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*Mountain Nyala Species Habitat Suitability Modelling in response to Species Sustainability and Ecotourism Development Using Geospatial Technologies: The Case of Bale Mountain National Park, Ethiopia*

*A thesis Submitted to the Department of Geography and Environmental Studies, School of Graduate Studies of Jimma University, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geographic Information System and remote sensing*

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## Declaration

I hereby declare that the thesis entitled “*Mountain Nyala Species Habitat Suitability Modelling in response to Species Sustainability and Ecotourism Development Using Geospatial Technologies; The Case of Bale Mountain National Park, Ethiopia*” had been carried out by me under the supervision of Dr. Girma Alemu Department of Geography and Environmental Studies, Jimma University, Jimma during the year 2023 as part of a Master of Sciences Programme in GIS and Remote Sensing. I further declare that this thesis is original work of the author and has not been submitted to any other University or Institution for the award of any degree or diploma. Any work taken from other authors or organizations is duly acknowledged within the text and references chapter.

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This is to certify that the thesis prepared by ZELALEM INDALKACHEW, entitled: “*Mountain Nyala Species Habitat Suitability Modelling in response to Species Sustainability and Ecotourism Development Using Geospatial Technologies; The Case of Bale Mountain National Park, Ethiopia*” and submitted in partial fulfillment of the requirements for the Degree of Masters of Science in GIS and Remote sensing complies with the regulations of the University and meets the accepted standards with respect to the originality and quality.

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## ACRONYMS

AHP	Analytical Hierarchy Process
BMNP	Bale Mountains National Park
DEM	Digital Elevation Model
ESM	Ethiopia Spatial Mapping
EWCA	Ethiopian Wildlife Conservation Authority
EWCD	Ethiopian Wildlife Conservation Department
EWCP	Ethiopian Wolf Conservation Program
FAO	Food and Agriculture Organization
FZS-BMCP	Frankfurt Zoological Society _ Bale Mountains Conservation Program
GCP	Ground Truth Point
GIS	Geographic Information System
GPS	Global Positioning System
HSM	Habitat Suitability Model
IUCN	International Union for Conservation of Nature
LULC	Land Use/Land Cover
MCDM/A	Multi-Criteria Decision Making/Analysis
MCE	Multi-Criteria Evaluation
NGO	Non-Governmental Organizations
NMSA	National Meteorology Service Agency
RS	Remote Sensing
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United State Geological Survey
WOA	Weighted Overlay Analysis

## ABSTRACT

The Mountain Nyala (*Tragelaphus buxtoni*) is an endangered and endemic flagship species to Ethiopian highlands. This study aims to identify and map the distribution of suitable habitats for the Mountain Nyala in response to species sustainability and ecotourism development in the Bale Mountain national park. Environmental and anthropogenic factors, such as vegetation cover, topography (i.e., slope, elevation), soil type, precipitation, temperature, settlement, river, and road buffer zones were included to develop a Geographic Information System (GIS) based habitat suitability model for the Mountain Nyala. The statistical method such as pairwise comparison was applied to rate the individual classes of each factor and weight the impact of one factor against the other which helped to determine the suitability model. Basically, all factors were converted into raster and combine by using weight overlays in ArcMap with weights from the analytical hierarchy process (AHP) which based on the distribution of each class of habitat factors to generate the final thematic map. The map shows that within all park zones, 4% or ~ 80 ha, 27% or ~ 58767 ha, 51% ~ 109143 ha, 21% ~ 45289 ha, and 6% or ~ 131 ha lie in suitability zone 'unsuitable', 'less suitable', 'marginal suitable', 'moderately suitable', and 'high suitable', respectively. Three environmental variables, vegetation cover, slope, and elevation, were the most important predictors having the greatest contribution to the habitat suitability model. The result revealed that habitat fragmentation is a common problem for the survival of the Mountain Nyala species throughout its ranges of distribution. Thus, future conservation and management action should address toward solving this problem through designing appropriate corridors that help connect the fragmented suitable habitat patches for this endangered flagship species in the park.

**Keywords:** *Habitat suitability, Ecotourism development, Geospatial technologies, Species sustainability*

# CHAPTER ONE

## 1. INTRODUCTION

### 1.1. Background of the Study

Wildlife management is an issue of global importance where its habitat suitability modelling is an essential for the better management, conservation and protection of threatened species (Ganawa et al., 2015; Imam et al., 2013; MacDonald, 2003). These necessities permit to outline of living and environmental situations that restrict the species distribution (Acevedo et al., 2010; Moreau et al., 2012). In many cases, the modern-day habitat fragmentation for rare or endangered species diminished because of numerous factors associated with humans (e.g., urbanization, forestry, agricultural lands, ranching, mining) or weather alternate factor (Mikoláš et al., 2017).

For effective management and conservation strategies, the potential habitat fragmentation of the target species permits to (i) examine the effectiveness of the current network of safety regions, (ii) enhance the nearby connectivity through putting in place new conservation regions, and (iii) discover regions for potential recovery or reintroduction programs (Klar et al., 2008; Zheng et al., 2016). Besides this, potential habitat fragmentation additionally permits the discovery of synergies and trade-offs with different financial activities (Carpentier et al., 2017). Natural reserves need to be created to maintain precise landscape values or to preserve precise habitats' suitability (Barr et al., 2016), which aids in the conservation planning of endangered species (Worku et al., 2021).

Although previously habitat changes were relatively a minor factor in decline of species, being overshadowed for centuries by overexploitation and introduction of exotic species, their relative importance has increased in recent decades. Habitat loss has emerged the most severe threat to biodiversity worldwide threatening some 80% of all species classified as "threatened" and "endangered" in the IUCN's *Red Lists* (IUCN, 2020).

In Africa loss of wildlife habitats is a widespread phenomenon. The current loss is estimated at 60% (Bloomfield et al., 2020). Human population pressure is cited as the main contributor to this loss, mainly through deforestation prompted by increased demand for arable land, settlements and fuelwood (Batool & Hussain, 2016).

Ethiopia, one of the African countries, is by no means exceptional to this scenario. According to the World Resources Institute report on status of the world habitats, the country had 43% of its original habitats (ca. 886 200 km<sup>2</sup>) lost (WRI, 2011). Local extinction of wildlife species and increased number of species that are prone to extinction in different localities manifest the impact of this loss (Qi et al., 2021). Thus, data on the country's wildlife resources is limited to mammals, birds, reptiles, amphibians, and a few categories of arthropods as a whole. It should be noted that Ethiopia has unusually high incidence of endemism of flora and fauna, including at least 31 endemic mammals (Begna, 2022). One species of particular concern is the Mountain Nyala *Tragelaphus buxtoni*, a spiral-horned antelope endemic to the southern highlands of Ethiopia.

The Mountain Nyala (*Tragelaphus buxtoni*) has been brought to the attention of the scientific community in 1908 by Major Ivor Buxton (Lydekker, 1911), and its extensive range within the Bale Mountains was only confirmed in 1963 (Brown, 1969). The species belongs to the spiral-horned family of Bovidae (Genus *Tragelaphus*), and is endemic to Ethiopia. This species has no recognized subspecies or synonyms, and there are no records of the animals in captivity (Mamo et al., 2010). The mountain nyala, is a relatively understudied antelope, unlike its closest relatives, such as the greater kudu (*Tragelaphus strepsiceros*) and nyala of southeast Africa (*Tragelaphus angasii*) (Evangelista et al., 2007; Mamo, 2015).

The International Union for the Conservation of Nature (IUCN, 2016) designated the conservation status of the Mountain Nyala as endangered due to a reduced population size of fewer than 2,500 mature individuals when compared with earlier reports of 7000-8000 animals (Brown, 1969). The species is known to inhabit the Afro alpine and montane vegetation's of the Bale, Arsi, and chercher or Ahmar Mountains in the southeast highlands of Ethiopia (Worku et al., 2021), and occur at elevations of 1,800-4,000 m (Evangelista et al., 2008). The most prominent population of Mountain Nyala species is found in the Bale Mountain National Park. The species require a relatively large home range and diverse habitat resources (Tadesse, 2018). However, the wild populations of this species are under threat mainly due to hunting, habitat destruction, encroachment by cattle, expansion of montane cultivation, roads, and harassment by dogs. Permanent occupation of suitable habitat as a result of increasing human and livestock populations is exerting tremendous pressure on Mountain Nyala habitat throughout the range (IUCN, 2016).

Habitat suitability for wildlife in Protected areas is necessary for many goods and services, such as economic, cultural, recreational, and spiritual nourishment that play an important role in maintaining our lives (Salamawi et al., 2021). For instance, the existence of Mountain Nyala, or other natural features offers a great contribution to the development of ecotourism (Andualem et al., 2020). This wildlife becomes an integral part of ecotourism as people are demonstrating increased interest in wildlife-based tourism which helps the country's economy and protects the country's future protected areas (Katuwal et al., 2020).

Habitat suitability modelling (HSM) is the most effective and perhaps the most frequently used form of ecological models (Tadesse, 2018) as well as with the use of environmental variables to estimate the likelihood presence of the wildlife species (Baig et al., 2022). It is vague and ambiguous to define the environment of such species, this will use Mountain Nyala habitat as a case study to model habitat suitability, by using GIS technology will represent the environmental preferences of such species (Ganawa et al., 2015).

Therefore, remote sensing and GIS is a tool for obtaining information and is becoming important technology in habitat suitability modeling and monitoring for various wildlife species (Ahmad et al., 2018). This study aims to identify the major Mountain Nyala suitable habitat determining factors and analyze their influence to develop suitable habitat modelling for sustainable conservation of species and ecotourism development. Thus, characterizing habitat choice and identifying Mountain Nyala suitable habitat distribution in the park through utilizing geospatial technologies offers an insight for decision support systems and assist for better conservation and ecology management.

## **1.2. Statement of the Problem**

Human activities such as agricultural development, commercial conifer afforestation, and urbanization have led to the loss of the original wildlife habitat, reduction in suitable habitat patch size, and increasing isolation of suitable habitat patches (Andren, 1994). These have continually been a problem and continue to get worse as the populations of wildlife need sufficient space for survival.

Bale Mountains National Park is one of the protected areas in Ethiopia. It has unique biodiversity, which is tentatively listed by UNESCO as one of the world heritage sites having the largest Afro-alpine ecosystem, grassland, woodlands, and most extensive natural forest (BMNP, 2017). The

Park is home to a variety of unique, rare, and endemic species which is explained by the motto of "one park many worlds". This means the park with huge potential of providing a diversified visitor experience.

Regardless of the high tourism potential of the park, the ecotourism development of the park is not at the expected level due to multiple problems. The challenges of the park include the habitat of the Mountain Nyala species are at risk due to changing natural phenomena and imprudent human actions at the BMNP (Solomon, 2014). These challenges have a direct negative impact on species sustainability and ecotourism development. According to (Mamo et al., 2010) defined, the rapid human population growth followed by extensive cultivation and overgrazing has negatively affected the animals' potential to inhabit their suitable range. Although it is, evident that habitat loss is decreasing, the known range of Mountain Nyala and the full distribution of the species has never been adequately determined. These have decreased the source of food and shelter for Mountain Nyala.

Excessive hunting seriously affects the larger mammals in the area and the number of Mountain Nyala reduces from time to time with only 1,500-2,500 adult Nyalas present in the wild (IUCN, 2016). Visitors have suggested a substantive reduction in the woody vegetation, both inside and outside the park. Fire is a recurrent phenomenon in the BMNP mainly in the Bale Mountains massif. Another, the biggest risk to the park is the paved road through the northern part of BMNP, which is causing a sharp increase in human population and vehicle traffic (Evangelista et al., 2012). Besides, livestock encroachment and the expansion of farms as well as settlements to areas currently inside the park (Worku et al., 2021). These distresses the suitable habitat distribution of Mountain Nyala and lack of the clear suitable areas for this endangered species. Meanwhile, a limited study approach leads to limited information and a knowledge gap on the functional suitable habitat landscape matrix of Mountain Nyala in the study area.

Furthermore, in previous literature reviews, (Brown, 1969; Evangelista et al., 2007; Mamo, 2007; Atickem et al., 2011; Evangelista et al., 2012; Mamo et al., 2012; Solomon, 2014; Evangelista, 2015) the following environmental and anthropogenic factors were only included: vegetation cover (e.g., trees, herbs, and shrubs cover), landform or topography (i.e., slope), elevation, towns, and roads. The remaining key Mountain Nyala suitable habitat is either unmapped and therefore unknown, or it is too fragmented to sustain viable Mountain Nyala subpopulations. To address the

suitable habitat distributions of wildlife species GIS and remote sensing have a profound application package that can deal through involving suitable habitat factors (Imam & Yohannes, 2013). Unlike to other parts of the world in Ethiopia the application of GIS and remote sensing in wildlife suitable habitat study is rare.

Consequently, this research was tried to fill the gap by doing research applying the GIS technique and remote sensing data through a multi-criteria evaluation process as one way to provide more spatial referenced information. On top of this, the GIS model provided here is devised to remedy this deficiency by presenting suitable wildlife corridors for Mountain Nyala and preserving and defending them properly. Building this information into conservation plans and management for BMNP protected areas will help to address for conservation and Management of Mountain Nyala wildlife and effective decision-making for sustainable ecotourism development activities and planning.

