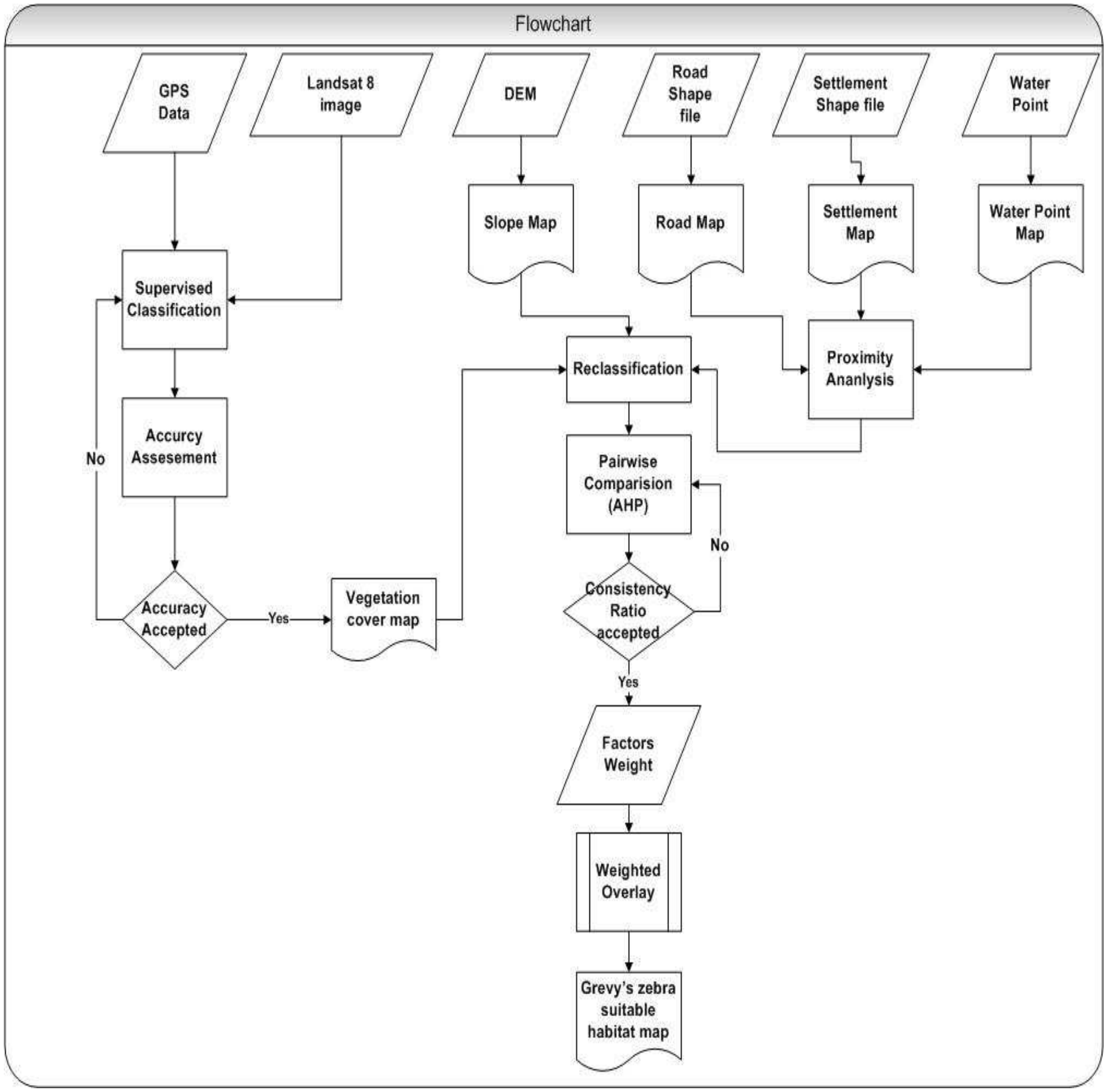

Figure 7: Methodology flowchart.

In order to technically enable habitat suitability analysis in a GIS environment, every habitat factors were converted to a raster format map layer. These map layers describe the spatial variation of each habitat factor in a certain area. The standardized score layers were weighted according to the priority function prepared for the decision situation. This was done by multiplying each map layer by its weight coefficient.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Suitability for Grevy's zebra

4.1.1.1 Vegetation cover

The major vegetation type in the reserve includes grassland, bush land, shrub land, wooded grassland, gallery/riverine forest and highland forest and settlement/ agricultural land use. Classifying the study area vegetation cover/land use land cover establishes the baseline to performed suitability analysis through reclassifying the suitability of the study area according to the availability of the grassland.

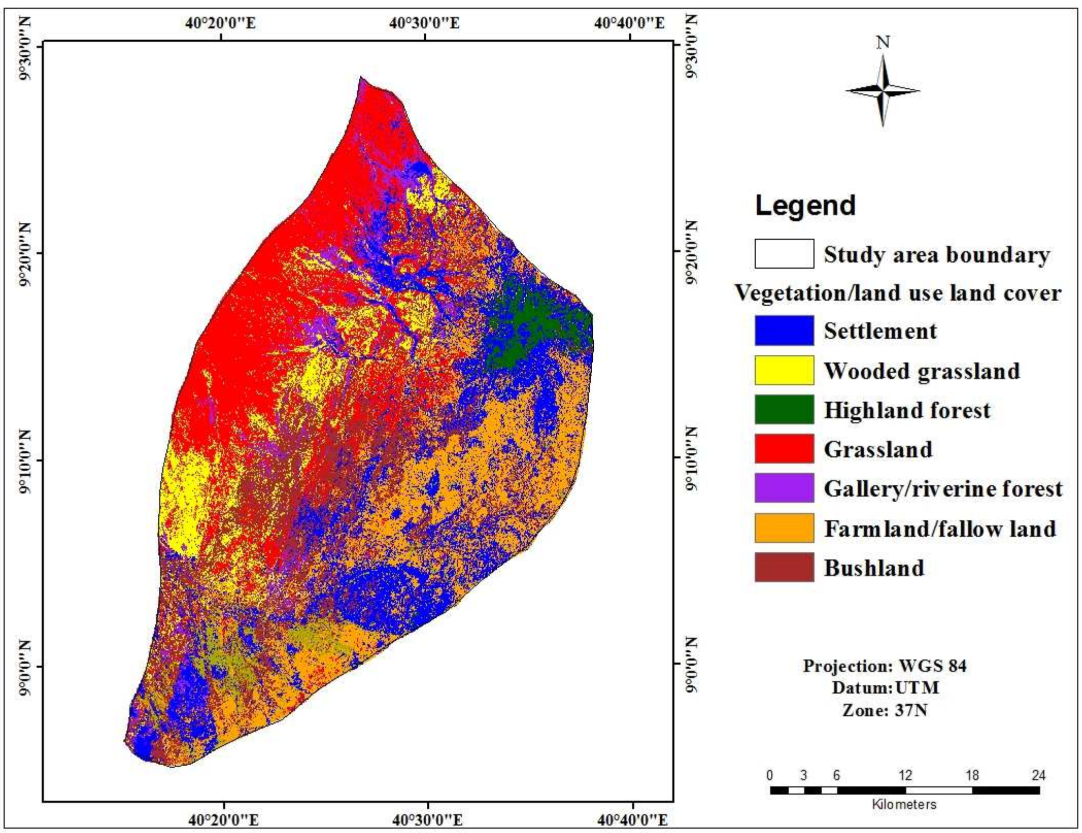

Figure 8: Vegetation cover/land use land cover map of the study area Allidegi wildlife reserve.

The overall accuracy of the supervise image classification was found to be 88.8% and the overall kappa statistics of 0.86; this indicates good results of classification to use it in the model.

Table 5: Confusion matrix for image classification

		Reference data								
	Class	GL	WL	BL/SL	RF	HF	ST	FL	Total	User accuracy (%)
CLASSIFICATION DATA	GL	**11**	1	1	0	0	0	0	13	84.6
	WL	0	**15**	1	1	1	0	0	18	83.3
	BL/SL	0	1	**9**	1	2	0	0	13	69.2
	RF	0	0	0	**11**	0	1	0	12	91.7
	HF	0	0	1	0	**12**	0	0	13	92.3
	ST	0	0	0	0	0	**33**	0	33	100
	FL	0	1	0	0	0	2	**20**	23	86.9
	Total	11	18	12	13	15	36	20	**125**	
Producer accuracy (%)		100	83.3	75	84.6	80	91.7	100		

Note: GL: grassland, WL: wooded grassland, BL/SL: bush land/shrubland, RF: riverian forest, HF: highland forest, ST: settlement, FL: farmland/fallowland

Table 6 : Vegetation cover/land use land cover of the study area Allidegi wildlife reserve.

Vegetation cover/land use land cover	**Area coverage in (Km^2)**
Grassland	367
Wooded grassland	135
Gallery/river forest	70
Settlement/road/bare land	354
Bush land/shrub land	239
Farm land/ fallow land	273
Highland forest	33
Total	**1460**

Different studies showed that Grevy's zebra highly prefers grassland area. Therefore, the vegetation cover/land use land cover of the study area was ranked according to the availability of grasslands. Accordingly, grasslands were classified as highly suitable habitat and wooded grassland area as moderately suitable habitat. While bare lands, settlement, farmland/fallow land, highland forest and gallery /riverine forest were classified as unsuitable habitat (Figure 9).