### **1.3. Objectives**

#### **1.3.1. General Objective**

The main objective of this to model Mountain Nyala habitat suitability in response to species sustainability and ecotourism development using Geospatial technologies: the case of Bale Mountain National Park, Ethiopia

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

- To consolidate available geospatial and non-spatial data of various environmental and socio-economic attributes for the habitat of Mountain Nyala at the study area
- To assess the relative importance of habitat parameters for Mountain Nyala suitable habitat identification
- To develop a habitat suitability model for Mountain Nyala at the study area
- To assess the contribution of habitat suitability modelling for the survival of the species and development of ecotourism sector

### **1.4. Research Questions**

The following research questions need to be addressed in achieving the above-mentioned objectives:

- What are the major abiotic, biotic, and socio-economic factors that determine the suitable habitats for the Mountain Nyala at the study area?
- How to assess the relative importance of habitat parameters for mountain Nyala species?
- Where are the areas of the best habitat suitability for the Mountain Nyala? And,
- How to contribute a suitability model that is conducive to the survival of the species and ecotourism development?

### **1.5. Significance of the Study**

The information concerning Mountain Nyala suitable habitat distribution developed through this study would assist to craft sound planning and prioritizing wildlife conservation approaches. Thus, provides background information to exercise the right judgment in functional landscapes, suitable habitat utilization, and conservation in BMNP. Especially, the study produces a suitable area map of Mountain Nyala and characterizes the study area into different ranges of suitability zones. This helps to understand the status and distribution of the habitat matrix in the protection and sustainability of this flagship species and contributes to the development of ecotourism in the BMNP. Furthermore, the result of this study provides insight to divulge the habitat characteristics of the landscapes for the newly proposed boundary of the park. In general, by doing habitat suitability modeling for Mountain Nyala species has a great role in ecotourism development in order to conserve and maintain the biological richness of the area as well as economic uplifting of the local people.

### **1.6. Scope of the study**

The study has spatial, temporal and analytical scopes. Geographically, the study emphasizes only on two woredas were surrounded to BMNP. From these woredas, four kebeles such as Gojera, Horo soba, Fasile Angeso, and Chiri were selected. Thematically, the scope of this study is involved in Mountain Nyala species habitat suitability at BMNP in Ethiopia to support decision-making to help in locating the suitable area at the park for conserving these valuable species for future generations through spatially parameters. Methodologically, the spatial extent of the study was limited to the available satellite image of sentinel-2A data in time. The study also used concurrent mixed approach and collected a data by using focus group discussions, key informant interviews and field observation.

### **1.7. Limitations of the study**

The study would have some limitations, and attempts are made to figure out some of them. The socio-economic survey may be limited to secondary data that should have been mainly due resource competition involved in the modelling of Mountain Nyala suitable habitat in response to species sustainability and ecotourism development in the study area of Bale Mountain National Park.

### **1.8. Organization of the study**

This thesis is composed of five chapters. The first chapter of the thesis involves background information of the study regarding the application of GIS multi criteria evaluation and remote sensing in wildlife habitat study and Mountain Nyala habitat factors. Meanwhile 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, and their implications. The findings of the study had been also discusses the results and provides management recommendations. Finally, based on the findings conclusion and recommendation had been drawn that would aid the decision making, policy formulation process and provides further recommendations.

## CHAPTER TWO

### 2. LITERATURE REVIEW

#### 2.1. Concepts and definitions of wildlife and habitat suitability

Currently, the term wildlife applies to all biotic elements that comprise every species of plant and animal in the world, excluding man and his domesticated pets (Alemneh, 2015). In the past, the term was often used to address a limited number of spectacular animals, which enjoyed public recognition. Therefore, wildlife refers to the variety of all living organisms inhabiting the wild, at the genetic, species, and ecosystem levels on earth.

In the U. S. Fish and Wildlife Service Habitat Evaluation Procedures, habitat suitability is defined in terms of a habitat's potential to support a particular species. These procedures utilize Habitat Suitability Indexes (HSI's) that range from 0, for completely unsuitable habitat, to 1 for optimal habitat (McCullough et al., 2001). Usually, HSI models associate structural features of the habitat, such as vegetation or snag density, with an animal's population density (as an indicator of carrying capacity). Thus, an HSI of 1 is assigned to habitats that possess characteristics indicative of the highest carrying capacity, while an HSI of 0 is given to habitats that possess characteristics associated with low or no carrying capacity. HSI models are easy to implement and are relatively inexpensive to produce. However, we recognize three problems in their use. (1) heavy reliance on structural habitat characteristics as surrogates for all factors that influence habitat suitability, (2) reliance on density as an indicator of a habitat's ability to support a species is questionable, and (3) HSI's do not indicate where on the scale of 0 to 1 a habitat becomes capable of sustaining a population (Kellner et al., 1992).

To contend with the above problems, we propose that habitat suitability be considered a dichotomous variable. We suggest that habitats are either suitable or unsuitable for a given species or community because suitability depends on the potential of habitat to support a viable population over an appropriate ecological time frame.

##### 2.1.1. Wildlife's spatial distribution

In the natural world, the clumped pattern of spatial distribution is the most common amongst almost all living creatures. The pattern, however, relies upon some factors, such as characteristics

of the environment, social bonds, or anti-predator strategy. Nevertheless, such behavior reasons aggregation of individuals in a few components in their domestic variety and consequently determines the depth of habitat use (Kie et al., 2002).

Estimates of spatial distribution are important for effective control and conservation of wildlife populations. Such understanding is essential for the determination of home range and habitat preferences, the identification of concentration regions, and the delineation of migration routes. Most commonly, spatial distribution is assessed on the premise of presence data acquired randomly with telemetry or through direct observations, snow or mud tracking, and recognizing of signs of animal foraging or faeces (Charytanowicz et al., 2020). The reliability of such facts relies strongly upon the technique of its collection. It is thus crucial to carry out systematic surveys to avoid gaps that might distort the sample of animal dispersal. Moreover, the distribution of acquired data needs to be representative of actual animal densities inside their home range (Charytanowicz et al., 2020).

### **2.1.2. The species-habitat relationships**

The species-habitat relationship is one of the most widely reported ecological theories accounting for biodiversity of plants and animals. An experimental proof of concept for the microbial species-habitat relationship is needed to support future studies aiming to detect these types of relationships in real world ecosystems (Delgado-Baquerizo et al., 2018). The spatial distribution of species depends on their requirement and their response to environmental characteristics. Traditional wildlife management considers three fundamental physical variables of the environment, which represent basic vital requirements: food, water and shelter. The local conditions and available resources contribute to define the habitat of a given species, and the presence and survival of species are directly dependent on environmental conditions (Anderson & Danielson, 1997). The identification of key habitats for wildlife species is essential for development programs, where drastic land changes could cause the disappearance of some environmental structure.

When sampling wildlife environmental preferences for management purposes, the consideration of all areas occupied by a species can be difficult if basic information about the species' life history are not available. Behavioral studies give a fundamental contribution to conservation and little management action can be successful without knowledge of species' habitat requirements, range size, mating system, and inter-specific relationships (Sutherland, 2003).

### **2.1.3. Habitat loss/Fragmentation**

The special feature (food, shelter, water, space) of an area that is necessary for survival is the habitat of animals. When a large area is converted into smaller patches and these patches are isolated from each other it is termed as habitat fragmentation (Hassan, 2006). Habitat fragmentation includes both loss of habitat and fragmentation of habitat and it has a negative impact on wildlife. The fragmentation and destruction of natural habitats lead to a reduction in population size and abundance, a change in genetic diversity, and the extinction of wildlife. Due to patches of habitat, the food chain length becomes smaller, which changes the species interaction and reduces the specialists and large species of wildlife. Habitat loss also affects the animal's breeding, foraging, dispersal behaviors, and predation rate (Batool & Hussain, 2016).

## **2.2. Wildlife conservation and threats**

Wildlife conservation is the practice of protecting plant and animal species and their habitats. As part of the world's ecosystems, wildlife provides stability and balance to nature's processes (Ganawa et al., 2015). The aim of wildlife conservation is to ensure the survival of these species, and to train people on living sustainably with other species.

The human population has grown exponentially over the last 200 years, to more than seven billion people today, and it continues to rapidly grow. This means natural resources are being consumed faster than ever through the billions of people at the planet. This growth and development also endanger the habitats and existence of varieties of wildlife across the world, specifically animals and vegetation that may be displaced for land improvement, or used for food or other human purposes. Other threats to wildlife consist of the introduction of invasive species from different parts of the world, habitat destruction, climate change, pollution, hunting and poaching (NGS, 2020).

### **2.2.1. Wildlife conservation in Ethiopia**

Ethiopia, located in the horn of Africa, has long been recognized for its wealth of natural resources, endemic species, and high biodiversity (Table 1). While Ethiopians have recognized the commercial value of their natural assets for some time, those properties remained largely unprotected until the mid-1960s, when the government instituted conservation and protected area program. The primary intention of this program was to establish bylaws and areas for the

conservation and protection of a range of species and habitats (Schlo, 2001). The promotions of tourism and income generation have been secondary priorities (Turton, 2019).

Conservation in Ethiopia has carried out a considerable amount and should be counseled for its efforts. Most essential has been its attempt to conserve the largest area of afro-alpine habitat on the continent and ensure the survival of several endangered species and endemics (Table 1). These consist of the Ethiopian wolf (*Canis simensis*), African wild dog (*Lycaon pictus*), Mountain Nyala (*Tragelaphus buxtoni*), Walia ibex (*Capra walie*), African elephant (*Loxodonta africana*), African wildass (*Equus africanus*), Soemmerring's gazelle (*Gazella soemmerringii*), Swayne's hartebeest (*Alcelaphus buselaphus swaynei*), and the genetic material of many different species. Other notable activities include the establishment of numerous protected areas and the conservation of diverse native species within this area (Schlo, 2001; Schloeder et, 2001).

### **2.3. The role of wildlife for ecotourism and its trend**

Wildlife opportunities are an important part of the marketing and promotion of ecotourism operations. All wildlife has the potential to be interesting to tourists visiting protected areas (Folmer, 2013). The centrality of wildlife encounters to the ecotourism experience was apparent in promotional statements like:

- 'Native wildlife abounds'
- 'Opportunities to see wildlife in its natural habitat'
- 'Fascinating and amazing rainforest and wildlife'
- 'Take small groups to experience the wildlife'
- 'The rich variety of wildlife will simply delight everyone'.

The available research into visitor perspectives on ecotourism opportunities confirms the importance of wildlife viewing opportunities for visitors. (Chan & Baum, 2007b) review of research into Eco tourist motivation concluded that observation and appreciation of wildlife was a common reason for their travel, as well as a key activity selected and a primary factor in travel decisions. In this review of Eco tourist, motivation wildlife viewing was one of three main reasons for travel along with learning and spending time in natural environments. While little detailed research is available about the nature of ecotourism experiences, the studies that have been published suggest that wildlife encounters are important elements that visitors remember and incorporate into their ecotourism stories (Chan & Baum, 2007a). Given the importance of wildlife

viewing to Eco tourist motivations and experiences, it is not surprising to find that proximity to wildlife is a key component of Eco tourist satisfaction (Mackoy & Osland, 2004).

An aspect of ecotourism is emerging as a rapidly growing trend - interactive marine wildlife experiences. Their sustainable future is dependent upon not only operational best practices, but also the extent to which the ecotourism guide can facilitate a positive environmental perspective and foster tourist behaviors to protect animals and their habitats beyond the ecotourism experience (Walker, 2014).

### **2.3.1. Development of ecotourism in Ethiopia and its contribution for economy**

The concept of ecotourism is a new phenomenon and it is difficult to explain its Significance achievement since the approach of ecotourism is not widely disseminated in Ethiopia. The government of Ethiopia also have recognized the development and promotion of ecotourism and provided consultancy services for a number of potential developers of ecotourism sites (Geda, 2021). Bishangari Eco-Lodge located at Eastern of Langano Lake in Oromia Region and Village Ethiopia located at Afar Region (Bilen) is examples of these private ecotourism developments in Ethiopia (Evangelista et al., 2012). There are some promising community based ecotourism initiatives like Adaba-Dodola, which is financially and technically supported by the German Agency of Technical Cooperation or GTZ (now GIZ) on the northern slopes of the Bale Mountains in Oromia National Regional State and a pilot ecotourism project on Semien mountain national park (TIES, 2006). The Ecotourism Association of Ethiopia, which was founded in 2003 by committed organizations of the private sector is basically formed to promote the principles of ecotourism and eco-efficient initiatives in order to address the challenges faced by the tourism sector (Adem et al., 2019).

At some ecotourism destinations, residents benefit from revenue sharing programs that either provides cash payments or, more commonly, funding for community projects such as wells or schools (Geda, 2021). It also provides new markets for locally produced goods, increased government revenues through fees and taxes paid by visitors, and serves as insurance for the protected areas from being converted to other land use types. Tourism is an excellent means for transferring income from wealthy nations and persons to the poorer sections of society (Adem et al., 2019). Ecotourism is especially effective in this transfer since travelers often vent in to remote, economically disadvantaged regions (Weaver & Lawton, 2007).

## 2.4. Mountain Nyala (*Tragelaphus buxtoni*)

### 2.4.1. Habitat

Mountain Nyala are commonly reported to range between 2,700 m and 4,300 m and to prefer heathland and alpine habitats (Brown, 1969). Mountain Nyala at elevations as low as 1,600 m occupying dense forests. Forested ecosystems provide concealment opportunities, critical cover for thermal regulation and a wide selection of available forage. Generally, Mountain Nyala species inhabit mesic habitats between 1,800 and 3,500 m. These habitats can be broadly categorized into four altitudinal zones that are utilized by Mountain Nyala (Evangelista et al., 2007). (Figure 1).

The Afro-alpine zone, or high wurch, encompasses the highest elevations (>3,700 m). This habitat type is characterized by steep, rocky outcrops and sparse vegetation dominated by *Alchemilla* spp., *Helichrysum* spp. and the endemic *Lobelia rhynchopetalum*. The Afro-alpine zone offers minimal cover for the mountain nyala but provides year-round water and seasonal forage (Brown, 1969). Mountain nyala species use of the Afro-alpine habitat tends to be irregular and is more likely during the dry season than during the rains. The sub-alpine and ericaceous zone, or moist wurch and wet wurch, ranges from 3,200 to 3,700 m in elevation. This habitat type is dominated by *Erica trimera* at higher elevations and *Erica arborea* at lower elevations (Wesche et al., 2000). The species is known to inhabit the Afro alpine and montane vegetation's of the Bale, Arsi, and Ahmar Mountains in the southeast highlands of Ethiopia (Worku et al., 2021).