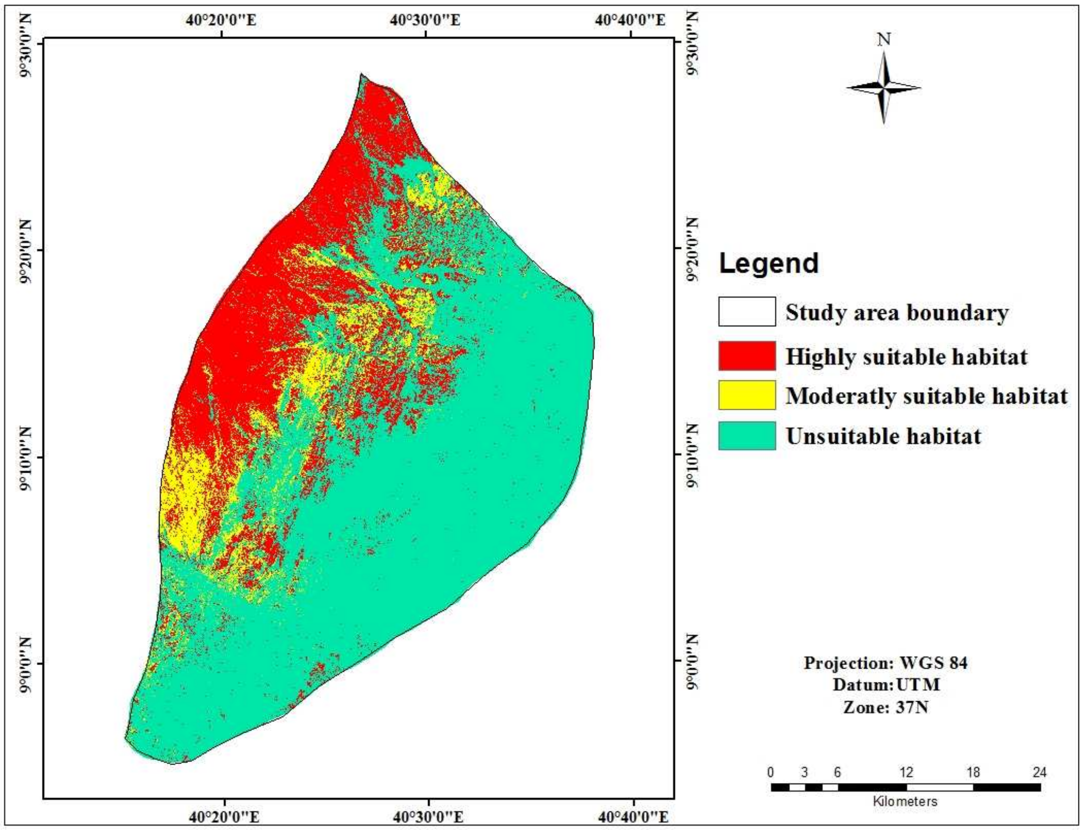

Figure 9: Reclassified vegetation cover map of the study area Allidegi wildlife reserve.

Out of the reserve total area 367 km^2 area of grassland found to be highly suitable habitat and 135 km^2 area of land covered by wooded grassland classified as moderately suitable habitat. However, the large extent of the reserve area covering 958 km^2 found to be unsuitable to Grevy's zebra.

4.1.1.2 Slope

The steeper slope is difficult for movement of species. Holecheck, (1988) justified that the inverse relation of steep slope with grazing capacity of wild animals. This is because steep slope will require more grading than gentle slope. The slope of the study area (Figure 10) derived from 30 meter ASTER DEM reviled that the slope of the study area ranges to 65^o.

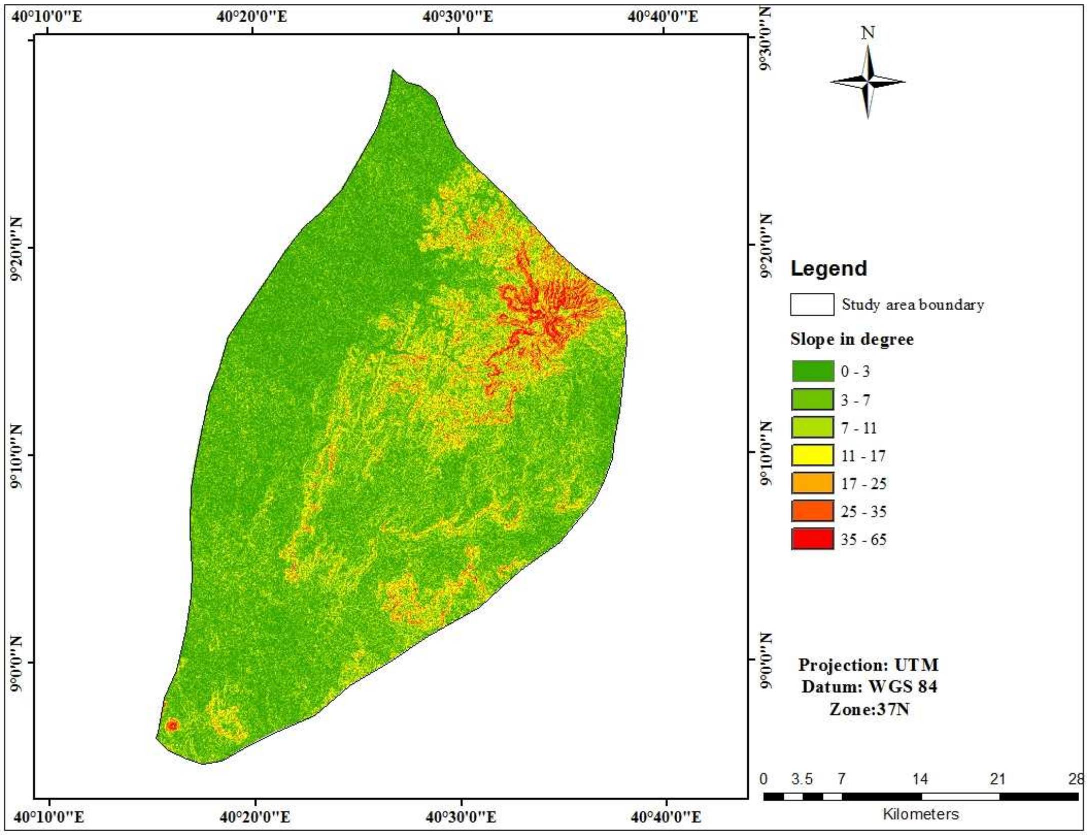

Figure 10: Slope map of the study area Allidegi wildlife reserve in degree.

Previous researches by Bauer (1994) Grooves (1974) outlined that Grevy's zebra mostly observed in plain areas with range of less than 10^{o} but they highly prefer plain area with less than 5^{o}.Therefore, plain area ranges between 0 and 5 degrees were classified as highly suitable habitat where slope ranges between 5 and 10 degrees classified as moderately suitable habitat (Figure 10).

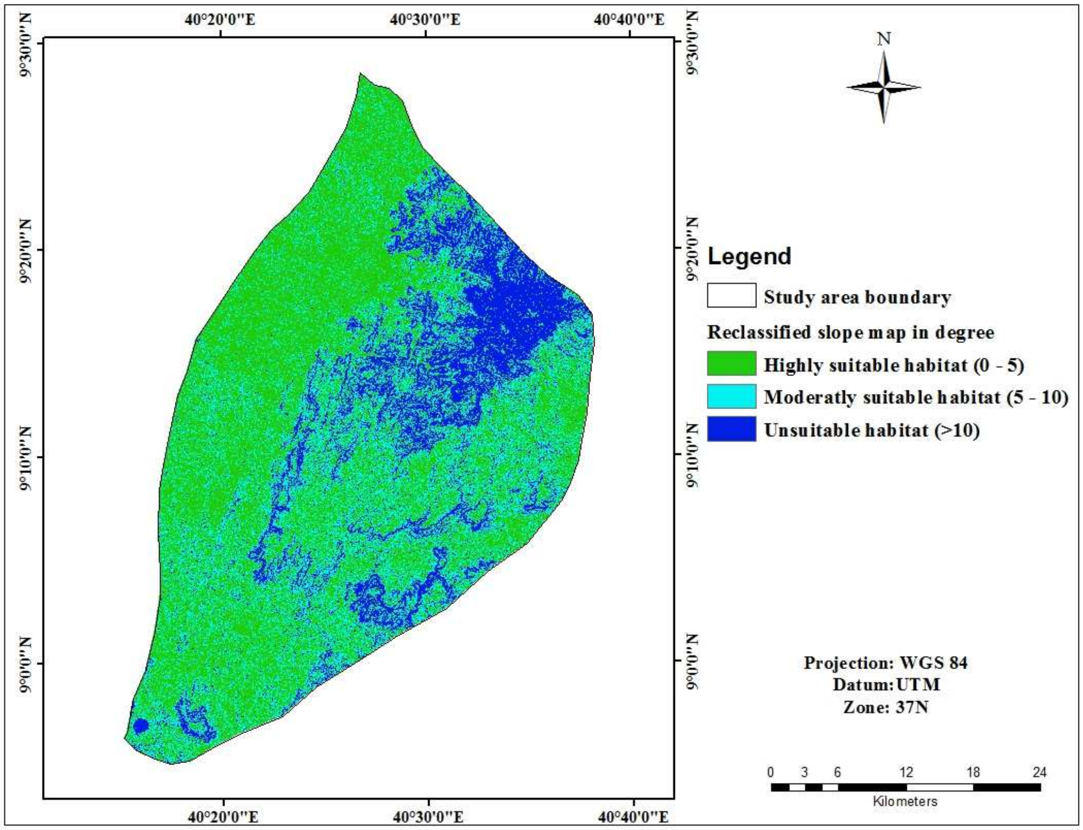

Figure 11: Reclassified slope map of the study area Allidegi wildlife reserve in degree.

Out of the total area of Allidegi wildlife reserve 757km^2 (52%) of land ranges between 0^o-5^o slope classified as highly suitable habitat while the rest 435 km^2 and 268 km^2 area of land ranges between 5^o-10^o and greater than 10^o considered as moderately suitable and unsuitable habitat, respectively.

4.1.1.3 Distance from settlement/farmland

Settlement and agricultural activities affects space use of Grevy's zebra. Therefore, Grevy's zebra avoid locations close to such areas due to disturbance and competition for resources. From the response of the expertise value judgments distant area greater than 16 km from settlement classified as highly suitable habitat, while are ranges from 8.5 km to 16 km and less than 8.5 km from settlement/farmland were classified as moderately suitable and unsuitable habitat, respectively.

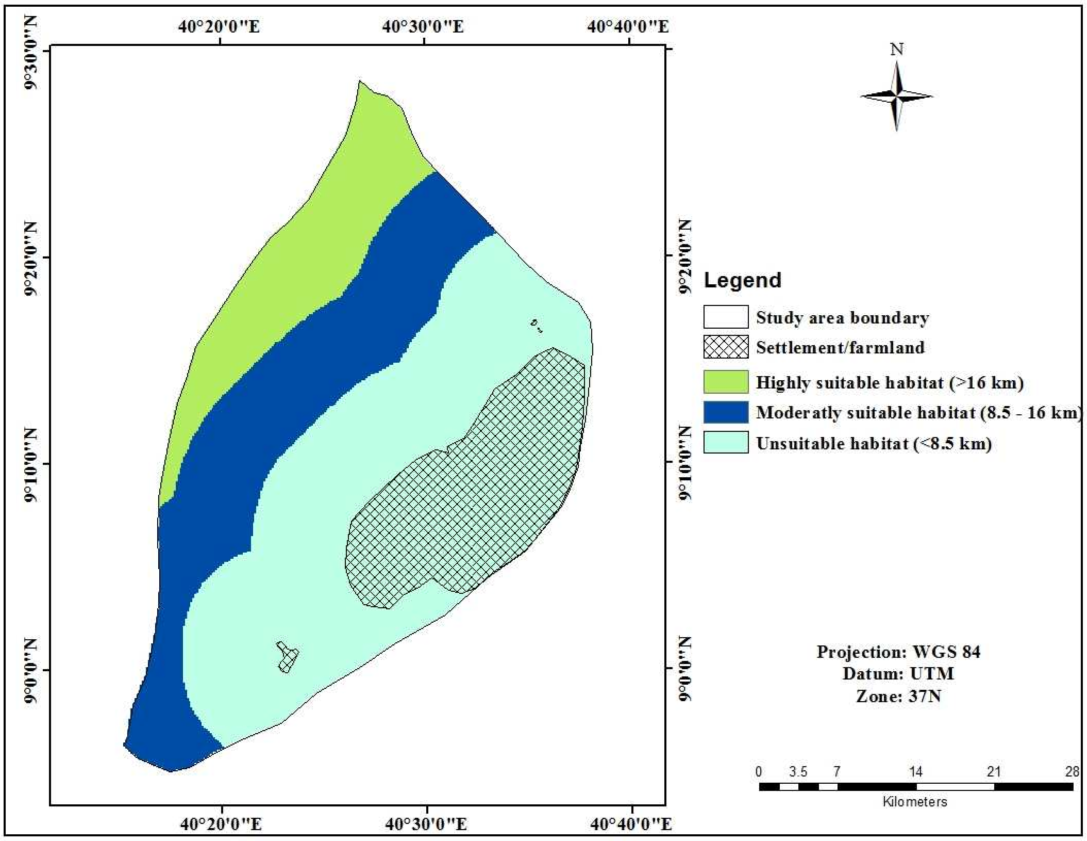

Figure 12: Reclassified settlement map of the study area in kilometer.

Out of the total area coverage of the study area 230 km^2 found to be highly suitable habitat for Grevy's zebra and the rest 396 km^2 and 834 km^2 areas founds to be moderately suitable and unsuitable habitat, respectively.

4.1.1.4 Road

Roads act as a barrier for wildlife movement and causes habitat fragmentation. Grevy's zebra avoids permanently using areas near to the road. Therefore, according to the expertise opinion the area closer to the major road crossing the reserve in the east side less than 11 km classified as unsuitable habitat, and the area located 11 to 17 km far from the road had been classified as moderately suitable habitat and the area located greater than 17 km from the road classified as highly suitable habitat.

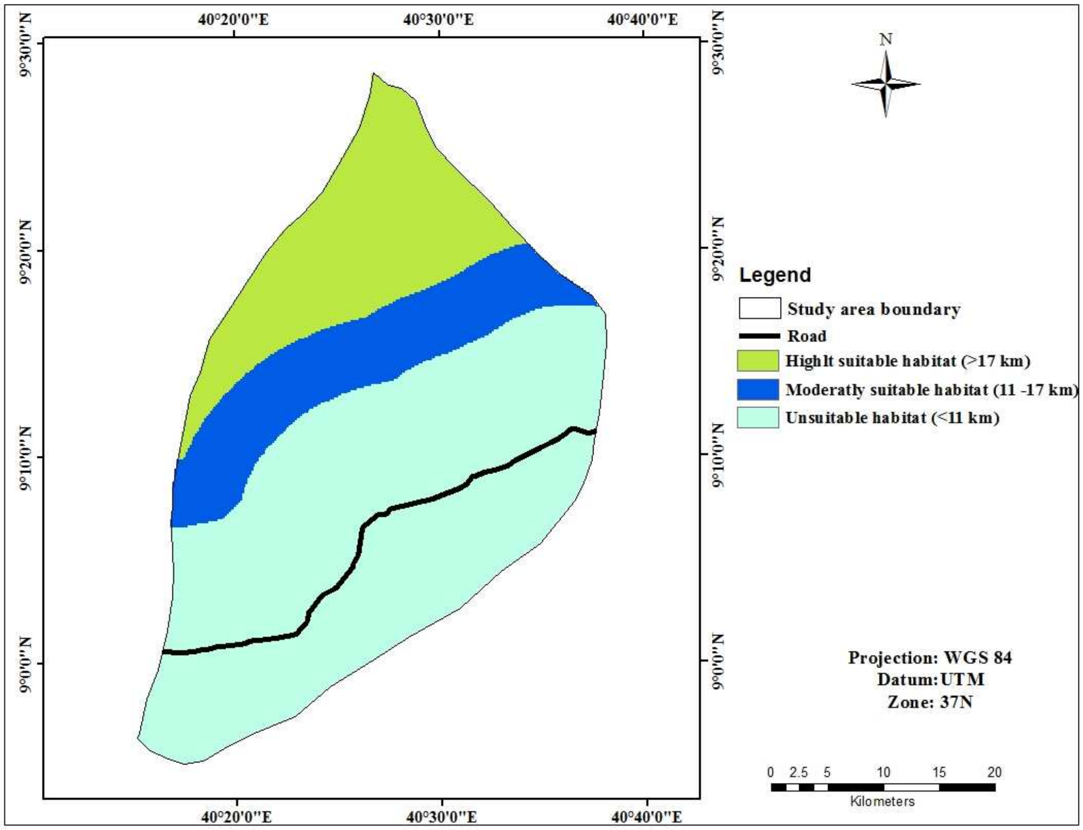

Figure 13: Reclassified road map of the study area in kilometer.

Accordingly the reclassification result showed that 250 km^2 of area found to be highly suitable habitat for Grevy's zebra and the rest 882 km^2 and 328 Km^2 of area of land founds to be unsuitable and moderately suitable habitat, respectively.

4.1.1.5 Water point

Grevy's zebra drinks at least once in a day (Daniel, 1989). Therefore, they always choose areas closer to the water point. The water point used by Grevy's zebra (Kede Bilen) located outside of the reserve boundary. Therefore, the vicinity area of the reserve less than 10 kilometers to the water point (Kede Bilen) was classified as suitable habitat.

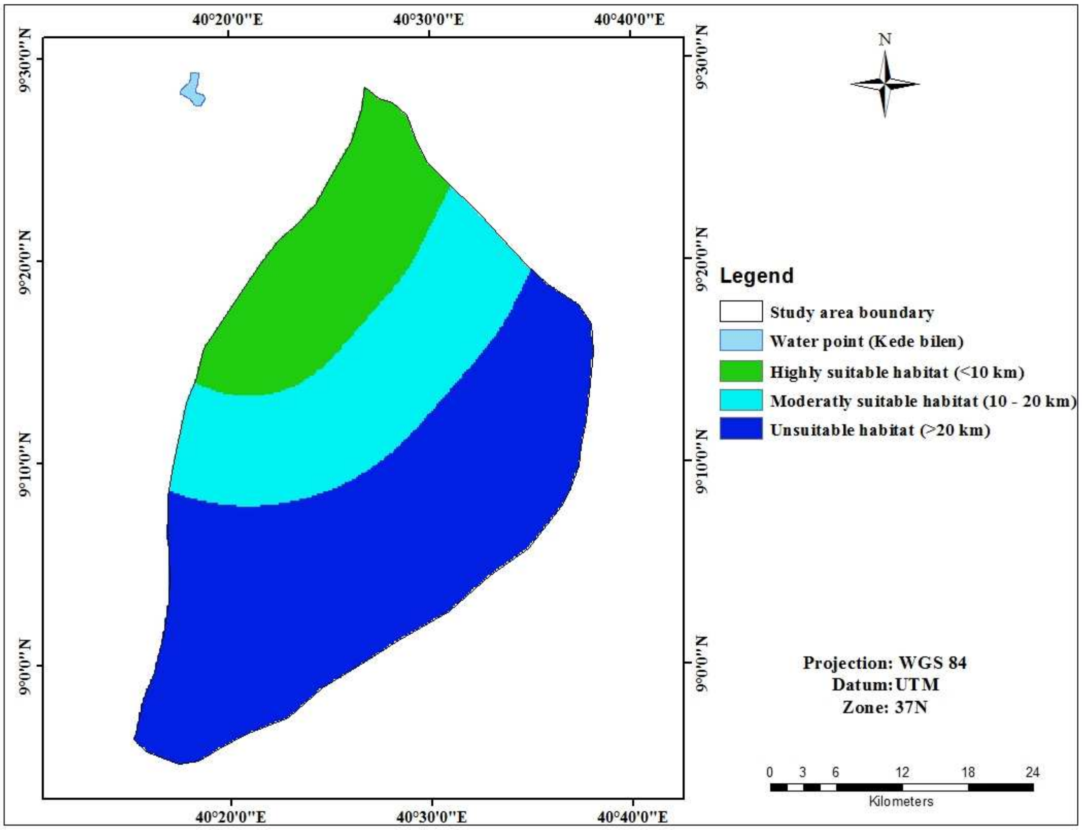

Figure 14: Reclassified water point map in kilometer.

The classification showed that around 290 km^2 area of the reserve near to the water point Big Bilen (Kede Bilen) found to be highly suitable habitat and 380 km^2 and 790 m^2 area of land found to be moderately suitable and unsuitable habitat.