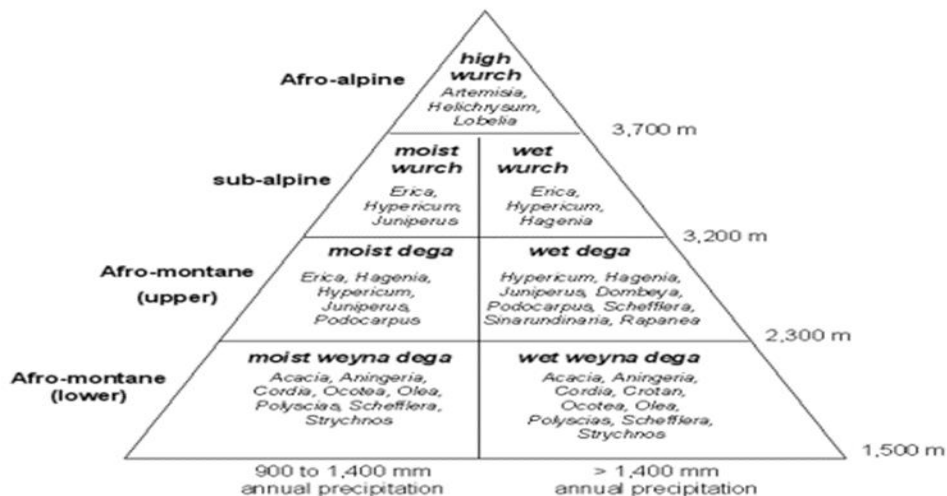


Figure 1: Ethiopia's highlands of major habitat types and sub-types.

#### **2.4.2. Diet requirements**

There have been several insightful observations regarding the diet requirements of Mountain Nyala species. Indeed, the forage use of this species is varied with seasons, habitat types, and land-use activities. For example, Mountain Nyala mostly forage on grass species during the early rainy season when young shoots have greater nutrition values and high digestibility. As Mountain Nyala are mostly browsers, they are able to feed on a variety of vegetation. Herbs and shrubs are good sources of food for Mountain Nyala. However, Mountain Nyala occasionally feed on lichens, ferns, fallen leaves, fruits, cultivars, and aquatic flora suggests that Mountain Nyala rarely drink water (Solomon, 2014).

#### **2.4.3. Population of Mountain Nyala**

The first attempt to determine the total population has been conducted by (Brown, 1969). From observations in the Arussi and Bale Mountains, he estimated that Mountain Nyala numbers ranged between 7,000 and 8,000 individuals. Hillman, (1986) reported that the population of Mountain Nyala at Bale Mountain National Park was 1,500 and that the total population was 3,000. Refera & Bekele, (2004) reported a total Mountain Nyala population of 1,000 with 95 % of the population found at BMNP headquarters and Gaysay Valley. The most regular estimates of populations Mountain Nyala species have been conducted by the EWCD and ORLNRD. EWCD is the federal agency responsible for managing all wildlife in Ethiopia, in cooperation with each regional government, and is responsible for setting hunting quotas. Based on ORLNRD and EWCD census reports between 2002 and 2005, total population estimates in the six CHAs are 2,483 mountain nyala (Evangelista et al., 2007).

A census of Kuni-Muktar Wildlife Reserve by EWCD in 2002 suggested that Mountain Nyala estimates to be approximately 200. Refera & Bekele, (2004) estimated the population of Mountain Nyala in Gaysay Valley and Park Headquarters of BMNP to be 732. And Evangelista estimated the population of Mountain Nyala at the Galama and Chilalo to be between 125 to 150 in 2000 (Evangelista et al., 2007). These estimates only represent a portion of the total area of Mountain Nyala are known to inhabit, nor do they reflect large amounts of potential habitat that has yet to be surveyed. Based on these estimates, it is reasonable to settle that the total population of mountain nyala in Ethiopia exceeds 4,000 (Evangelista, 2006).

A recent survey has indicated the total population of mountain Nyala may be lower, perhaps up to 2500 and the largest population currently occurs outside Bale Mountain National Park on the eastern escarpment of the Bale massif, mainly in Besemena Odobullu and Shedom Berbere, and it has indicated the population decreasing ( IUCN, 2016; Abebe et al., 2020).

#### **2.4.4. Threats of Mountain Nyala**

Threatened by illegal hunting, destruction of montane forest and heathlands, encroachment by cattle, expansion of high-altitude farmland, roads, and harassment by dogs. Permanent occupation of suitable habitat as a result of increasing human and livestock populations is exerting tremendous pressure on Mountain Nyala habitat throughout the range, with anecdotal evidence suggesting they actively avoid livestock disturbance ( Solomon, 2014; Gashaw, 2015; IUCN, 2016; Worku et al., 2021). Its restricted range, and fragmented populations, make it highly vulnerable to human activities and stochastic events (Worku et al., 2021).

#### **2.5. Causes and consequences of wildlife habitat degradation**

Wildlife is a land resource of cultural, ecological and economic significance. It is a renewable resource whose survival depends, among other factors, on the suitability of habitats. The importance of habitats is derived from their ecological roles in provision of shelter, breeding places, dispersal and foraging grounds for a variety of wildlife species. They also allow free movement for animals to other geographical localities where access to critical resources for wildlife species survival and exchange of the genetic material occur. Wildlife habitats are, therefore, critical components for ecological integrity and the long-term survival of the ecosystem or continuity of species (Hassan, 2006).

When resources in a habitat for a given species is diminished or disturbed by natural or manmade factors it is termed as habitat degradation which poses serious threats to the wildlife leading to its extinction. The major factors that are responsible for wildlife habitat degradation are Habitat loss, soil erosion, deforestation, desertification, Climate shift, overgrazing, bush fires, mining, resource depletion, urbanization, cultivation, invasive species and habitat fragmentation. All these factors are responsible to upset the habitat and the resulting habitat is unfit for the survival of animals, so major biodiversity is lost (Batool & Hussain, 2016).

Driven by human population growth, unsustainable consumption of natural resources, and policies that do not fully value biodiversity, habitat destruction is widely accepted as the leading cause of

wildlife extinction rates in recent decades (Evangelista et al., 2012). In many cases, the absence of adequate survey data to monitor wildlife populations and distributions prevents timely management and conservation decisions that could ultimately save a species or population. This is especially true with rare and endangered species in developing countries, where wildlife managers have limited resources and information to formulate effective conservation strategies. Given the urgency with many at-risk species, wildlife managers are increasingly looking for new approaches to assess a population's range and distribution, identify critical habitats, and guide conservation priorities.

## **2.6. Application of remote sensing and GIS in wildlife suitable habitat study**

Geographically explicit models have become extremely powerful tools for representing the species-habitat relationship and they are extensively used in applied contexts for management. A variety of statistical and mathematical models have been developed in the last decades for the representation of species habitat relationships (Ikhumhen et al., 2020).

The application of remote sensing (RS) and GIS (Geographic Information Systems) is the most common technique used which has immense significance in the modeling and mapping of species habitat suitability. This is due to the fact that remote sensing data have the ability of detecting and monitoring the physical characteristics of an area remotely at a distance hence making it an important parameter for analyzing species habitat suitability (Ikhumhen et al., 2020; Store & Jokimäki, 2003).

Remote sensing and GIS technologies were used for gathering information regarding physical parameters of wildlife habitats and geospatial modeling of wildlife habitat suitability (Ahmad et al., 2018; El Kafrawy et al., 2020; Kushwah, 2012; Kushwaha & Roy, 2002). 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 (Sundaresan et al., 2008). Therefore, the application GIS in wildlife suitable habitat study improves decision making utility (Zhang et al., 2020) and it is essential tool in species conservation (Stratmoen & Hood, 2021).

### **2.6.1. 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 (Guisan & Zimmermann, 2000; Stratmoen & Hood, 2021). Further, wildlife habitat suitability modeling has been advanced by the application of 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 (Kafley, 2008). The deductive habitat suitability models use literature and expert knowledge to identify suitable combinations of environmental variables (Carvalho et al., 2012; Imam & Yohannes, 2013). The deductive habitat 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 (Zarri et al., 2008). 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 (Imam & Yohannes, 2013; Treves et al., 2020).

### **2.6.2. Multi-Criteria Decision Making/Analysis (MCDM/A)**

MCDM/A is a framework that can help decision-makers and scholars to choose among alternatives by showing the tradeoffs between the criteria, which enables them to make choices in a rational, consistent, and documentable manner and the primary issue in Multi-criteria Evaluation (MCE) is concerned with how to combine the information from several criteria and to form a single index

of evaluation (FAO, 2009). As stated by Eastman, (2001) the framework includes a procedure such as: defining the desired objectives, selecting evaluation criteria, identifying the alternatives, selecting performance indices/ measurement scales, constructing an evaluation matrix of the alternatives vs. the criteria array, and performing the selection process.

A decision is a choice between alternatives and in wildlife, a decision may need to be made about what areas are the most suitable for target species and this requires to set up and test with different variable very carefully through, the MCE and GIS analysis. These variables images representing suitability combined to form a single suitability map from which the final choice will be made. GIS-based decision-support systems sustain decision-makers, in evaluating alternatives to enhance decisions and to achieve specific objectives. Ghosh et al., (2012) explained this as the spatial multi-criteria analysis results depend not only on the geographical distribution of attributes but also on the value judgments involved in the decision-making process and multiple factors must be cross-checked.

Therefore, two considerations are important for spatial multi-criteria decision analysis: the GIS component i.e., data acquisition, storage, retrieval, manipulation, and analysis capability; and the MCDM/A component for example spatial data aggregation and decision-makers' preferences into discrete decision alternatives.

### **2.6.3. Analytic Hierarchy Process**

The Analytic Hierarchy Process (AHP) is one of the most extended MCDM techniques that have been seen as a method that provides a structural basis for qualifying the comparison of decision elements and criteria in a pair-wise comparison technique produces the relative preference weight for each criterion. AHP was first developed by Saaty in the late 1970s, which is a simple and flexible decision-making tool to conduct a MCE that can be used with integrated GIS spatial analysis for the site selection in wildlife habitat and has been used to estimate weights of various sets of criteria, which are then integrated with GIS to display the location and size of those ranked wildlife destinations (Marinoni, 2004; Khwanruthai, 2011; Chaudhary et al., 2022).

The AHP with GIS combines decision support methodology with powerful visualization and modelling capabilities which in turn the creation of wildlife suitability map and the Combination of GIS capabilities with MCDM techniques involves the phases of intelligence, design, and choice

to assess the wildlife sustainability by matching the characteristics of an area with those attributes most appropriate for wildlife species (Khwanruthai, 2011).

There are five steps to be sequentially performed to output a structured decision using expert judgment through AHP (Marinoni, 2004). These are: Model the problem as a hierarchy, establish a pair-wise comparison matrix to evaluate the priorities among the elements of the hierarchy, synthesize those judgments to yield a set of overall priorities for the hierarchy, check the consistency of the judgments, final decision based on the results of the process.

## **2.7. Criteria or parameters of habitat suitability for Mountain Nyala**

The description of the physical and biological properties of an animal's preferred habitat can be referred to as habitat use (Everett, 1991). The knowledge acquired by such studies is imperative to the successful conservation of habitat and is a precondition for the conservation of target species. The knowledge obtained also permits a man to manipulate the key habitat factors essential for the animals' survival and is a prerequisite for the prediction of a successful reintroduction of a species.

In the BMNP, different habitat requirements affect the habitat suitability of Mountain Nyala species. For instance, the Mountain Nyala are a strong correlation between the species' range and specific weather, environmental and topographic conditions were the most critical variables determining habitat quality of species (Tadesse, 2016). Nevertheless, the habitat deterioration and associated change in its vegetation composition which is getting worse, in the BMNP, could have negatively affected the wildlife preferred habitat and its supplies to the species. This could in turn negatively affect the number of individuals of the species associated with the habitat, Mountain Nyalas reproduction and survivals in the area (Mamo et al., 2012; Yosef et al., 2015). Since Brown's observation about 35 years ago in the BMNP, a lot have changed with regard to the abundance and distribution range of the species. The number of individuals of the species has decreased across the entire area of BMNP (Worku et al., 2021).

In addition, most of the species have been pushed down from the upper altitudes as a result of settlements, roads, cultivation, and grazing (Mamo et al., 2012). Brown, (1969) and Evangelista, (2015) also noted that water distances has been affected the species because Nyala keep their distance close to the permanent water point. This has deteriorated the quality of the habitats and

decreased the vegetation composition available for Mountain Nyala leading them to leave their formerly preferred habitats.

Thus, a study that links available vegetation type, range and composition in the BMNP to the Mountain Nyala habitat preference, selection and utilization, is vital to conservation endeavors aiming to restore or rehabilitate the species habitat suitability and vegetation cover. This suggests it may be important to model the potential habitat and connectivity of these species which presupposes some understanding of the need of a species (Mohammadi, 2022). Therefore, in an attempt that assesses a species habitat requirement and preference, habitat suitability studies of the species is indispensable (Garshelis, 2000).