4.1.2 Relative importance and weight of habitat controlling parameters

To evaluate suitable habitat of Grevy's zebra in MCE set of weights for each of the factors had been established. A matrix is constructed, where each factor was compared with the other factors relative importance (Table 4) and the weight to each factors derived. The relative influence to each factors were assigned from one to seven based on expert opinions and value judgment (Table 6). Thus based on the response of expertise high numeric value had been given to grassland and low to road and settlement. Fanuel *et al*., (2012) also justified that Grevy's zebra had significantly avoid closer area from settlement and farmlands and the highly significance preference of closer area to water point.

Table 7: The relative importance of factor layers in AHP.

Layer	Vegetation cover	Water	Slope	Settlement	Road
Vegetation cover	**1**	__	__	__	__
Water	1/2	**1**	__	__	__
Slope	1/3	1/2	**1**	__	__
Settlement	1/7	1/4	1/3	**1**	__
Road	1/7	1/5	1/5	1/2	**1**

Note: Source from the responses of expertise value judgments.

Table 8: Calculating Principal Eigen vector of the factors compared in the matrix (AHP).

Factors	Vegetation cover	Proximity to water point	Slope	Proximity to settlement	Proximity to road	**Priority vector**
Vegetation cover	0.47	0.50	0.46	0.45	0.35	0.4501
Proximity to water point	0.24	0.25	0.30	0.26	0.25	0.2622
Slope	0.16	0.13	0.15	0.19	0.25	0.1742
Proximity to settlement	0.07	0.06	0.05	0.06	0.10	0.0681
Proximity to road	0.07	0.05	0.03	0.03	0.05	0.0454
					Sum	**1**

Note: Principal Eigen vector obtained by averaging of normalized relative weight across the rows.

From analytical hierarchy process (AHP) consistency ratio (CR) of 0.02 was achieved. This shows a good consistence in comparison of each factors relative importance. Thus, the achieved consistency ratio was acceptable for weighting the suitable habitat controlling parameters and developing Grevy's zebra habitat suitability index.

From the analytical hierarchy process (AHP) (Table 7 and 8) the most important factor in Grevy's zebra suitable habitat index found to be grassland with the weight of 45% (Table 9). Whereas settlement and road act as limiting factors for this reason Grevy's zebra significantly avoids the proximate area to the settlement and road for this matter they been assigned with low relative importance by the expertise. Consequentially, their influence in the index found to be lower (Table 9).

The weight of Grevy's zebra habitat factors that had been derived through calculating Eigen vector of the factors relative importance that filled out in the pairwise comparison matrix (AHP) **(**Table 7). Accordingly, the respective weight of each habitat factors had been obtained (Table 9).

Table 9: Weight of Grevy's zebra suitable habitat controlling parameters derived from Analytical hierarchy process.

Factors	**Weight**
Vegetation cover	0.4501
Proximity to water	0.2622
Slope	0.1742
Proximity to settlement	0.0681
Proximity to road	0.0454
Total	**1.00**

4.1.3 Multi-Criteria Evaluation and Grevy's zebra habitat suitability

Multi-criteria evaluation can be achieved through either Boolean overlay operations or weighted linear combination. In Boolean overlay operations, all criteria are reduced to logical statements of suitability and then combined by means of weighted average. However, in weighted linear combination this study applies continuous criteria (factors) are standardized to a common numeric range (reclassified), and then combined by means of a weighted average which was derived through AHP.

Habitat Suitability Index = *0.4501 *(Reclassified Vegetation cover map) + 0.2622*(Reclassified water proximity map) + 0.1742 *(Reclassified Slope map) + 0.0681*(Reclassified settlement proximity map) + 0.0454 *(Reclassified road proximity map)*

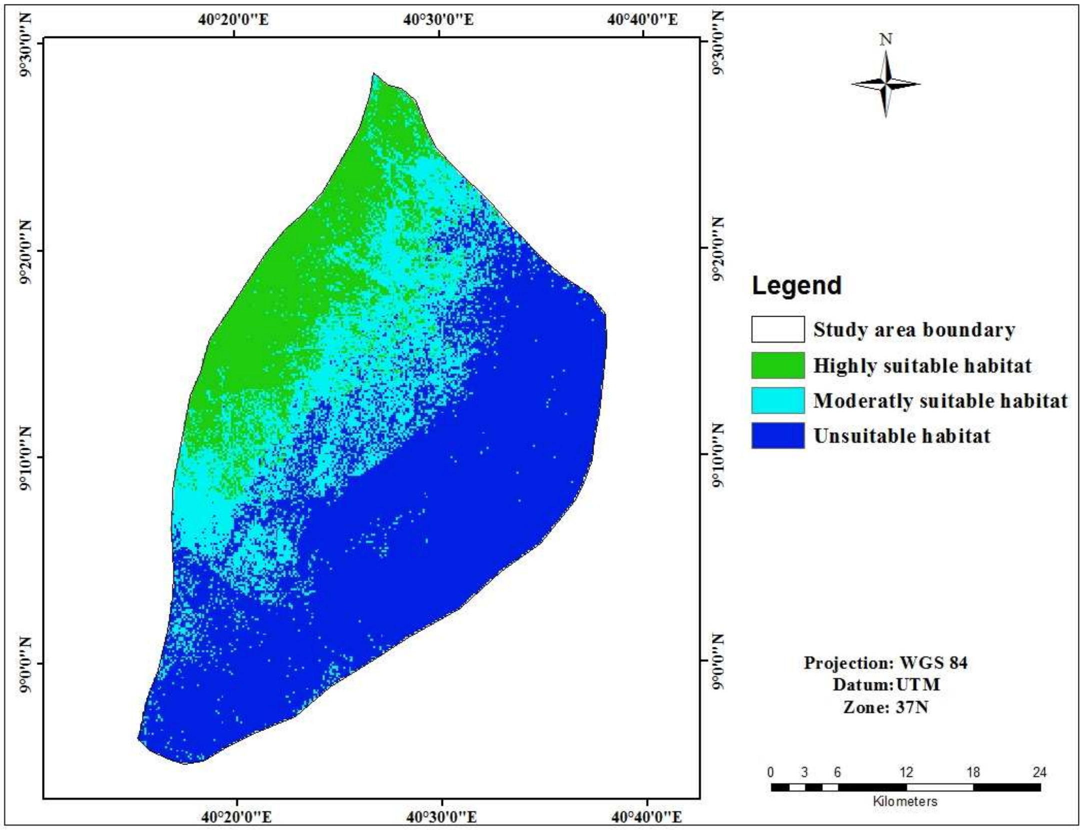

Figure 15: Suitable habitat map of Grevy's zebra in the study area Allidegi wildlife reserve.

The result showed that 272 km^2 (19 %) area of land are highly suitable habitat for Grevy's zebra; and 368 km^2 and 820 km^2 area of land found to be moderately suitable and unsuitable habitat, respectively. This implies that much of the reserve areas are not suitable for Grevy's zebra. The suitable habitats are located in the west side of the reserve where the grassland founds in abundant and closure to water and far-flung area from settlement/agriculture and road. And also from the analysis of individual suitable habitat controlling parameters the west side of the reserve is also classified as suitable habitat. However, due to disturbances the area classified as suitable habitat located in the north east did not used by the species.

Table 10: Area coverage of Grevy's zebra habitat classification in Allidegi wildlife reserve.

Habitat suitability range	Area in (km^2)	Area in (%)
Highly suitable	272	19
Moderately suitable	368	25
Unsuitable	820	56
Total	1460	100

The habitat classification of this study corresponds with the observed occurrence of Grevy's zebra presence that had been collected from two sample plots in February 2014 using GPS to record the spatial location and laser range finder to estimate the distance of Grevy's zebra from the standing point. The collected data of Grevy's zebra presence data reviled that the species mostly located in the area classified as highly suitable habitat. Meanwhile, the presence of the species had been also observed in moderately suitable habitat (Figure 17).

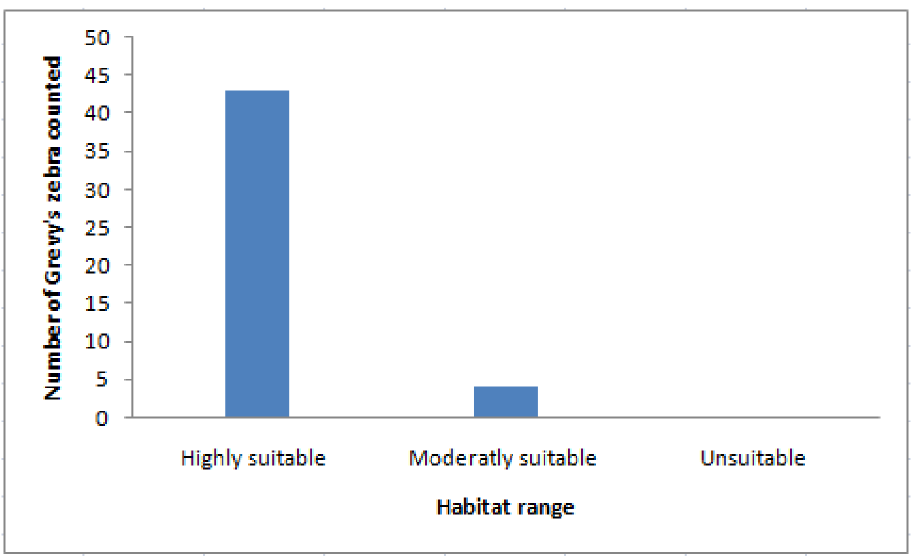

Figure 16: Number of Grevy's zebra counted from sample plots in the study area Allidegi wildlife reserve.

Deductive and inductive approaches can be utilized for wildlife suitable habitat analysis, depending on objectives and data availability. The deductive approach such as MCE extrapolates known habitat requirements to the spatial distributions of habitat factors. If more than one spatial data layers are involved, they are usually combined by either logical or arithmetic map overlay operations. A habitat suitability index can also be calculated from the spatial configuration of a single data layer. The GIS output of the deductive approach is a map depicting levels of habitat suitability range and land matrix. This map can guide decisions regarding land acquisition or habitat preservation priorities, land management practices, or sites for reintroduction of endangered species. Though, it should be noted that the model only identifies "potential" habitat, but does not imply that the species is actually present at all given location identified as suitable habitat. But the results can be extrapolated to predict the spatial distribution of suitable habitat for better and effective habitat management.