## **2.8. Empirical evidence**

The literature pertaining to Mountain Nyala ecology reviewed in this study may be limited to work completed at a localized spatial scale. (Evangelista et al., 2007; Mamo, 2007) produced a detailed study on the ecology conservation of Mountain Nyala in the Bale Mountain National Park (Atickem, 2013) studied their general behavioral ecology in the southern highlands of Ethiopia. Aspects such as conservation, population size, habitat preferences, social organization and home range size are adequately covered by ( Hillman, 1986; Atickem et al., 2011; Yosef et al., 2015; Tadesse, 2016; Worku et al., 2021). (Befekadu, 2001) evaluated the populations status and diurnal activity pattern in Bale mountain National Park; (Mamo, 2015) subsequently compared (Brown, 1969) population numbers in demography and population dynamics to a 2012 Mountain Nyala population census (Mamo et al., 2012). However, many ecologically centered Mountain Nyala studies can be criticized because of the paucity of habitat evaluation information at a regional scale. No studies have examined Mountain Nyala habitat corridors or habitat linkages using Geospatial platforms.

## **2.9. Conceptual framework/Research paradigms**

In order to conserve wildlife habitat information on the spatial suitability of the habitat is necessary for more effective policies and planning for these valuable resources. The study will describe the habitats and spatial preferences of Mountain Nyala (*Tragelaphus buxtoni*) in BMNP. This is a multi-criteria study whereby it involves more than one input. The inputs are GIS survey Mountain Nyala movement points collected by using GPS, Base map of BMNP, and satellite imagery such

as sentinel 2A. GIS has become a promising tool for the information on physical parameters of the wildlife habitats and geospatial modeling for BMNP habitat Suitability management.

# CHAPTER THREE

## 3. MATERIALS AND METHODS

### 3.1. Description of the study area

#### 3.1.1. Location

Bale Mountains National Park (BMNP) is geographically located between  $6^{\circ} 29' - 7^{\circ} 10' N$  latitudes and  $39^{\circ} 28' - 39^{\circ} 57' E$  longitudes. It is situated on the southeast Ethiopian plateau, in Bale Zone of Oromia National Regional State. The Park headquarter is on the northern border at Dinsho, 400 km from Addis Ababa. Administratively, the park boundary falls in four Weredas of Bale zone and one Wereda of West Arsi zone: Dinsho (north), Goba (northeast), Mena (southeast), Harena (southwest) and Adaba (west) and covers 26 rural kebeles.

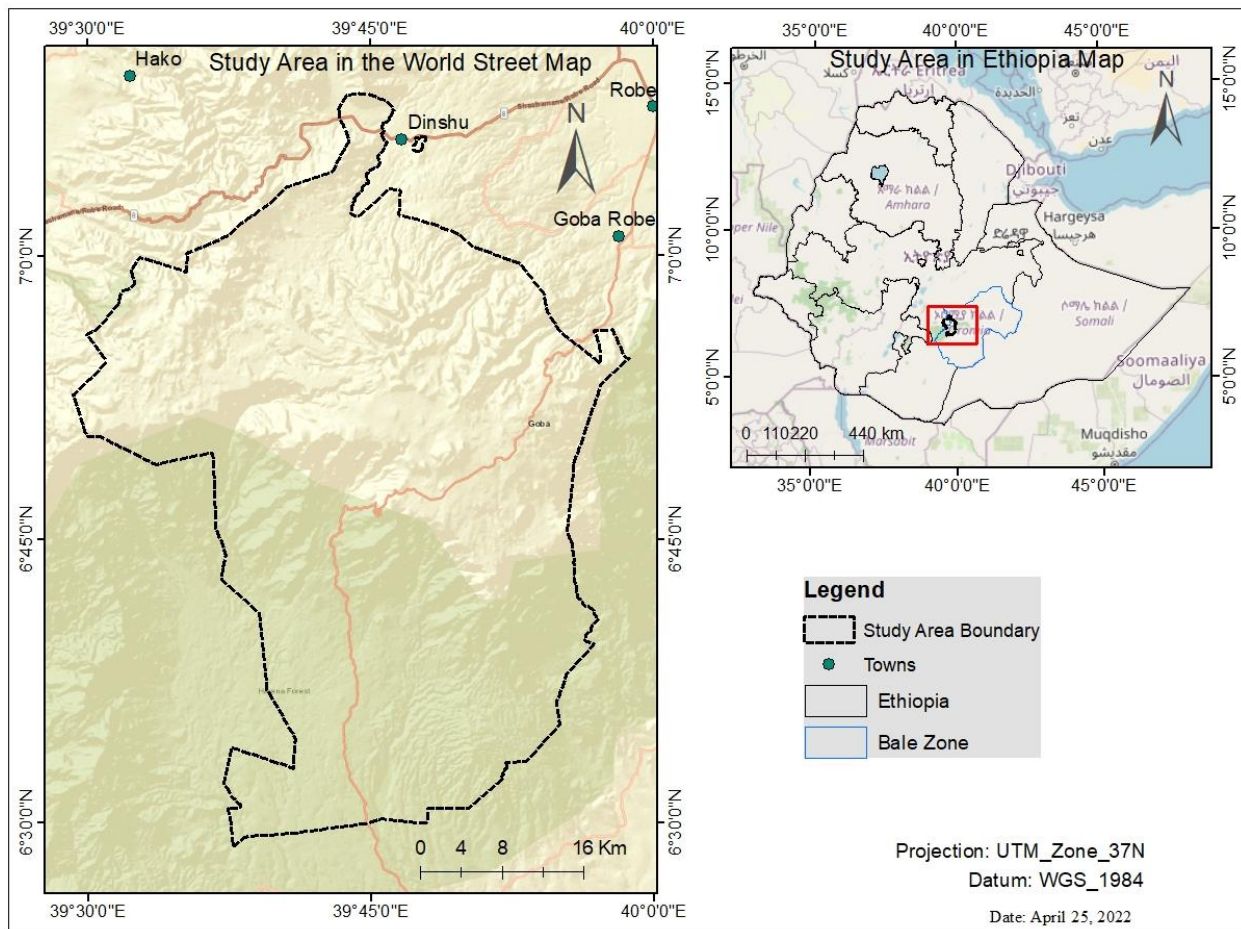


Figure 2: Location map of the study area

The Park was first proposed in the 1960s, by the late Leslie Brown and John Blower, and established as a park in 1970 to conserve the endemic and endangered species Mountain Nyala (*Tragelaphus buxtoni*) and Ethiopian Wolf (*Canis simensis*). Finally the BMNP gazette and formally announced through proclamation number 338/2014 under Council of Ministers Regulation with an area of 2,150 km<sup>2</sup> (BMNP, 2017).

### **3.1.2. Ecological and major habitats classification**

The Bale Mountains National Park are a center of endemism, and evolution for several biological taxa and is part of the Eastern Afromontane Hotspot of Biodiversity area (Richman et al., 2013). The Park is comprised of three major zones and five major habitats division based on vegetation type and altitude. The three park zones are: i) the northern Gaysay/Adelay forest and grassland area having elevation from 3000 to 3500m.a.s.l. ii) the central peaks and Sanetti plateau Afro-alpine vegetation areas with an elevation between 3500 and 4389m.a.s.l. and iii) southern Harena forest area falling in the elevation of 1600m to 3500m.a.s.l.(BMNP, 2017).

### **3.1.3. Topography**

Bale Mountain is a chain of mountains structure; to the west, north and east by an extensively formed plateau of approximately about 2500 m. They rise to a high altitude plateau the higher proportion of that is over 4000 m and rapidly fall away to the south on the Harena Escarpment Forest. The plateau is result of ancient volcanic rocks dissected by many rivers and streams which have cut deep gorges into the edges over the centuries. In some areas this has resulted in scenic waterfalls (BMNP, 2022). From the plateau rise numerous mountain massifs of rounded and craggy peaks, consisting of Tulu Dimtu the second-highest mountain in Ethiopia at 4,377 meters a.s.l. The major part of the central peak's region is covered by a capping of more recent lava flows, still mainly un vegetated, and forming spectacular rock ripples and pillars. Many shallow depressions on the plateau are filled with water in the wet season, forming small lakes which mirror the surrounding scenery (Aisha Tours Ethiopia, 2022).

### **3.1.4. Climate**

#### **3.1.4.1. Temperature**

Temperature of the area is variable, mainly in areas of the highest altitudes during the dry season and more or less the same pattern of temperature during the wet seasons. The highest temperature is 12.60<sup>0</sup>c in March and the lowest temperature is 5<sup>0</sup>c in December. However, the temperature of

the park normally ranges between 5<sup>0</sup>c and 20<sup>0</sup>c. The warmest period of the year is between March and April. The coldest period is between November and December and it can reach up to 1.5<sup>0</sup>c (EMA, 2021).

#### **3.1.4.2. Rainfall**

Rainfall in BMNP is bimodal, with heavy rain during June-October and short rain during March-June. The annual rainfall ranges from 1000 to 1400mm. Over 60% of the annual rainfall occurs between April-September or wet seasons. The Bale Mountain massif plays a crucial role in climate control in the areas, attracting large amounts of orographic rainfall. Rainfall can occur in any month of the year, although peak rainfall occurs between March and October, peaking in August and March. Some 600-1000mm falls annually in the lower altitude areas, and 1000-1400mm in the higher areas (EMA, 2021).

#### **3.1.5. Geology and Soils**

Geologically, the Bale Mountain massif consists of Tertiary (Oligocene) lavas, which covered the Mesozoic marine sediments by underlying the Precambrian rocks after the Eocene uplifting of Ethiopian highlands. During the Plio-pleistocene rifting phase, the Arsi-Bale massif was separated from the northwest Ethiopian mountains by the rift valley system, which also isolated the southwest Arabian part of land mass. As the upper geological strata of the Bale Mountains are entirely volcanic, the soils mainly derived from the basaltic and trachytic parent rock, are fairly fertile silty loams of reddish-brown to black color (Befekadu, 2001).

#### **3.1.6. Vegetation and Wild Animals**

Bale Mountains National Park (BMNP) possesses one of the highest incidences of animal and plant endemism of any terrestrial habitat in the world. In BMNP, there are at least 1600 species of flowering plants, of which 163 are endemic (23 to Bale alone) to Ethiopia. In Bale Mountains National Park afro alpine areas of altitude > 3400m.a.s.l have a vegetation composition of *Erica arborea*, *Helichrysum* spp., *Alchemilla* spp., and giant *Lobelia* (*Lobelia rhyncoptalum*) (Jira et al., 2013). The mountains are one of the centers of faunal diversity and endemism, which generate numerous natural processes vital to human existence and support an important reservoir of genetic resources.

Bale Mountains National Park is the home of diversity and endemism of fauna (Hillman, 1986). The park is to largest population of both the endemic and endangered Mountain Nyala

(*Tragelaphus buxtoni*) and Ethiopian wolf (*Canis simensis*) and, as well as the endemic Bale monkey (*Chlorocebus djambensis*) and the giant mole rat (*Tachyoryctes macrocephalus*) (All Africa, 2015). The Park has exceptionally wide diversity of habitats from alpine meadows to low land evergreen forests supporting a wide range of plants and animals including 5 of the “unique 7” which refers to five distinctive and endemic mammals found only in Ethiopia; Mountain Nyala, Ethiopian wolf, Giant mole rat, Menelik Bushbuck and Bale monkey. It protects a broad range of habitats from 1,500 m asl in moist montane forest and ericaceous shrub land to 4370 m.a.s.l in Afro- alpine. Over 310 bird species have been recorded in BMNP to date, about 20% of the species recorded for Ethiopia. Among the endemic birds of Ethiopia, 57% are found in Bale Mountains (Hillman, 1986). Due to its unique diversity and density of rodent community it is also very important for many rare large eagles, vultures and raptors.

### **3.1.7. Drainage**

Ethiopia's high plateau is home to numerous rivers, earning it the nickname "the water tower of Eastern Africa." These rivers flow from the highlands and out through deep valleys and gorges throughout the country. BMNP is an essential water catchment and source of more than 40 rivers and streams, which includes 5 major rivers: Wabe Shebelle, Welmel, Dumal, Web, and Ganale. The mountains and forests of this ecosystem are a significantly essential water catchments region offering perennial water to more than 20 million people in the lowland regions of Ethiopia, Somalia and Northern Kenya mainly in the dry season (BMNP, 2017).

The rivers also serve to generate hydroelectric energy such as the Melkawakena hydroelectric power station plant of Wabe Shebelle River, which generates energy for the entire Bale demand operates due to the streams flowing from the Bale Mountains. The mini hydroelectric energy at Delo-Mena additionally generates power from the Yadot River which is a tributary of the Genalle River.

This Water body's different crater lacks, wetlands, streams and big rivers located throughout the park that is home to different watering birds, amphibians and used as a water point for the wildlife exist. The water sources are essential ecotourism attraction and there are various natural mineral water springs, known as Hora, that are locally believed to offer a vital source of minerals for livestock.

### 3.2. Materials and software's

The modeling approach used to integrate Mountain Nyala 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 model of Mountain Nyala has been generated via analytical hierarchy process (AHP) using AHP template software. The overly analysis to combine the habitat factors layer map with their respective weight were conducted using ArcGIS 10.8 software spatial analyst extension. Details of software and instruments used in this study are presented in Table 1.

Table 1: The software's and instrument were used to execute the study

No	Types of Software's and instruments	Description
1	ArcGIS 10.8	For data editing, digitizing, creating, analyzing and mapping
2	ERDAS Imagine 15	For satellite image preprocessing and classification
3	AHP excel template	For weighting factors
4	Global Mapper 20.0.1	Map generation
5	GPS 78	Coordinate data collection on the site
6	Google Earth Pro	Visualize current park level and Accuracy assessment for land-use land cover

### 3.3. Research Design

From the mixed approach (qualitative and quantitative), a triangulation research design was selected to conduct this study. This research design enables the researcher to collect both quantitative and qualitative data concurrently in a short period of time. The investigator applied

this design because the concurrent mixed approach enables a gathering of quantitative and qualitative data at the same time and in a short period of time. The overall purpose of this design is to collect data from different sources and applied in the triangulation method to enable and improve the quality of the data during the analysis and interpretation. In concurrent triangulation design, the researcher collects both quantitative and qualitative data concurrently and then compares the two databases to determine if there is convergence, deference, or some combination (Creswell, 2012).