4.2. Discussion

Suitable habitat analysis involves integration of the major influential habitat defining factors and establishing of their influences. The factors identification and analysis would be done based on previous works, existing data and expert opinions (G. Yohannes and Imam 2012; Ron and Jukka 2003; Ron and Jyrki 2001; Suman *et al*. 2011). Almaz (2009), Fanuel *et al*., (2012), Daniel (1989), Daniel (2014), EWCA (2013), Ginsberg (1990), Grooves (1974) had been outlined the influence of grassland, distance to water point, proximity to settlement, plain area and road on Grevy's zebra habitat selection and use. Consequentially, the factors identified by this study for Grevy's zebra suitable habitat analysis in Allidegi wildlife reserve were vegetation cover (grassland), water point, slope, proximity to road and settlement/farmland.

Bauer *et al*., (1994), Daniel (1989) Ellen and Thomas (2013), Ginsberg 1974), Daniel (2014), Grooves (1994), Rowen (1992) had conducted a comprehensive review of known habitat preferences of the large and medium sized mammals of Africa including Grevy's zebra, in order to model species distribution in relation to several environmental factors. They have included distance from water as a variable useful in identifying suitable habitats, distinguishing between three main categories: species occurring near water, species occurring in riverine or gallery forests, and water dependent species and they explicitly explores the higher occurrence of wildlife species closer to the water sources.

Grevy's zebra requires the presence of standing water and regular access to drinking water (Bauer *et al*., 1994; Daniel, 1989; Daniel, 2014; Rowen, 1992; Sundaresan, *et al*. 2007a; Williams, 2002). The water point for wildlife in Allidegi wildlife reserve is Big Bilen (Kede Bilen) (Almaz, 2009; Fanuel et al., 2012); consequentially, Grevy's zebra prefers the closer distance to the water point as well as quality and quantity of forage.

Wildlife prefers gentler terrain in a case where mixture of gentle and steep terrain exists typically congregate on the preferring slopes of 10 percent or less (Holecheck, 1988). Fanuel *et al*., (2012) had discussed the direct relation of grazing capacity of Grevy's zebra with plain area in the reserve. For this reason Grevy's zebra mostly seen on plain area with slope of less than 5 degree. Meanwhile, as slope and horizontal distance to water increase, grazing use often decreases Holecheck, 1988). In gentler topography, horizontal distance to water has stronger influence on grazing capacity than vertical distance to water.

Grevy's zebra highly prefer open grassland areas (Almaz, 2009; Fanuel, 2012; Daniel, 1989; Daniel, 2014; Low *et al*., 2008). Bauer *et al*., (1994), Daniel (2014), Grooves (1974), Guy *et al*., (2010), Low *et al*., (2009) claims being in open grassland helps Grevy's zebra to detect predators. However, grassland areas in Allidegi wildlife reserve are diminishing from an intensively expansion of invaded tree species *Prosopis Juliflor,* (Almaz, 2009) and no longer provide high-value herbaceous forages in the understory and this is reducing the suitable habitat of Grevy's zebra by changing grassland areas to shrub/bush lands. According to Almaz (2009) the grazing potential of grassland areas were decreased by 16% over the past 10 years as more and more livestock were using it extensively and the consequences of *Prosopis Juliflora* encroachments.

The habitat losses of Grevy's zebra are mainly from human-induced factors such as grazing, expansion of settlements, encroachment by invasive species, and poaching (Moehlman 2002). Expansions of settlement/farmland in wildlife reserves are significantly affecting Grevy's zebra distribution and habitat use and this had been justified by Almaz (2009), Fanuel *et al*., (2012). Increasing of settlement and other developmental activities such as ground water exploration had also staggering effect on suitable habitat use of Grevy's zebra in Allidegi wildlife reserve (Almaz, 2012, EWCA, 2014). In less than four decades more than 30 permanent settlements had been established in the reserve mainly to the west side of the reserve (Almaz, 2009). In the mean time frequently erupting conflict between Afar and Somalia pastoralists for grazing area had been also avoid the species from using of the available suitable habitat; especially in north western part of the reserve (Almaz, 2009; Fanuel *et al*., 2012). In general, human presence has affecting Grevy's zebra habitat use in Allidegi wildlife reserve. Andrén (1994) claims that human activities such as agricultural development, ground water exploration, grazing and urbanization have led to habitat fragmentation, namely loss of the original habitat, reduction in habitat patch size and increasing isolation of habitat patches.

According to the final analysis, the western parts of the study area Allidegi wildlife reserve are highly suitable and central parts of the reserve are moderately suitable habitat for Grevy's zebra. However, due to disturbances caused by human activities, farming and presence of road most part of the eastern area of the reserve are unsuitable (Figure 15). This study found out that the highly suitable and moderately suitable habitat of Grevy's zebra in Allidegi wildlife reserve found to be 272 km^2 (19 %) and 368 km^2 (25 %), respectively. However, the larger areas of the reserve covering around 820 km^2 (56 %) are unsuitable habitat for Grevy's zebra. Fanuel *et al*., (2012) prediction Grevy's zebra suitable and optimum habitat by applying maxent modeling using the presence data of Grevy's zebra observed within two years between and states the suitable and optimum habitat of Grevy's zebra between 273 km^2 to 306 km^2 and 164 km^2 to 257 km^2, in dry and wet season, respectively and also the location of the suitable habitat corresponds with this study Grevy's zebra habitat classification. However, the effect of road in habitat fragmentation did not involve in their prediction and this possibly discriminate the effect of road on habitat fragmentation. Further, unlike to 90 meter pixel resolution used by Fanuel *et al*. (2012) this study uses 30 meter pixel size of image and DEM data used in the analysis enhances the output of the study. But, still increasing of settlement and competition livestock for resource is limiting the species distribution in using of the available suitable habitat (Almaz, 2009; Fanuel *et al*., 2012, EWCA, 2013).

The results obtained from the land suitability analysis for Grevy's zebra correspond with the realities of the study area. The results of this investigation were also adequate in terms of the evaluation criteria set used here. Thus, the final suitability map represents a more realistic outcome, given that it takes into account the land characteristics instead of land qualities to evaluate land suitability, because land quality information was not available for the study area.

Generally, the application of remote sensing and GIS based MCE in wildlife suitable habitat study provides spatial data and permits evaluating the spatial variations of landscape matrix for suitable habitat analysis which is essential for wildlife management. The results obtained from this types of habitat study serve as a basis for determining an improved habitat relationships and better action plan (Imam and G. Yohannes , 2012; Ron and Jukka, 2003; Suman *et al*., 2011; João *et al*., 2012).

The suitable habitat distribution of Grevy's zebra in Allidegi wildlife reserve illustrates that the potential extent of the species suitable habitat regardless of seasonal changes and this exemplifies the means for crafting better conservation plan and is dole out an input for the newly proposed boundary extent of the reserve.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study addresses the suitable habitat distribution of Grevy's zebra in Allidegi wildlife reserve covering an area of 1,832 km^2. The modeling approach used by this study applies GIS based MCE and remote sensing to develop Grevy's zebra habitat suitability index, and assists to identify the available suitable habitat by producing thematic suitable habitat map.

For Grevy's zebra suitable habitat analysis five factors namely vegetation cover, slope, water point, settlement/farmland and road were identified and analyzed by employing expertise opinion and all factors had been reclassified at different suitability ranges (Table 3). This study of Grevy's zebra suitable habitat analysis target was undertaken to decrease anthropogenic impacts. Thus more emphasis had been given to areas at safe distance from settlements/farmlands and road; hence distance more than 16 km buffer radius from settlement/farmland and 17 km buffer radius from road were classified as highly suitable habitat of Grevy's zebra. The closer area to the permanent water sources with distance of 10 km or less buffer inside the reserve were also classified as highly suitable habitat. Regarding vegetation cover grassland area were identified as highly suitable habitat for Grevy's zebra. Plain areas with less than 5^o slope were also classified as suitable habitat.

The relative influence of the factors derived using pairwise comparison (AHP) for suitability analysis and the weight of the factors selected out of one reviled that grassland areas have higher influence with the weight of 0.4501 and slope, proximity to water, and distant area from settlement/farmland and road factor maps have the weight of 0.1741, 0.2622, 0.0681, and 0.0454, respectively. This justifies that grassland areas have higher importance in Grevy's zebra suitable habitat index.

The results of the suitability analysis demonstrated that the area in the west side of the reserve had been categorized as highly suitable habitat for Grevy's zebra. The final out put also indicated that out of the total area 272 km^2 (19%) and 368 km^2 (23%) of land found to be highly suitable and moderately suitable habitat, respectively. However, almost all parts of the eastern side of the reserve are unsuitable habitat for Grevy's zebra. This is basically related with the presence of settlement/farmland and road.

Generally, predicting the available suitable habitat distribution and status of wildlife perceived to be essential for better conservation and management. For this matter GIS and remote sensing helps to gain a deeper understanding of the problems and bring more precise information. GIS based MCE modeling approach provides a means to consider habitat factors on different scales (influence) and type (highly suitable, moderately suitable and unsuitable). Additionally, it enables to integrate empirical models and the knowledge of experts in the preparation of the variables needed for the evaluation process on several scales and several ways especially the variables describing composition (e.g. quantifies of different habitat types) and configuration (e.g. edge length) of the spatial structure.

This study provides strategies for better conservation and management for wildlife, especially for suitable habitat site analyses and habitat evaluation. The research findings also suggest that plain area in the west side of the reserve has great potential to be categorized under an ideal habitat of Grevy's zebra. If the reserve is properly managed and maintained by implementing effective conservation and management strategies it can support more number of the Grevy's zebra than currently estimated of less than 200 individuals. However, human activities are affecting space use of Grevy's zebra and continuously Grevy's zebra are avoiding locations close to active livestock corrals, or bomas. Invasion species *Prosopis Juliflora* is also aggravating the current trend of Grevy's zebra suitable habitat diminishing. As more areas are encroached with *P. juliflora* Grevy's zebra are forced to graze in increasingly limited areas and less suitable habitats.