### 3.3.1. Data type and Sources

For GIS-based analysis, the input remote sensing data were collected from various sources and relevant information was extracted. Accordingly, the following data shown (Table 2) were obtained from various governmental and non-governmental organizations.

Table 2: List of data used and their sources

No	Data types	Source	Remarks
1	SRTM-DEM	United States Geological Survey ( <a href="https://earthexplorer.usgs.gov">https://earthexplorer.usgs.gov</a> )	30m
2	Sentinel-2A multispectral satellite images	United States Geological Survey	10m spatial resolution (Path168/55) and (Path167- Row/55/56)
3	Meteorological data (Temperature and Rainfall)	National Metrological Service Agency	30 Years Data
4	Study area Boundary	Bale Mountain National Park	Shape file
5	Road Network	Ethiopian Wildlife Conservation	Shape file
	River	Authority and Frankfurt	
	Settlements	Zoological Society – Bale Mountains Conservation Program	
6	Soil types	Food and Agriculture Organization	1:5 000 000

### **3.3.2. Study area selection and sampling**

The study area is purposefully selected for different reasons especially, the park has diversified ecotourism resources that are very sensitive for disturbance, endowed with the different representative ecosystems, and harbors several rare and endangered species.

Purposive sampling was employed to select the key informant interviews (KIIs) and focus group discussions (FGDs) from stakeholders and community members of the park based on the responsibilities they have, their knowledge, experience, representativeness, high population distribution and their proximity to the park.

### **3.4. Data collection tools**

The study implemented both primary and secondary data collection tools. To get the relevant information in order to meet the stated objectives of the research study. Two types of primary data collection methods were utilized: contact (key informant interviews and focus group discussions) and field observation methods. Review of data from secondary sources were used to set weight and rank the suitability analysis factor. Generally, the following tools had been utilized in the data collection.

#### **3.4.1. Key informant interviews/KIIs**

In the case of KIIs the checklists were designed and administered with 15 experts and guides (see annexes 1; section B). The checklist mainly focuses on their preferences of factors, and alternatives to the factors to determine the appropriate weights for the analytic hierarchy process (AHP). The KII respondents were asked to suggest their preferences about each factor. The experts were mainly ecotourism association members, park management and expertise, and expertise from two actively working NGO. The key informants were selected purposively based on the responsibilities they have, their knowledge, experience, and relevance about the previous condition of the area and the current situation, extents of its challenge and the contribution of community-based conservation (if there).

Therefore, a total of 15 semi-structured interviews was conducted at each sample with systematically selected from different actors, mainly 3 experts from Ethiopian Wildlife Conservation Authority (EWCA), 2 administrators from Ethiopian Wolf Conservation Program

(EWCP) and Frankfurt Zoological Society \_ Bale Mountains Conservation Program (FZS-BMCP), 5 experts from BMNP, and 5 guides from Nyala guides associates.

#### **3.4.2. Focus group discussion/FGDs**

FGDs were arranged with the community members, leaders and elders of the surrounding community who are knowledgeable in the area of study and the site. In this case, purposive sampling was employed to select the four sample villages namely; Fasile Angeso, Horo soba, Chiri and Gojera from two districts (Goba and Dinsho) based on their proximity to the park, representativeness, high population distribution and availability of the information to the researcher. In the village level, a total of 7 to 10, people were drawn from each target villages. The discussions were held in each village. Open-ended general questions on the research issue were prepared to dig out relevant information from the discussants (see annexes 1; section C). The discussion was made using Afan Oromo and translations was made to Amharic to communicate easily.

#### **3.4.3. Field Observation**

Field observation was applied for identifying and understanding suitable habitat site and for recording information about different natural features and site, through simply observing their characteristics which are located in the district. Ground control point (GCP) was collected through field observation and survey assisted by Global Positioning System (GPS) and datasheet. The data collected involves characterization and biophysical data information, and a photograph was taken using a digital camera. The field observations also support the researchers at the time of determining the scale of importance for factor maps using pairwise comparison technique.

#### **3.5. Method of data analysis**

The study was applied a combined GIS techniques with a multi-criterion evaluation (MCE) framework to develop habitat suitability model for Mountain Nyala species. This helps to identify the basic factors that specie needs to survive and helps to analyze their response to Species Sustainability and ecotourism development (Ganawa et al., 2015). In this process, different criteria were identified and assigned numbers to the evaluation process for the suitability analysis to yield a suitability model.

### **3.5.1. Criteria rating and standardization**

The GIS-based multi-criteria were performed to model Mountain Nyala suitable habitat based on some criteria. To start the suitable habitat identification process, a list of relevant criteria and factors was selected based on literature review from different studies, opinion experience and expertise of experts, and information from various sources.

Accordingly, four criteria and nine factors were identified and used to prioritize for Mountain Nyala habitat suitability modelling (Table 3). These are namely: climate characteristics (temperature (Te) and rainfall (Ra)), topography (slope (Sl) and elevation (El)), environmental characteristics (land use/land cover (LULC) and soil type (So)), accessibility (proximity to river (DRi), proximity to a road (DRo), and proximity to a settlement (DSe)). The factors were prepared to integrate to the GIS environment and for the analysis each factor was converted to raster format and reclassified based on the responses of key informant interview, and previous works.

Therefore, this process helps define the suitable habitats for the Mountain Nyala because the intersect tool allows integrating multiple input layers and create a new layer that contains only the features falling within the spatial extent which are common to all the input layers (Tadesse, 2018). Besides this, to identify and prioritize the factors that affect the habitat suitability of Mountain Nyala has a great role in ecotourism development in order to conserve and maintain the biological richness of the area as well as economic uplifting of the local people (Khwanruthai, 2011).

According to FAO, (1976) land suitability classification standards, the land classes are grouped. Those are highly suitable (S1), moderately suitable (S2), marginally suitable (S3), less suitable (N1), and not suitable (N2). Therefore, Food and Agriculture Organization (FAO) guidelines for land evaluation outlined by (Booth, 1986; Moloudi & Yaghmaeian Mahabadi, 2019) land suitability study, five degrees of suitability classes was applied in this study for analyzing land evaluation of the Mountain Nyala habitat suitability modelling in the study area.

Based on national manuals and guidelines, various publications and literature reviews, and relevant literature suitability levels the criteria, factors, and their ratings was defined (Table 3).

Table 3: Different weight values assigned to the core Mountain Nyala habitat buffer classes in the study area

<b>Habitat requirement</b>		<b>Factor Suitability Rating</b>					<b>Reference</b>
<b>Criteria/factors</b>		<b>High suitable</b>	<b>Moderate suitable</b>	<b>Marginal suitable</b>	<b>Less suitable</b>	<b>Not suitable</b>	
		<b>(S1)</b>	<b>(S2)</b>	<b>(S3)</b>	<b>(N1)</b>	<b>(N2)</b>	
1.Topography	(1) Slope	5.7-16.25 <sup>0</sup>	0-5.7 <sup>0</sup>	16.25-36.86 <sup>0</sup>	36.28-45 <sup>0</sup>	45-90 <sup>0</sup>	Mamo et al., 2012; Su et al., 2021
	(2) Elevation	2800- 3250m	3200- 3650m and 2500- 2800m	3650-3800m and 1800- 2500m	3800-4000m and 1400- 1800m	>4000 and <1400m	Evangelista et al., 2007; Solomon, 2014
2.Environmental condition	(3) Land use /land cover	Closed canopy woodland	Grassland	Heathland /Alpine moorland	Erica forest, Alpine vegetation and waterbodies	Moist montane forest, Bare land and cultivated land	Solomon, 2014
	(4) Soil type	Chromic Luvisols	Eutric Nitisols	Eutric Cambisols	Dystric Histosols and Leptosols	Pellic Vertisols	Questionnaire

3.Climate Characteristics	(5) Temperature	10.5-12.5°C	12.5-15°C and 7.5-10°C	15-17.1°C	17.1-20°C	> 20°C and < 2. 01°C	Gao et al., 2022; Mohammadi, 2022
	(6) Rainfall	900-1400mm	800-900mm	700-800mm	500-700mm	< 500mm	Evangelista et al., 2008; Payne, 2015
4.Accessibility	(7) Proximity to river	< 2.9km	2.9-4.2km	4.2-5.1km	5.1-7km	>7km	Baig et al., 2022; Mosissa et al., 2021
	(8) Distance from roads	>8.5km	7-8.5km	5-7km	1.5-5km	<1.5km	Ahmad et al., 2018; Chaudhary et al., 2022
	(9) Distance from settlement	>13km	10-13km	7-10km	4-7km	<4km	Maiti et al., 2022

### **3.5.2. Classification of criteria maps (in form of 9 GIS-based layers)**

With regards to the acquired information, there were 9 important factors in the form of 9 GIS-based layers incorporated for suitability analysis for Mountain Nyala habitat. These factor maps were overlaid together for final habitat suitability classification of the study area for Mountain Nyala. However, in this process the data of all the selected factors shown in Table 3 are kept, displayed, and managed individually. Because the factors have different scales of measurement; they cannot be compared by their raw scores. Therefore, in order to allow comparability, the factor maps were standardized. Standardization allows comparison of criterion scores within one alternative. In order to standardize, the raster features of all the factors were reclassified into a common scale range. It should be noted that not all attributes have a range from 0 (not suitable) to 1 (high suitable).

#### **3.5.2.1. Topographic factors**

For the topographic variables, slope and elevation were used as they are the most critical topographical factors impacting habitat selection by terrestrial animals (Su et al., 2021). Slope has a great impact on wildlife movements. The largest population of Mountain Nyala prefer steep slope terrains so as to easily escape from risks of predation (Mamo et al., 2012). Hence, slope with the highest degree has given less weight whereas those with the medium degree (i.e., 5.7 to 16.25) have given more weight meaning they are more suitable for Mountain Nyala. Slope measures the rate of change of elevation at a surface location and expressed in degree (°).

Slope of the study area was generated from the 30x30m resolution Digital Elevation Model (DEM) of the country. Hence, DEM data clipped (masked) using the study area of shape file in the analysis tool of ArcMap 10.8. Then, the clipped DEM data were analyzed (reclassified) in the surface analysis tool of ArcMap 10.8 using slope criteria developed for this purpose.

Elevation determines the distribution and abundance of wildlife and influences the plant growth. Previous studies suggested that the highly preferred elevation for the Mountain Nyala ranges between 2500 and 3250 m asl (Brown, 1969; Evangelista et al., 2007; Hillman, 1986; Solomon, 2014). (Table 3). However, the species are generally found between 1800 and 4000 m, but have been observed at elevations as low as 1500 m (Evangelista et al., 2008). The elevation map of the study area was generated from the DEM of the study area which ranges from 1400 to 4389 m.a.s.l and reclassified in the surface analysis tool of ArcMap 10.8.

### **3.5.2.2. Climatic factors**

The habitats of Mountain Nyala are heavily affected by temperature and precipitation, which are known to have direct influences on vegetation structure and diversity (Solomon, 2014). Temperature has the most important influence on the distribution of Mountain Nyala because it determines the physical state of water. It was classified on to common scale with the assumption that the medium temperature amount ranging from 10.5-12.5°C is a more suitable area for the Mountain Nyala wildlife corridor (Table 3).

Concerning rainfall/precipitation supplies the water for feed growth i.e., herbs, bushes, shrubs, and general foliage. Hence, the rainfall surface was classified on to common scale with the assumption that the higher the rainfall amount the more the area is suitable (Evangelista et al., 2008; Payne, 2015). Like other suitability factors, the rainfall is classified into five suitability classes ranging from highly Suitable to permanently not Suitable as shown in Table 3.

Temperature and rainfall data were acquired from National Meteorology Service Agency (NMSA) i.e., the 30 years average temperature and precipitation of nearby stations and then interpolate to the surface or to elevation difference of the study area using inverse distance weighted techniques. Each of the dataset with its associated attribute data are digitally were encoded in the GIS database. A geodatabase including all factor layers created in ArcGIS10.8 then each dataset was raster zed using conversion tools to prepare for reclassification.

### **3.5.2.3. Land use land cover**

Vegetation provides essential requirements for animals, such as cover and food (Mamo et al., 2012). Mountain Nyala needs dense cover for camouflage, and higher grounds and open sightlines to detect the risk of predation and quickly escape. As Solomon, (2014), described that the habitat where the species is found ranges from closed canopy woodlands to grasslands and open alpine moorlands for Mountain Nyala, especially in the rainy season (Table 3). Land use map in 2022 was classified and reclassified into 9 classes of land use/ cover according to bio-physical vegetation characteristics of Mountain Nyala habitat potential resources as seen in Table 4.

Table 4: Description of habitat types in the study area BMNP

<b>Habitat type</b>	<b>Description</b>
Alpine vegetation	It is found in high altitude. Vegetation types of the class are <i>Helichrysum citrispinum</i> , <i>Helichrysum splendidum</i> , and one of the notable plant species is the giant lobelia found from 3,100m to 4,377m growing to a maximum height of 6m (Evangelista et al., 2008; Mamo et al., 2012).
Erica forest	Habitat dominated by one of the two species <i>Erica arborea</i> and <i>Erica trimera</i> , either in tree or shrub form (Solomon, 2014).
Grassland	Area dominated by grass species including <i>Festuca abyssinica</i> , <i>Poa schimperiana</i> , and grass species mixed with other herbs lower than 10 cm of height (Atickem et al., 2011).
Moist montane forest	Habitat with natural and plantation trees including <i>Hagenia abyssinica</i> , <i>Podocarpus falcatus</i> , <i>Maytenus obscura</i> , and other bigger tree species excluding Erica Forest. This area is one of the most extensive natural forests remaining in Ethiopia, called “Harrena forest” (Solomon, 2014).
Woodland	The species that dominate the northern woodlands are the trees African juniper ( <i>Juniperus procera</i> ) and <i>Hagenia abyssinica</i> (Mamo et al., 2012).
Bare land	It is the land which is devoid of vegetation and lava flow areas. Many places on the Sanete plateau which is around central part of the park looks as though they have been ploughed (Tadesse, 2016).
Heathland	Habitat dominated by woody herbs and shrub species forming a closed layer including <i>Achyranthes aspera</i> , <i>Artemisia afra</i> , <i>Carduus nyassus</i> , <i>Echinops ellenbeckii</i> , and others (Mamo et al., 2012).
Cultivated land	Area for farmland and land being prepared for growing crops (barley) (Atickem et al., 2011).
Water class	It refers to rivers and water bodies in the study area (Rwanga, 2017).

Land use land cover of the study area was derived by employing supervised method of image classification using the maximum likelihood algorithm in Erdas imagine 15.1 software. The supervise classification was applied with ground truthing on preprocessed Sentinel-2A multispectral satellite images of the year 2022 which was obtained from United State Geological Survey (USGS) web page (<https://earthexplorer.usgs.gov>). Then the classified image was reclassified according to suitability ranges as highly suitable habitat (woodland), moderately suitable habitat (grassland), marginally suitable (heathland), and other types of vegetation cover are less suitable and not suitable habitat for Mountain Nyala species.

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 (Rwanga & Ndambuki, 2017). 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 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. Overall accuracy, users and producers, and the Kappa statistic were then derived from the error matrices (Congalton, 2019).

The overall accuracy was computed by dividing the total number of correctly classified pixels (Eqn1) (i.e., the sum of the elements along the major diagonal) by the total number of reference pixels.

$$\text{Overall accuracy} = \frac{\text{Total Number of Correctly classified Pixels(Diagonal)}}{\text{Total Number of Reference Pixels}} \times 100 \quad (1)$$

The accuracies of individual classes can be calculated by dividing the number of correctly classified pixels in each category by either the total number of pixels in the corresponding row or column (Eqn 2 and 3). The producer's accuracies result from dividing the number of correctly classified pixels in each category (on the major diagonal) by the number of test set pixels used for that category (the column total). This statistic indicates the probability of a reference pixel being correctly classified and is a measure of omission error. User accuracies are computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category (the row total).

$$\text{User's Accuracy} = \frac{\text{Total Number of Correctly classified Pixels in each category}}{\text{Total Number of Classified Pixels in that category(RowTotal)}} \times 100 \quad (2)$$

*Producer Accuracy*

$$= \frac{\text{Total number of Correctly classified Pixels in each category}}{\text{Total number of Classified Pixels in that category (ColumnTotal)}} \times 100 \quad (3)$$

The other accuracy evaluation of the image classification is Kappa. Kappa was 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 (Rwanga & Ndambuki, 2017). It is a discrete multivariate technique that used in accuracy assessments. Kappa analysis yields a Khat statistics (Eqn4) (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 (Congalton, 2019).

The Kappa factor is given by the formula:

$$Kappa\ Coefficient\ (\hat{k}) = \frac{N(\sum_{i=1}^r x_{ii}) - (\sum_{i=1}^r (x_{i+} * x_{+i}))}{N^2 - \sum_{i=1}^r (x_{i+} * x_{+i})} \quad (4)$$

Where: r = number of rows and columns in error matrix, N = total number of observations (pixels)

X<sub>ii</sub> = observation in row i and column i

X<sub>i+</sub> = marginal total of row i, and X<sub>+i</sub> = marginal total of column i

A Kappa coefficient equal to 1 means perfect agreement whereas a value close to zero means that the agreement is no better than would be expected by chance. As per (Rwanga & Ndambuki, 2017) categorization of Kappa statistics is widely referenced (Table 5).

Table 5: Rating criteria of Kappa statistics

<i>S.No</i>	<i>Kappa statistics</i>	<i>Strength of agreement</i>
1	<0.00	Poor
2	0.00 - 0.20	Slight
3	0.21 - 0.40	Fair
4	0.41 - 0.60	Moderate
5	0.61 - 0.80	Substantial
6	0.81 - 1.00	Strong agree

#### 3.5.2.4. Soil types

Soil is crucial for rating functional landscape for suitability because the fodder for wildlife i.e. grasses and waterlogging characteristics of the land-dependent on the soil type (Brown, 1969; Melese et al., 2014). Soil types were analyzed to identify the most suitable soil for species habitat since it determines the growth of tree plants, grass, mangroves, and other vegetation types. On the gently sloping foothills below the escarpment are relatively fertile chromic luvisols occasionally with high water tables are the high suitable soil types in the study area (Table 3).

Soil types data obtained from the Ministry of Agriculture were used to extract soil types in the ArcGIS 10.8 environment. Soil types were converted to polygon feature and dissolved to grid code which enables to know the area coverage of each category and then reclassified based on their suitability rate.

#### **3.5.2.5. Proximity to river**

The movements of Mountain Nyala shape by the availability of water resources to maintain body condition and reproductive success. Therefore, limited access to water is a significant threat to the survival of wild asses and can negatively affect foal survival (Fanuel et al., 2014; Mosissa & Yesus, 2021). Based on expert opinions, the perennial river buffer zone for the park was determined at the less than 2.9km scale interval assuming that nyala preference for habitat decreases as distance increases from river or water sources (Table 3).

The river shape file of Ethiopia was obtained from ESM and clipped by the study area shape file boundary, then cross-check with the data acquire from Bale Mountain National Park (BMNP) and FZS\_BMCP. Then the proximity factors were processed in ArcMap 10.8 using analysis tools, i.e.; Proximity (buffer) and the river line feature was converted into a raster feature and reclassified into five classes based on the distance from the river. This study has considered distance to major rivers for the selected species of habitat suitability model.

#### **3.5.2.6. Proximity or distance to road and settlement**

Roads within the Park are one of the important parameter and cause disturbance in the park (Ahmad et al., 2018). Buffer road effect on Mountain Nyala species with a buffering distance of 8.5km was classified based on expertise value judgments and previous works. This indicates that habitats that are situated 8.5km away from roads are supposed to be highly suitable (Table 3).

To escape from the disturbance caused by humans and associated activities Mountain Nyala significantly avoids areas mainly from settlement and farmland (Atickem et al., 2011). Some previous studies suggested that a buffering distance of 5km was used in the town buffer analysis to develop a habitat suitability models for the large body sized wild-animal species (Tadesse & Kotler, 2018). This implies that habitats that are situated 5km away from towns are considered to be highly suitable for the Mountain Nyala in the Bale Mountain National Park (Table 3).

The existing road network map and spatial data for the settlement of the study area was acquired from FZS\_BMCP, BMNP, and Google Earth. As for other parameters to integrate into the GIS environment and they were converted to raster format. The analysis was made on the analysis tool (proximity/buffer) in ArcMap 10.8 and reclassified into five classes based on the impacts of the road and town residents on the Mountain Nyala species.

### 3.5.3. Analytical Hierarchy Process (AHP)

For the sack of this study, producing the suitability map of habitat Mountain Nyala in support of GIS and a multi-criteria evaluation is the final output which makes the complex decision-making process by creating a hierarchy of decision criteria. Analytical Hierarchy Process pairwise comparison method was applied for weighting the criterion systematically which helps in determining the relative importance of one criterion over another. The method was introduced in 1977 and was developed and used by Saaty (1987).

The study applied the expert's opinion to calculate the relative importance of the nine criteria involved. In this regard, 15 experts from the BMNP and EWCA were questioned. The questionnaire (Appendix A) used contains the pairwise comparison matrices constructed, where each criterion is compared with the other criteria relative to its importance and scored with a fundamental scale preference from 1 to 9, in which 1 had equal importance and 9 had extreme importance between the two criteria shown in table 6 as explained by Saaty (1987).

The matrix format in pairwise comparisons defines  $A = [c_{ij}]_{n \times n}$  as follows (Appendix B):

$$\begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ c_{1n} & c_{2n} & \dots & c_{nn} \end{bmatrix} \quad (5)$$

Table 6: Saaty's scale for pairwise comparison

Numerical rating	Scale	Interpretation
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance	Judgements slightly favor one criterion over another
5	Strong importance	Judgements strongly favor one criterion over another
7	Very strong importance	A criterion is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one criterion over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed
<b>Reciprocals</b>	Opposites	Used for inverse comparison

Source: Saaty, (1987)

After generating all pairwise comparison matrices, the vector of weights,  $w = \{w_1, w_2, \dots, w_n\}$  is calculated according to Saaty's eigenvector method. This is followed by two steps to calculate weights; first, normalizing the pairwise comparison matrix  $A = [c_{ij}]_{n \times n}$  on the basis of the following equation (Figure 16):

$$c_{ij} = \frac{c_{ij}}{\sum_{j=1}^n c_{ij}} \quad (6)$$

Then, the weight for each criterion is computed by the following equation:

$$w_{ij} = \frac{\sum_{j=1}^n c_{ij}}{n} \quad (7)$$

In the pairwise comparison matrix,  $n$  refers to numbers of elements (Mikhailov, 2003). One of the strengths of the AHP method is measuring the inconsistencies by calculating the consistent ratio (CR) as follows:

$$CR = \frac{CI}{RI} \quad (8)$$

CR specifies the degree of consistency or inconsistency. It denotes the probability that the matrix judgments were made randomly (Saaty, 1977). The CR depends on the consistency index (CI) and random index (RI) and can be calculated as follows:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (9)$$

Where,  $\lambda_{\max}$  is the largest eigenvalue of the matrix,  $n$  indicates the order of the matrix. RI refers to the average of the resulting consistency index, depending on the order of the matrix (Saaty, 1977) (Table 7). If the CR value is  $< 0.10$ , the pairwise consistency is fairly acceptable. On the contrary, if the value is  $> 0.10$ , this indicates inconsistencies in the evaluation and hence the original weights should be recalculated.

Table 7: Value for RI (Saaty, 1987)

<i>Matrix size</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>
<i>RI</i>	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	<b>1.45</b>

In the suitability assessment stage, the weighting linear combination approach is used to produce composite suitability model. All spatial layers were converted into raster models and the reclassify tool was employed to classify all layers to a standardized measurement suitability scale between 1 and 5, where 1 indicates the most suitable while 5 denotes the least suitable. The weighted overlay technique was performed to combine all weighted spatial layers and produce the Mountain Nyala species habitat suitability modelling, using the GIS-based AHP extension developed by (Marinoni, 2004). The technique statistically is implemented by calculating the data layers of habitat suitability modeling were integrated using a weighted linear combination to produce a Mountain Nyala habitat suitability map as follows:

$$HSM = \sum w_k S_{ijk} \quad (10)$$

Where HSM is the habitat suitability model map,  $w_k$  is the assigned weight for criteria  $k$ , and  $S_{ijk}$  is the standardized value of pixel  $(ij)$ . The values of  $S_{ijk}$  range between 1 and 5. In Figure 4 the flowchart methodology of this research is presented.

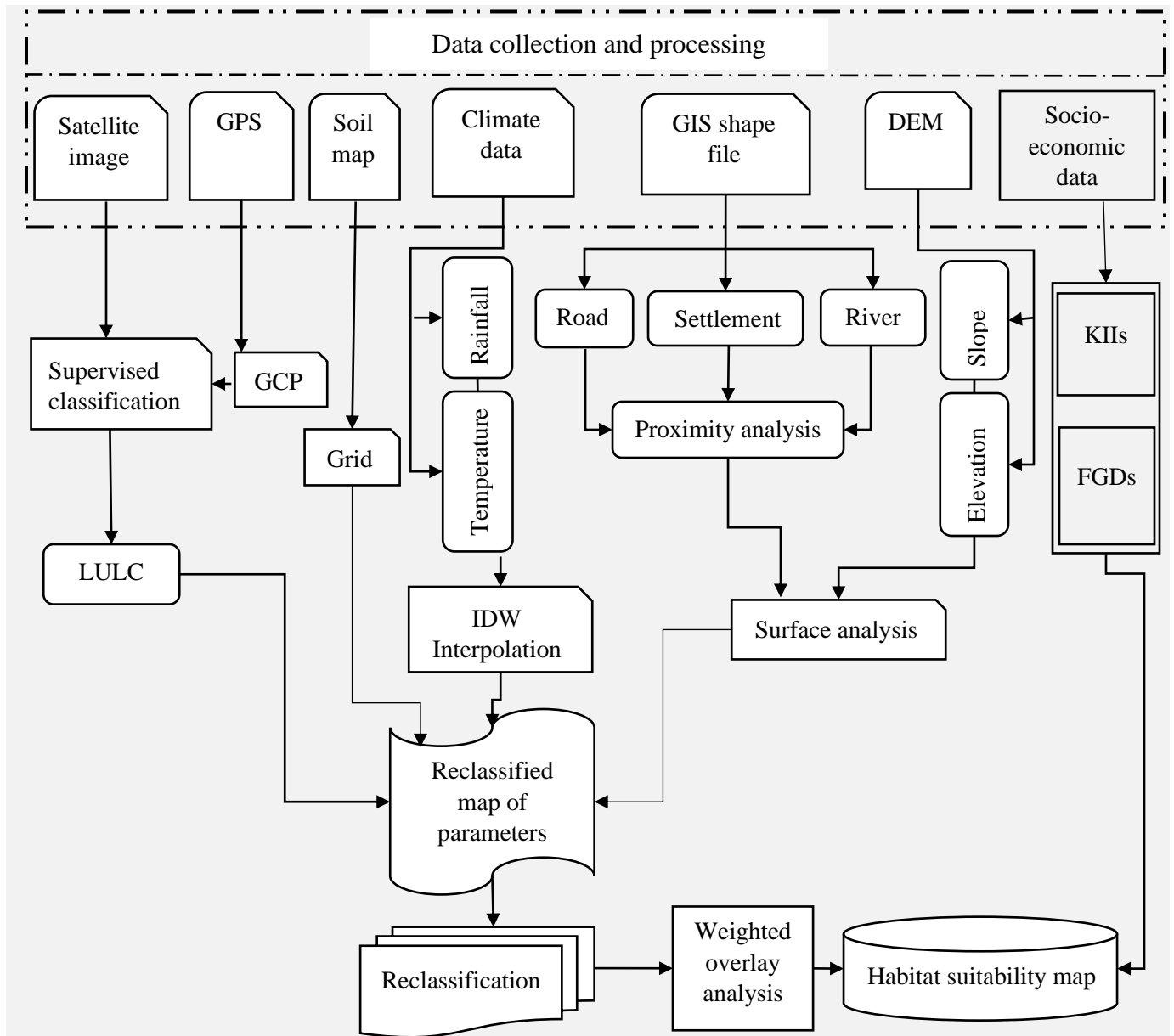


Figure 3: Flow chart of the methodology

## CHAPTER FOUR

### 4. RESULTS AND DISCUSSION

#### 4.1. Habitat suitability data analysis

##### 4.1.1. Land use land cover types

Land use land cover (LULC) maps that depict vegetation and land-use types are essential for modeling Mountain Nyala species habitat suitability and which helps to site a suitable location for the species. The analysis identified 9 LULC types using image analyses. These are afro-alpine vegetation, moist montane forest, erica forest, woodlands, heathlands, grasslands, water bodies, bare lands and cultivated lands. The results of the classified LULC map are shown in Figure 5.