5.2 Recommendations

This research on Grevy's zebra suitable habitat distribution analysis would initiate for the application of GIS and remote sensing for further wildlife suitable habitat studies. In the light of the findings obtained and conclusions reached the following recommendations were forwarded for direct application and future works.

- To enhance the conservation practices of the reserve future research should assess other wildlife species suitable habitat in Allidegi wildlife reserve.
- The present effort of applying GIS based MCE and remote sensing for Grevy's zebra suitable habitat analysis provides an insight in identifies the habitat parameters influence and their respective weight in the habitat index. Therefore, prioritizing the influential factor in decision making would leads to good result of habitat conservation. In the mean time a measure should be taken to reduce the effect of settlement and farmland on suitable habitat distribution of Grevy's zebra.
- Despite the fact that the selected factors explain Grevy's zebra suitable habitat distributions they are not the only one. Therefore, further research by involving the impact of livestock and ground water would improve in understanding Grevy's zebra suitable habitat use.
- Using of this study finding for conservation of the available suitable habitat and in the designing process of the new boundary of the reserve would help to improve decision making and planning process.

REFERENCES

Alan, R. (1997). *Wildlife conservation society wildlife field research and training manual*. Paul-Art Press Inc., New York, USA.

Almaz Tadesse (2009*).* Sustaining the Allideghi Grassland of Ethiopia: Influence of Pastoralism and Vegetation Change. PhD Dissertations, Utah State University, Logan, UT.

Andrén, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos.* **71**:355-366.

Antoine, G. and Zimmermann, N. E. (2000). Predictive habitat distribution models in ecology. *Ecological Modelling.* **135:** 147–186.

Asfaq, A. Z., Asad R., Singh, A. and Kushawaha, (2008). Habitat suitability assessment for the endangerd Nilgiri Lanughingthrush: A multiple Logistic regression approach. *Current science*. **94:** 1487-1494.

Awotwi, A. (2009). Detection of Land Use and Land Cover Change in Accra, Ghana, between 1985 and 2003 using Land sat Imagery. Masters of Science Thesis in Geoinformatics. Division of Geoinformatics. Royal Institute of Technology (KTH) Stockholm, Sweden.

Barnard, P. and Thuiller, W. (2008). Global change and biodiversity: future challenges. *Biological Letter*. **4**: 553-555.

Bauer, I.E., McMorrow, J. and Yalden, D.W., (1994). The Historic ranges of three equid species in northeast Africa: a quantitative comparison of environmental tolerances. *Journal of Biogeography*, **21:** 169-182.

Chambers, R. (2006). Participatory Mapping and Geographic Information System: Whose map? Who is Empowered and Who Disempowered? Who Gains and Who Loses? *EJISD* **25:** 1-10.

Daniel, G., Timothy, G. and Ulrike, Z. (2006). GIS-based modeling of spawning habitat suitability for walleye in the Sandusky River, Ohio, and implications for dam removal and river restoration. *Ecological engineering*. **2 8**: 311–323.

Daniel, I. R. (1989). Life history and social organization in arid adapted ungulates. *Journal of Arid Environment*: **17:** 145-156.

Daniel, L. (2014). Participatory spatial planning for reconciling human activities and conservation of Grevy's Zebra (Equus grevyi) in Northern Kenya. A Case Study of Meibae Community Conservancy, Samburu. *Merit Research Journal*, **2(5):** 092-103.

Douglas, E., and Sanga-Ngoie, K. (2004). Simulating the East African wildebeest migration patterns using GIS and remote sensing. *Afr. J. Ecol*. **42**: 355–362.

Eastman, J.R., Jin, W., Kyem, P.A.K. and Toledano, J. (1995). Participatroy multiple objective decision making in GIS. *Photogrammetric Engineering and Remote and Sensing*. **61:** 539–547.

Ellen, S. and Thomas, M. K. (2013). Historical distribution, habitat requirements and feeding ecology of the genus *Equus* (Perissodactyla). *Mammal Review*. **43:** 111–123.

Ethiopia Wildlife Conservation Authority (EWCA), (2013). In: Alledeghi wildlife reserve redemarcation and conservation upgrade report. (Arega Mekonnen and Kassaye Wami) EWCA, Addis Ababa, Ethiopia.

Fanuel Kebede, Afework Bekele., Moehlman, P. D., Paule H. E. (2012). Endangered Grevy's zebra in the Alledeghi Wildlife Reserve, Ethiopia: species distribution modeling for the determination of optimum habitat. *Endangered Species Res.***17:** 237-244.

Ginsberg, J.R. & Daniel, I. R. (1990) Sperm competition and variation in zebra mating-behavior. *Behav. Ecol. Sociobiol*. **26**, 427–434.

Grooves, C.P. (1974). Horses, asses and zebras in the wild. David and Charles, Newtton Abbott and London.

Guy, P., Sundaresan, S., Geoffrey, C. and Tim O'Brien. (2010). Using sample aerial surveys to estimate the abundance of the endangered Grevy's zebra in northern Kenya. *Afr. J. Ecol*. **49:** 56–61.

Hassan, A., Rashid, S., Faisal, M., Qamer, W., Ahmed, K., Sawaid, A., Kavinda, G., Manzul, H., Muhammad, S. and Muhammad, A. (2010). Habitat evaluation of smooth-coated otter (*lutrogale perspicillata*) in Indus plains of Pakistan using remote sensing and GIS. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science*. **38(8):** 127-132.

Holecheck, .J.L. (1988). An Approach for setting the stocking rate. *Rangelands.* **10:**10-14

Imam, E., Hussain, T. and Mary, T. (2012). Modelling of Habitat Suitability Index for Muntjac (*Muntiacus muntjak)* Using Remote Sensing, GIS and Multiple Logistic Regression. *Journal of Settlements and Spatial Planning.* **3 (2):** 93-102.

Imam, E. and G. Yohannes Tesfamichael (2012). Use of Remote Sensing, GIS and Analytical Hierarchy Process (AHP) in Wildlife Habitat Suitability Analysis. *J. Mater. Environ. Sci.* **4 (3):** 460-467.

Institution of Biodiversity Conservation (IBC) (2009). National Biodiversity Strategy and Action Plan. IBC, Addis Ababa, Ethiopia.

Jacek, M. (2006). GIS-based multicriteria decision analysis: a survey of the literature. *International Journal of Geographical Information Science.* **20(7):** 703–726.

Jane, E. and John, R. L. (2009). Species Distribution Models:Ecological Explanation and Prediction Across Space and Time. The *Annual Review of Ecology, Evolution, and Systematics.* **40:** 677–697.

Jensen, J. R. (2003). Introductory Digital Image Processing, a Remote Sensing Perspective.3rd edition, pp 505–508.

João, C., Luciano, M., José, P., Silva, J., Santos, R., Torres and Carlos, F. (2012). Habitat suitability model for red deer (*Cervus elaphus* Linnaeus): spatial multi-criteria analysis with GIS application. *Galemys.* **24 :** 47-56.

John, B. (1968). The wildlife of Ethiopia. *The International Journal of Conservation Oryx*. **9 (4):** *276-285.*

Josk, M., Pereira, C. and Robert, M. I. (1991) GIS-Based Habitat Modeling Using Logistic Multiple Regression: A Study of the Mt. Graham Red Squirrel. Photogrammeetnrgiince ering& remotes ensing. **57:** 1475-1486.

Kenya Wildlife Service (2008). Conservation and management strategy for Grevy's zebra (*Equus grevyi*) in Kenya 2007-2011, Kenya Wildlife Service, Nairobi, Kenya.

Kushwaha, K., Rao, R.J. and Bidyalakshmi, P. (2012). Geo-Spatial Modelling of Habitat Suitability of wildlife species of Kuno Wildlife Sanctuary. *Journal of Environmental Science, Toxicology and Food Technology*. **4**: 15-19.

Kushwaha, S.P.S. and Hazarika, R. (2004), Assessment of habitat loss in Kameng and Sonitpur Elephant Reserves**.** *Current Science*. **87:** 101447-1453.

Kushwaha, S.P.S. & Roy, P.S. (2002). Geospatial technology for wildlife habitat evaluation. *Tropical Ecology*. **43(1):** 137-150.

Leica Geosystems (2003). ERDAS Imagine Field Guide,7th Edition, Atlanta, Georgia, USA.

Leyequien, E., Verrelst, J., Slot, M., Schaepman-Stub, G., Heitk¨onig, I. M. & Skidmore, A. (2007). Capturing the fugitive: applying remote sensing to terrestrial animal distribution and diversity. *International Journal of Applied Earth Observation and Geoinformation,* **9(1):** 1–20.

Lillesand, M. and Kiefer, R.W. (2004). Remote Sensing and Image Interpretation. Fourth Edition. John Willy & Sons Inc. Newark, Chechister, Wenheim, Brisbane, Singapore and Toronto.

Low, B., Muoria P., Parker G., Sundaresan S. (2008). Report on the National Survey of Grevy's Zebra in Kenya. Kenya wildlife service (KWS), Nairobi.

Low, B., Sundaresan S., Fischhoff I., Daniel I.R. (2009). Partnering with local communities to identify conservation priorities for endangered Grevy's zebra. *Biological Conservation*. **142:** 1548–1555.

Mccarthy, K.P., Fletcher, R.J., Rota, C.T., and Hutto, R.L. (2011). Predicting Species Distributions from Samples Collected along Roadsides. *Conservation Biology*, ***26****:* 68–77.

Melka warer agricultural research center (2015). Metrological data from year 2008 to 2014.

Moehlman, Patricia D. (ed.). (2002). Equids: Zebras, Asses and Horses. Status Survey and Conservation Action Plan. IUCN/ SSC Equid Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. pp 11-27.

Mudasir, A. (2014). Habitat suitability modeling for exploration of the spatial distribution of Kashmir musk deer in Dachigam national park, Kashmir. *American Journal of Environmental Sciences.* **10 (5):** 446-457.