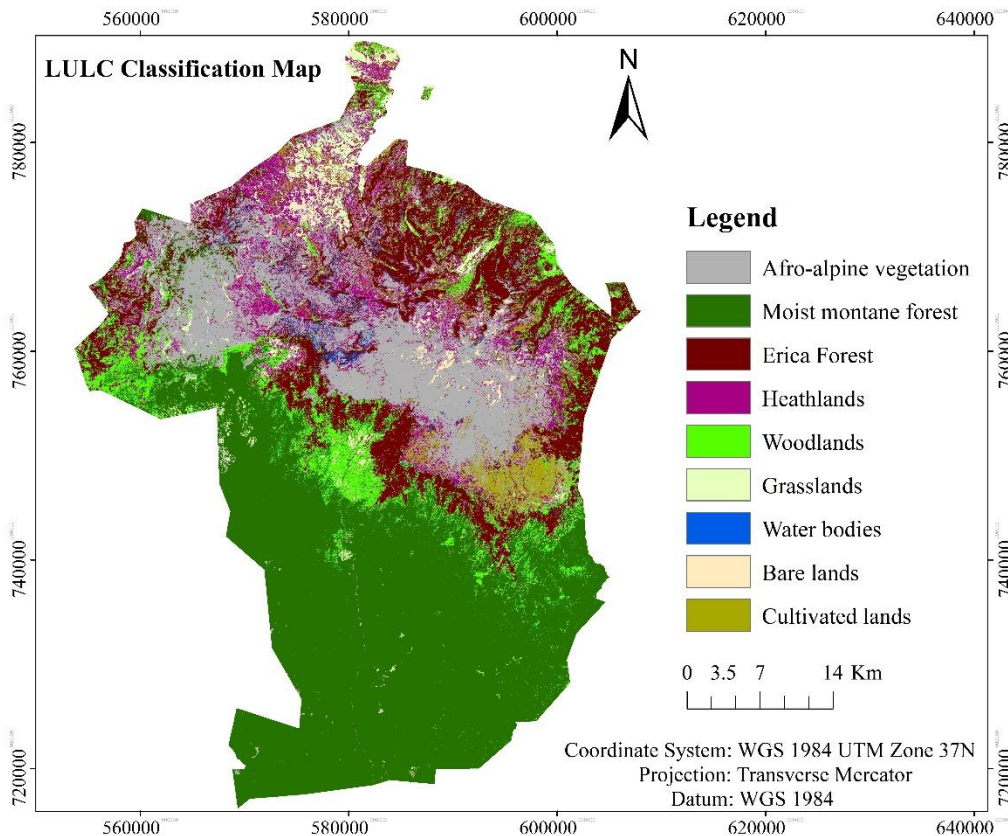


Figure 4: Land use land cover map of the study area in 2022

As shown in table 8, the analysis revealed that Moist montane forests are the major LULC types, which cover 40.1% (86490.04 ha) followed by Afro-alpine vegetation and Erica Forest dominated

that accounting for 17.9% (38685.63 ha) and 15% (32424.71 ha), respectively and the rest other LULC accounts below 10%.

Table 8: LULC types and the area coverage in the study area

Land use land cover classes	Area coverage	
	Hectares (ha)	Proportion (%)
Afro-alpine Vegetation	38685.63	17.9699
Moist montane forest	86490.04	40.1756
Erica forest	32424.71	15.0617
Heath lands	19807.39	9.2008
Woodlands	19780.47	9.1883
Grasslands	7106.17	3.3009
Water bodies	1712.97	0.7957
Bare lands	1673.82	0.7775
Cultivated lands	7598.63	3.5297

The overall accuracy of the supervise image classification was found to be 87.3% and the overall kappa statistics is 0.85 (Annexes 2). Thus, the Kappa results of this study showed a strong agreement for the classified images and the overall accuracies were within the acceptable range for further LULC analysis (Girma, 2017).

#### 4.1.2. LULC reclassified suitability

LULC types were reclassified into five different classes to evaluate their suitability for habitat Mountain Nyala species. Accordingly, woodland get the first rank (i.e., highly suitable); grassland, 2; heathland, 3; erica forest, alpine vegetation and water bodies, 4; and moist montane forest, bare lands and cultivated lands, 5. The result of the reclassified LULC map is shown in Figure 6.

In this study, above 44 % (95681 ha) of the area are ranked as not suitable and less suitable 33% (73127 ha), and less than 10% the area is covered as marginal 9 % (19632 ha); moderate 3 % (7106 ha) and high suitable 9% (19732 ha) (Table 9).

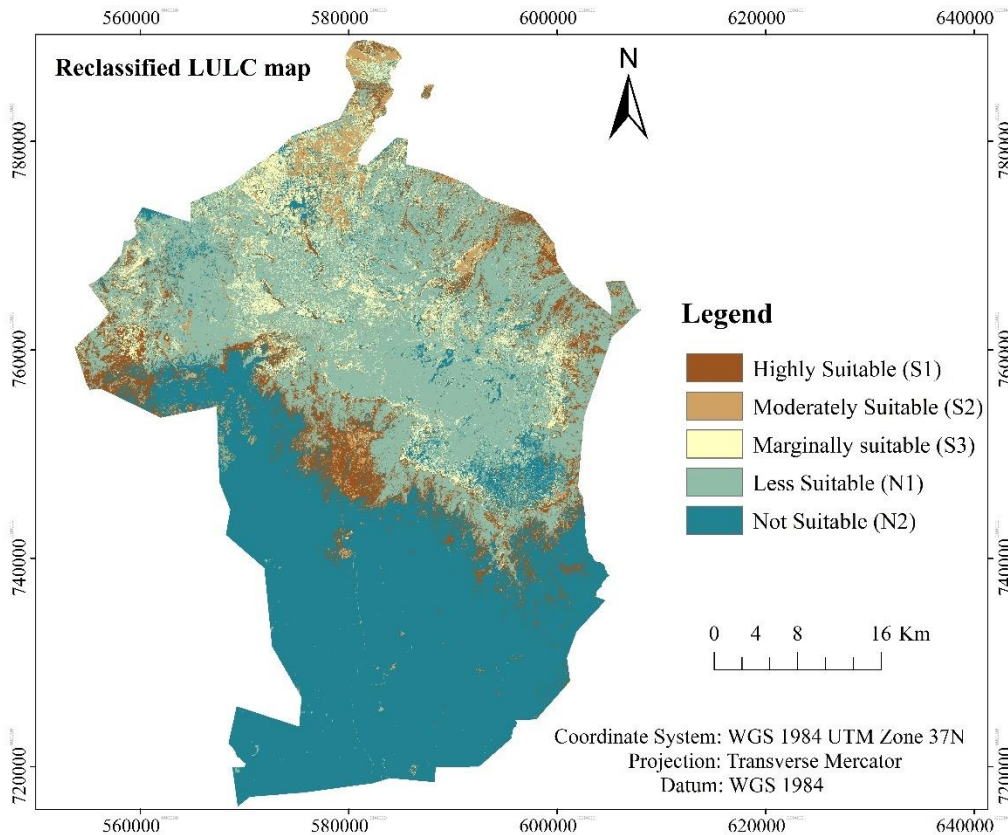


Figure 5: LULC reclassified suitability map in the study area

Table 9: LULC Suitability class and area coverage in the study area

Code	Suitability class	Habitat type	Area coverage	
			Hectares (ha)	Proportion (%)
1	Highly Suitable	Woodlands	19732.17	9.17
2	Moderately Suitable	Grasslands	7106.05	3.30
3	Marginally Suitable	Heathlands	19632.83	9.12
4	Less Suitable	EF, AV and WB	73127.05	33.97
5	Not Suitable	MMF, BL and CL	95681.66	44.45

Mountain Nyala species habitat criteria were used to generate suitability classes for the different LULC types which were used to generate overall suitability analysis. The decision-making process in land use requires to identify the most appropriate spatial pattern. Therefore, the LULC provides significant information for effective wildlife conservation and ecotourism development (Khwanruthai, 2011). As Mountain Nyala is illegally hunted by the local people for bush meat and

skin purposes, it has a good reason to avoid or detect approaching predators including people (Solomon, 2014), so they require open sightlines such as; woodlands, grasslands, and heathlands were given higher value and, identified as suitable areas (Table 9). The assumption, here is that, Mountain Nyala habitat unless such utilize open sightlines, it might request us to clear forested areas which are important habitats for the other wildlife as such intervention on forested area disturbs or damages the park ecosystem. Therefore, forestlands and Afro-alpine areas were considered as not suitable and less suitable areas due to their ecological diversity and sensitivity to disturbance.

The fieldwork and satellite imagery analysis revealed that the park has faced LULC fragmentation and transformations of the main Mountain Nyala species habitats. Field survey and observation confirmed that the local communities depending on the natural resources of the park for their livelihood. It was observed that peoples are expanding far away from settlements villages searching for new farm and grazing-lands. In connection to this, KII respondents indicated that human populations through settlement and expanded agricultural activities have considerably reduced the size of land availability for Mountain Nyala species. Many protected areas in Ethiopia are becoming isolated and the reasons for the isolation include growing human population in areas adjacent to protected areas and land-use change towards agriculture, settlement and infrastructure, in previously unpopulated areas (Worku et al., 2021).

In particularly the Sanetti plateau is degraded, which is the most important place for the conservation of endemic and endangered species. The other most importantly impacted area is northern part of the park, which is the population become increasing over time. KIIs respondents underlined that much of the habitat of Mountain Nyala in the northern and central mountains of its range has become highly altered and fragmented by human settlement and agriculture. When human population pressure increases and agriculture expands, the physical environment of Mountain Nyala is changed. Natural habitats of Mountain Nyala have been destroyed or mostly converted to other unsuitable land use types throughout their ranges of distribution (IUCN, 2016).

The field survey and KIIs verified that human encroachment, the increasing livestock grazing pressures, and the lack of the buffer zone for the park resulted habitat fragmentation on the connectivity process of important biodiversity areas. This is attributed to a lack of corridors to safeguard the Mountain nyala; moreover, the encroachment provides a suitable condition for

invasive plant species like *Solanum incanum* to expand in the open woodland and grassland parts of the park and transforming the habitat into other LULC types.

Meanwhile, most of the park area remains restless by human movement and domestic animals interfering with species mobility, specifically for Mountain Nyala which needs bigger land to survive. Human–wildlife conflicts have also been observed during field studies, particularly in many parts of the park with high intensity and prevalence along major LULC boundaries. Besides, FGDs held with local people the local participants noted that Mountain Nyala have never been seen to graze in an area heavily grazed by livestock in the region and currently facing multi-dimensional threats. These includes potential competition with livestock (i.e., numbers of cattle, horses, donkeys, sheep, and goats) are also negatively affected the land use by Mountain Nyala because livestock outcompete and prevent the Mountain Nyala from using optimal habitats. Besides, through trampling and overgrazing, livestock reduce the availability of habitats for this flagship species (Tadesse, 2016).

Furthermore, livestock induced disturbances may cause high levels of stress and increase diseases and parasite transmission in Mountain Nyala (Solomon, 2014). As per the KIIs and field observation, the human encroachment inside of the park is mainly associated with the discovery of new lands for settlements and farming (crop production), forest, and forest product extraction. The expansion of agricultural activities in moist montane forest accelerated deforestation and resulted significant reduction (in number) and disappearance of many of the Mountain Nyala species in the area. As a result, Mountain Nyala are confined to “sky islands” on a handful of peaks and ridges (Evangelista et al., 2007; Tadesse, 2016).

In line with this finding, different studies done in nature conservation areas confirm that the human encroachment owing to population growth, natural resources exploitation, crop production, livestock grazing, settlement, and natural and anthropogenic fire onset are among main causes for degradation of wildlife areas (Mucova et al., 2018; Kpienbaareh et al., 2022; Sobhani et al., 2022). Based on Ethiopian Biodiversity institute if the heavy utilization of resources continues at the same pace for the coming decades, the more easily accessible highland, Erica-Hypericum woodland might disappear. The studies have associated the Mountain Nyala habitat degradation with a socioeconomic factor with less attention on biodiversity conservation, inadequate collaboration

among development sectors, and poor human settlements programs that adversely degraded ecotourism sites and undermined the economic contribution of the resources.