Mwasi, S. and Mwangi, E. (2007). Proceedings of the National Grevy's zebra Conservation Strategy Workshop 11 -14 April 2007. Kenya Wildlife Service Training Institute, Naivasha, Kenya.

Norton-Griffiths, M. (1998). *Counting animals*, 2nd edn. African Wildlife Leadership Foundation, Nairobi, Kenya.

Phillips, S.J., and Dudik, M. (2008). Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*. **31:**161-175.

Ron, S. and Jukka, J. (2003). A GIS-based multi-scale approach to habitat suitability modeling. *Ecological Modelling* **169:** 1–15.

Ron, S. and Jyrki, K. (2001). Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modeling. *Landsacpe and urban palnning.* **55:** 70-93.

Rowen, M. (1992) *Mother-infant Behavior and Ecology of Grevy's Zebra*. Yale University, New Haven, USA. pp 123-141.

Saaty, T.L. (1977). A scaling method for priorities in hierarchical structure. *Journal of Mathematical Psychology*. **15:** 234–281.

Sanderson, E.W. and Pascual-Hortal, L. (2007). A new habitat availability index to integrate connectivity in landscape conservation planning: comparison with existing indices and application to a case study. *Journal of Landscape and Urban Planning*. **83:** 91-103.

Schulz, E. and Kaiser, T. M. (2013). Historical distribution, habitat requirements and feeding ecology of the genus *Equus* (Perissodactyla). *Mammal Review Journal*. **43:** 111–123.

Suman, Sinha, Laxmikant, S. and Mahendra, S. N. (2011). Retrieving Tiger Habitats: Conserving Wildlife Geospatially. *Applied Remote Sensing Journal*. **2(1):** 1-5.

Sundaresan, S., Fischhoff, R., Hartung, I. R., Akilong, H. M., P. and Daniel, I. R. (2007a). Habitat choice of Grevy's zebras in Laikipia, Kenya. *African Journal of Ecology,* **46(3):** 359–364.

Sundaresan, S. Ilya, R., Fischhoff, R. and Daniel, I.R. (2007b). Male harassment influences female movements and associations in Grevy's zebra (Equus grevyi). *Behav Ecol* **18:** 860–865.

U.S. Fish and Wildlife Service (1981), *Standards for the development of habitat suitability models for use in the Habitat Evaluation Procedures.* USDIFWS, ESM 103, Washington, DC. pp 27-48.

Wang, X.D., Zhong, X.H., Liu, S.Z., Liu, J.G., Wang, Z.Y. and Li, M.H., (2008). Regional assessment of environmental vulnerability in the Tibetan plateau: Development and application of new method. *Journal of Arid Environments*. **72:** 1929–1939.

Williams, S.D. (2002) *Status and action plan for the Grevy's zebra (Equus grevyi).In:Moehlman PD(ed) Equids: Zebras, Asses and Horses. Status Survey and Conservation Action Plan*. IUCN/ SSC Equid Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. 11-27.

Zhou, L.Z., Li, D.Q., Ma, Y. and Ye, X.D., (1999). **GIS** approaches to studying animal diversity*Chinese Journal of Zoology*. **34 (5):** 52-56.

Web sites

http://www.esri.com/library/bestpractices/enterprise-gis.pdf 15, Retrieved on 10.16.2014.

http://www.iucnredlist.org/details/7950/0, Retrieved on 7.1.2014.

http://earthexplorer.usgs.gov. Retrieved on February, 2014

http://gdem.ersdac.jspacesystems.or.jp. Retrieved on February, 2014

APPENDICES

Appendix 1 Ground control points

Coordinates		Vegetation/ Land use land cover
X-coordinate	Y-coordinate	
1019308	652058.58	Bush land
1018949	651968.73	Bush land
1018534	651876.44	Bush land
1017978	651784.84	Bush land
1017040	651674.36	Bush land
1016795	652068.81	Bush land
1016235	649727.42	Bush land
1016672	649161.08	Bush land
1015129	649946.13	Bush land
1000607	657886.03	Bush land
999859.8	659663.88	Bush land
1023565	655230.36	Wooded grassland
1023535	654901.91	Wooded grassland
1022159	654478.43	Wooded grassland
1021495	654079.64	Wooded grassland
1021016	653861.23	Wooded grassland
1020948	653296.71	Wooded grassland
1020366	652393.82	Wooded grassland
1020048	652229.11	Wooded grassland
1019445	651886.66	Wooded grassland
1018776	651632.98	Wooded grassland
1019794	651196.4	Wooded grassland
1012328	645057.59	Wooded grassland
1009517	642792.78	Wooded grassland
1006035	643436.91	Wooded grassland

1005250	644803.51	Wooded grassland
1023252	670982.56	Highland forest
1022766	670476.36	Highland forest
1022887	672039.14	Highland forest
1023224	673329.3	Highland forest
1024525	674838.46	Highland forest
1026224	674164.36	Highland forest
1026122	674714.94	Highland forest
1025930	675029.89	Highland forest
1025706	675702.89	Highland forest
1038702	662299.73	Gallery forest/ riverine forest
1037646	660287.25	Gallery forest/ riverine forest
1038404	660131.73	Gallery forest/ riverine forest
1038868	660241.77	Gallery forest/ riverine forest
1039531	660794.57	Gallery forest/ riverine forest
1042449	658805.05	Gallery forest/ riverine forest
1039982	661712.6	Gallery forest/ riverine forest
1035034	659714.67	Gallery forest/ riverine forest
1034086	660204.74	Gallery forest/ riverine forest
1033797	660735.29	Gallery forest/ riverine forest
1027045	656649.29	Gallery forest/ riverine forest
1037063	657537.13	Grassland
1034053	655621.78	Grassland
1032707	653258.12	Grassland
1023026	646312.69	Grassland
1022101	651156.27	Grassland
1021841	646317.51	Grassland
1030798	650630.78	Grassland
1027472	648317.36	Grassland
1025188	650426.31	Grassland

1014516	646737.53	Grassland
1015626	643005.59	Grassland
1042424	659523.57	Grassland
1009263	662072	Settlement/bare land
1009263	662087.96	Settlement/bare land
1009266	662095.65	Settlement/bare land
1009278	662138.28	Settlement/bare land
1009283	662160.32	Settlement/bare land
1009289	662214.9	Settlement/bare land
1009294	662233.43	Settlement/bare land
1009300	662252.49	Settlement/bare land
1009171	662194.76	Settlement/bare land
1009040	662245.12	Settlement/bare land
1009034	662303.15	Settlement/bare land
1008993	662282.06	Settlement/bare land
1008985	662193.76	Settlement/bare land
1008916	662249.07	Settlement/bare land
1008800	662157.64	Settlement/bare land
1008765	662289.88	Settlement/bare land
1008827	662323.92	Settlement/bare land
1008888	662389.02	Settlement/bare land
1008622	662112.54	Settlement/bare land
1008536	661923.7	Settlement/bare land
1008553	661933.02	Settlement/bare land
1008666	662016.47	Settlement/bare land
1008718	662216.46	Settlement/bare land
1008657	662257.13	Settlement/bare land
1008831	662263.24	Settlement/bare land
1010320	665229.74	Settlement/bare land
1010268	665195.91	Settlement/bare land

1010526	665400.48	Settlement/bare land
1010525	665234.7	Settlement/bare land
1010627	665054.37	Settlement/bare land
1010716	665237.35	Settlement/bare land
1010890	665144.15	Settlement/bare land
1011087	664999.97	Settlement/bare land
1009404	661999.44	Farmland/ fallow land
1009361	662014.64	Farmland/ fallow land
1009337	661975.51	Farmland/ fallow land
1009445	661965.61	Farmland/ fallow land
1009346	661971.5	Farmland/ fallow land
1009304	661931.98	Farmland/ fallow land
1009154	661954.33	Farmland/ fallow land
1009130	661839.61	Farmland/ fallow land
1009298	661818.84	Farmland/ fallow land
1009225	662523.27	Farmland/ fallow land
1009130	662496.99	Farmland/ fallow land
1009079	662477.27	Farmland/ fallow land
1008989	662481.31	Farmland/ fallow land
1008929	662547.41	Farmland/ fallow land
1008846	662646.64	Farmland/ fallow land
1008899	662777.96	Farmland/ fallow land
1008957	662939.35	Farmland/ fallow land
1009157	663126.3	Farmland/ fallow land
1009625	663235.09	Farmland/ fallow land

Grevy's zebra presence

Coordinates	
X-coordinate	Y-coordinate
1030572.3	649697.05
1029361.16	648881.67
1029184.91	649450.47
1029190.01	648559.5
1028669.46	649262.34
1031791.56	650639.99
1029526.25	650320.67
1030402.08	649146.56
1028493	650160.52
1030054.18	649393.59
1030218.13	651064.06
1030400.79	649371.1
1028836.88	650028.52
1029192.85	648225.21
1028329.49	649063.65
1031616.66	650423.55
1030749.38	649123.56
1029356.04	649773.61
1029708.48	648857.63
1031093.69	649889.91
1031616	650536.69
1031270.04	649653.43
1029536.55	648534.75
1028336.23	648730.83
1028498	649273.82
1019923.58	643160.75
1019605.71	643725.01

1019170.22	644279.31
1018389.93	644684.29
1018070.52	644266
1017367.02	644400.04
1017120.88	643608.67
1018041.53	642754.58
1017366.39	642395.42
1016508.15	642330.11
1016053.02	642322.45
1016355.69	643088.47
1017598.04	643784.38
1017597.89	643991.68
1018415.79	642957.43
1018100.64	643539.53
1017190.49	642621.83
1018329.22	642680.32
1018855.17	644874.59
1016203.25	642588.64
1017298.34	642909.67
1019170.22	643698.84

Appendix 2. Questions for key informant interviews (expertise).

Semi-structured interview used to evaluate the relative importance and classification effects of Grevy's zebra habitat defining parameters from expertise value judgments.

1. What are the major Grevy's zebra suitable habitat defining factors in Allidegi wildlife reserve?
2. How the factors are relevant in redefining the boundary of Allidegi wildlife reserve?
3. How to the proximity of water, road and settlement affects Grevy's zebra suitable habitat use in Allidegi wildlife reserve?
4. How do you rate the relative importance of Grevy's zebra habitat factors in defining the species habitat use? Use (√) to show the relative importance.

Habitat factors	Relative importance								
	1	2	3	4	5	6	7	8	9
Grassland to water									
Grassland to slope									
Grassland to settlement									
Grassland to road									
Water to slope									
Water to settlement									
Water to road									
Slope to settlement									
Slope to road									
Settlement to road									

Appendix 3 Model plates

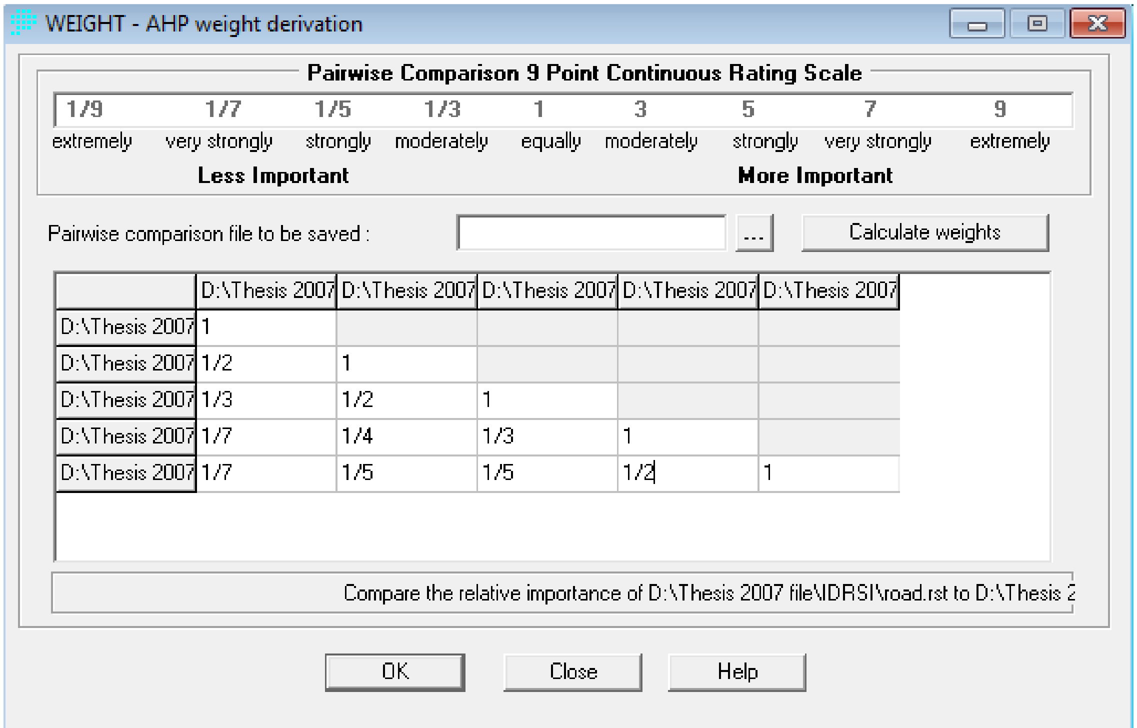

Plate 1: Pairwise comparison of factor maps

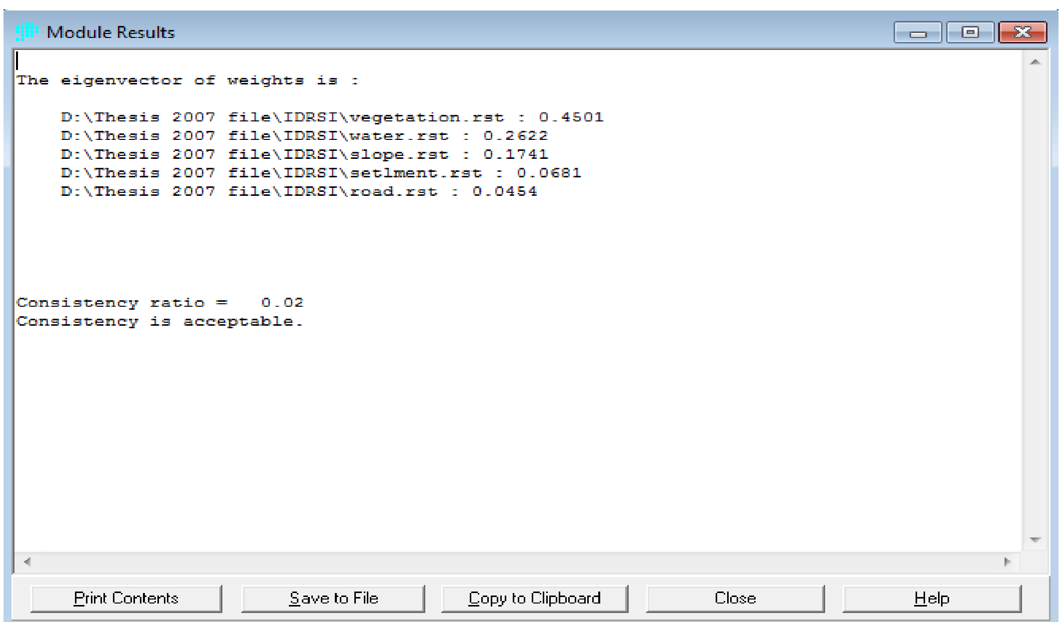

Plate 2: Eigen vector of factor map weights

Appendix 4 The Analytical hierarchy process steps using pairwise comparison matrix developed by Saaty (1977) for deriving factors weight for HSI and checking consistency of comparison.

Step one: Comparing the relative importance of the factors in pairwise comparison matrix.

Factors	Vegetation cover	Proximity to water point	Slope	Proximity to settlement	Proximity to road
Vegetation cover	1				
Proximity to water point	1/2	1			
Slope	1/3	1/2	1		
Proximity to settlement	1/7	1/4	1/3	1	
Proximity to road	1/7	1/5	1/5	1/2	1

Step two: Reciprocal value of the upper diagonals

Factors	Vegetation cover	Proximity to water point	Slope	Proximity to settlement	Proximity to road
Vegetation cover	**1**	2	3	7	7
Proximity to water point	1/2	**1**	2	4	5
Slope	1/3	1/2	**1**	3	5
Proximity to settlement	1/7	1/4	1/3	**1**	2
Proximity to road	1/7	1/5	1/5	1/2	**1**

Note: If $\mathbf{a}_{ij}$ is the element of row ***i*** and column ***j*** of the square matrix the upper diagonal is derived by using $\mathbf{a}_{ij} = \mathbf{1/a}_{ij}$

Step three: Sum each column of the reciprocal matrix.

Factors	Vegetation cover	Proximity to water point	Slope	Proximity to settlement	Proximity to road
Vegetation cover	1	2	3	7	7
Proximity to water point	1/2	1	2	4	5
Slope	1/3	1/2	1	3	5
Proximity to settlement	1/7	1/2	1/3	1	2
Proximity to road	1/7	1/5	1/5	1/2	1
Sum	**2.12**	**3.95**	**6.58**	**15.5**	**20**

Step four: Finding normalized relative weight (computed by dividing each element of the matrix with the sum of the column from step three).

Factors	Vegetation cover	Proximity to water point	Slope	Proximity to settlement	Proximity to road
Vegetation cover	0.47	0.50	0.46	0.45	0.35
Proximity to water point	0.24	0.25	0.30	0.26	0.25
Slope	0.16	0.13	0.15	0.19	0.25
Proximity to settlement	0.07	0.06	0.05	0.06	0.10
Proximity to road	0.07	0.05	0.03	0.03	0.05
Sum	**1**	**1**	**1**	**1**	**1**

Step five: Calculation of final weight using final priority vectors (Principal Eigen vector)

Factors	Vegetation cover	Proximity to water point	Slope	Proximity to settlement	Proximity to road	**Priority vector**
Vegetation cover	0.47	0.50	0.46	0.45	0.35	0.4501
Proximity to water point	0.24	0.25	0.30	0.26	0.25	0.2622
Slope	0.16	0.13	0.15	0.19	0.25	0.1741
Proximity to settlement	0.07	0.06	0.05	0.06	0.10	0.0681
Proximity to road	0.07	0.05	0.03	0.03	0.05	0.0454
					Sum	**1**

Note: Principal Eigen vector (Priority vector) obtained by averaging of normalized relative weight across the rows from step four.

Evaluating the consistency of the comparisons

Checking consistence index

CI = $\frac{\lambda_{max} - n}{n-1}$ Where: $\boldsymbol{\lambda_{max}}$ is principal Eigen value and $\boldsymbol{n}$ is number of factors (Saaty, 1977)

$\boldsymbol{\lambda_{max}}$ is the summation of the multiplication of products between each elements of Eigen vector with the sum of columns of the reciprocal matrix.

$\boldsymbol{\lambda_{max}} =$ 2.12(0.45) + 3.95(0.26) + 6.58(0.17) + 15.5(0.068) + 20(0.046)

=**5.0224**

CI= 5.0224-5/5-1

=0.0224

Checking inconsistency (Consistency ratio (CR))

CR= CI/RI   Where RI Ration consistency index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Saaty (1977)

CI = 0.0224/1.12

= 0.02

Appendix 4 Photos of the study area

Alledeghi plane land

Grevy's zebra in Allidegi wildlife reserve

Declaration

I hereby declare that the thesis entitled **"Suitable habitat zone analysis in Allidegi wildlife reserve: a case study for Grevy's zebra**" had been carried out by me under the supervision of Dr. Getachew Berhan Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2015 as part of a Master of Sciences Programme in Remote Sensing and GIS (Earth Science). I further declare that this thesis is my original work and has not been submitted to any other University or Institution for the award of any degree or diploma and that all sources of material used for the thesis have been dully acknowledged.

Name: Yared Mesfin

Signature: ___________________________

Date: _______________________________

This thesis have been submitted for examination with my approval as a university advisor

Major advisor: Dr. Getachew Berhan

Signature: ____________________________

Date: ________________________________