### 4.1.3. Topographic suitability mapping

#### Slope suitability

In this part, after calculating the slope from DEM, it was further reclassified into a suitable slope class required for Mountain Nyala habitat suitability. The outcome of the categorized slope map is displayed in Figure 7.

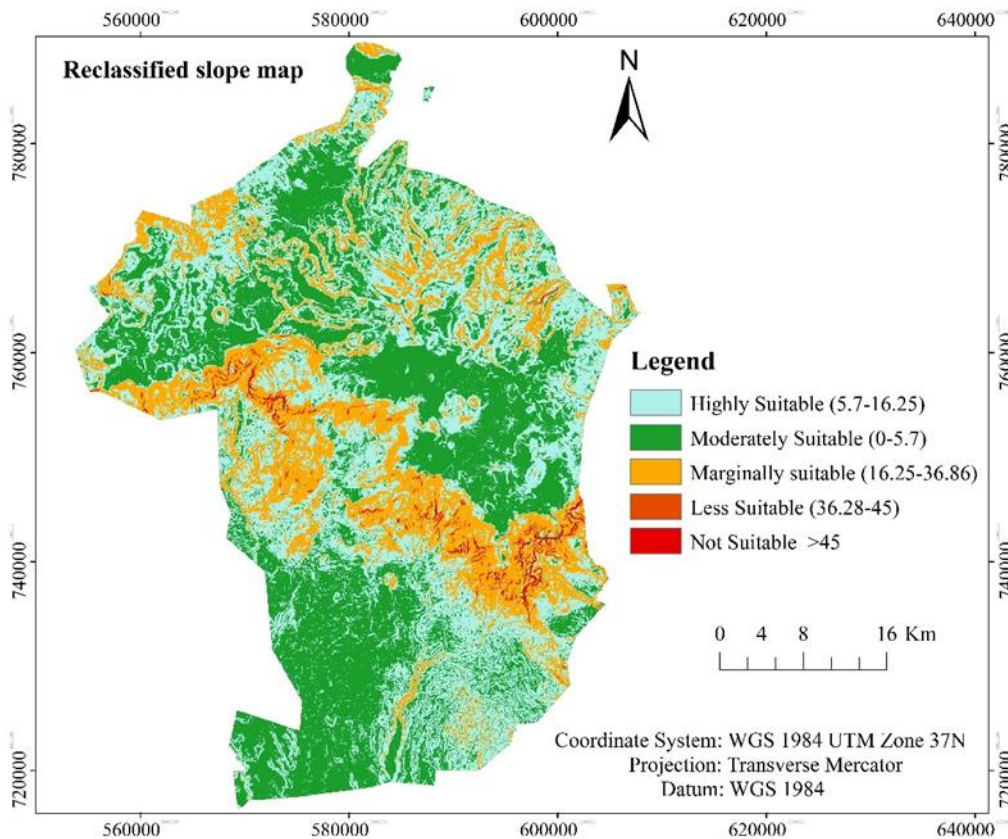


Figure 6: Reclassified slope map of the study area

As shown in table 10, the land having 0-5.7<sup>0</sup> cover relatively larger proportion which accounts about 39.5% (84793.1 ha) which is classed as moderately suitable followed by land with 5.7-16.25<sup>0</sup> and 16.25-36.86<sup>0</sup> slope, covering about 39.2% (84116.9 ha) and 19.8% (42513 ha) which classed as highly suitable and marginally suitable, respectively.

Depending on the slope, the two cover the smallest classes, i.e., Less suitable and not suitable classes respectively account 1.1 and 0.5%, which cover 2280.7 and 998.7 ha.

Table 10: Suitability class based on slope and the area coverage

Code	Score range	Suitability class	Area coverage	
			Hectares (ha)	Proportion (%)
1	5.7-16.25 <sup>0</sup>	Highly Suitable	84116.9	39.2
2	0-5.7 <sup>0</sup>	Moderately Suitable	84793.1	39.5
3	16.25-36.86 <sup>0</sup>	Marginally suitable	42513.0	19.8
4	36.28-45 <sup>0</sup>	Less Suitable	2280.7	1.1
5	45-90 <sup>0</sup>	Not Suitable	998.7	0.5

Slope predictor variables were the most important in having the greatest contribution to the habitat suitability model. This variable estimation from DEM delivers the extent of flatness and steepness of the area (Melese et al., 2014; Chaudhary et al., 2022). The study area was divided into five slope categories: level to gentle slope or flat with slope degrees varied between 0.00 and 5.70; moderate slope ranges between 5.70 and 16.25; strong to steep slope ranges between 16.25 and 36.86; very steep slope ranges between 36.28 and 45.00; and extremely slope or cliff ranges between 45:00 and 90.00 as designated by (Mamo et al., 2012). The moderate or steep slope is seated as the more suitable habitat for Mountain Nyala species, which should not be surprising given that the species needs steep slope terrains to easily escape from poaching and also for predator avoidance (Atickem et al., 2011; Tadesse, 2016).

### **Elevation suitability**

To analyze the elevation over the study area, the whole elevation data was evaluated which ranges from 1400 to 4389 meter above sea level. The five elevation zones, i.e. (2800-3250m, 3200-3650m and 2500-2800m, 3650-3800m and 1800-2500m, 3800-4000m and 1400-1800m and >4000m and <1400m) and was ranked as 1, 2, 3, 4 and 5 with description ranging from highly Suitable, moderately Suitable, marginally suitable, less Suitable and not Suitable respectively, are given in Figure 8.

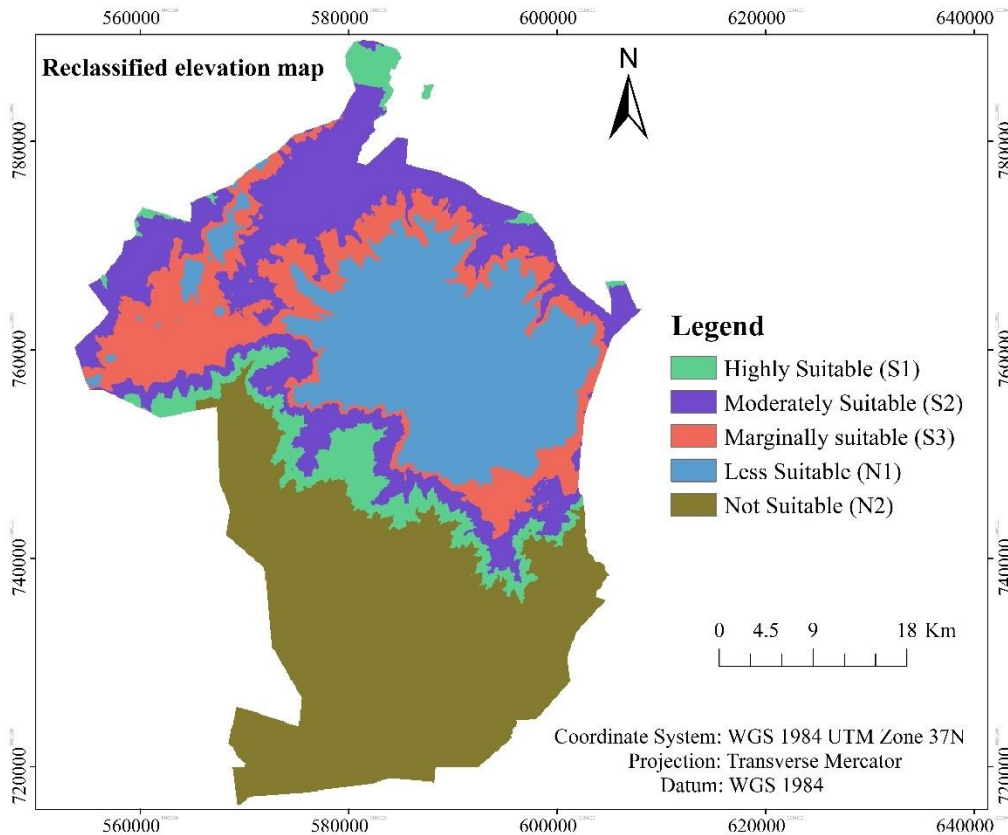


Figure 7: Reclassified elevation map in the study area

As indicated in table 11, areas with the extremely high and low altitude (>4000 and <1400m a.s.l.) are ranked as not suitable covers an area of 78220 ha, 3800-4000m and 1400-1800m a.s.l as less suitable covers an area of 47599 ha, 3650-3800m and 1800-2500m a.s.l as marginally suitable covers an area of 31586.8 ha, 3200-3650m and 2500-2800m a.s.l as moderately suitable covers an area of 43104.4 ha and the highest altitude in the study area 2800-3250m a.s.l are ranked as highly suitable covers an area of 14758.5 ha.

Table 11: Suitability class based on elevation in the study area

Code	Altitudinal range (m)	Suitability level	Area coverage	
			Hectares (ha)	Proportion (%)
1	2800-3250	Highly Suitable	14758.5	6.9
2	3200-3650 and 2500-2800	Moderately Suitable	43104.4	20.0
3	3650-3800 and 1800-2500	Marginally suitable	31586.8	14.7

4	3800-4000 and 1400-1800	Less Suitable	47599.0	22.1
5	>4000 and <1400	Not Suitable	78220.0	36.3

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Another variable to strongly affect the predicted suitable habitat is elevation because the Mountain Nyala is often found in high altitude areas so as to avoid human and livestock disturbances. However, as human population and demand for cultivated lands expand, Mountain Nyala populations will become increasingly fragmented and isolated to smaller and smaller patches of habitat even at higher elevations (Solomon, 2014). This may prevent long distance movements and dispersal of Mountain Nyala and thereby limit gene flow among populations of the species and may ultimately cause deterioration of genetic viability in Mountain Nyala species. Previous studies also noted that the species are commonly reported to be found in a mosaic of high-altitude, ranging from 2700 m up to 4300 m above sea level (Evangelista et al., 2007; Mamo et al., 2012; Mamo, 2015). Even though, their range is much broader than previously reported, and they are distributed across a variety of montane forest habitats. For example, based on the key informants the Mountain Nyala observed at elevations as low as 1,600 m occupying dense forests.

#### **4.1.4. Climate suitability mapping**

##### **Rainfall suitability**

The rainfall map was reclassified into five classes i.e., rainfall value between 900 and 1400mm was ranked as 1 (i.e., highly suitable), between 800 and 900mm as 2, between 700 and 800mm as 3, between 500 and 700mm as 4, and <500mm as 5 (Figure 9).

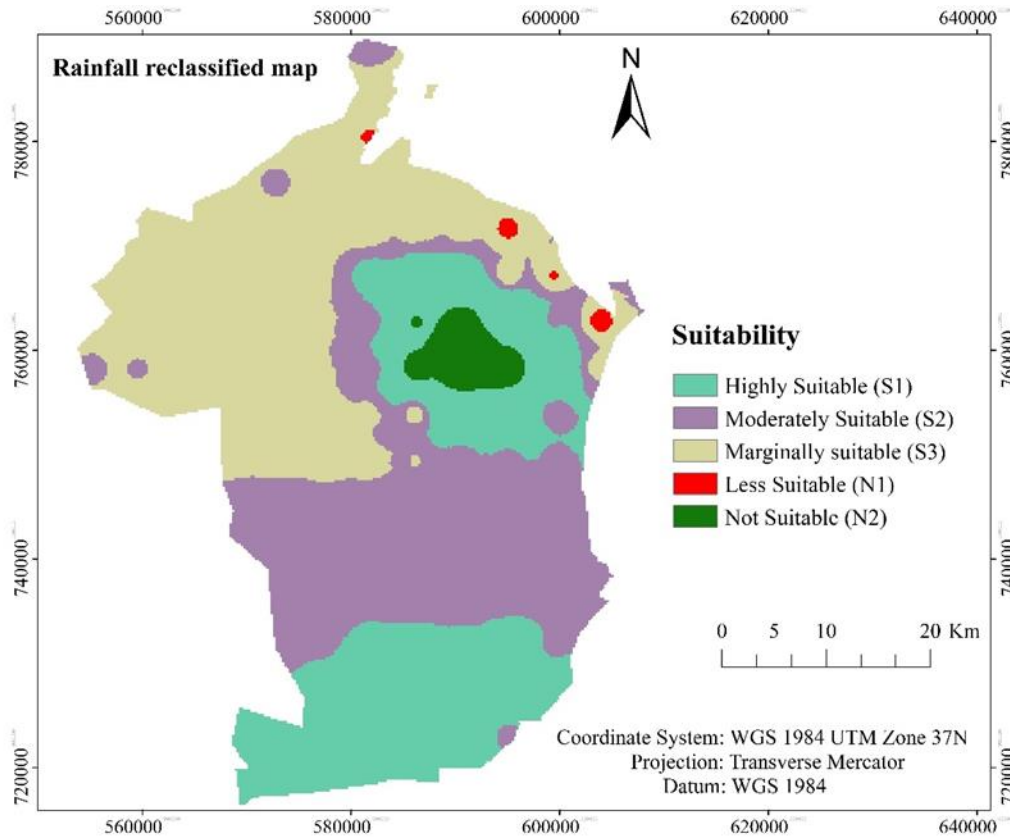


Figure 8: Reclassified rainfall map in the study area

Rainfall in the study area analyzed, about 61459.9 ha (28.6%), 69648.5 ha (32.4%), 77307.2 ha (35.9%) of the area was identified as highly suitable, moderately suitable, marginally suitable, and the remaining 808.6 ha (0.4%) less suitable and 5981.9 ha (2.8%) not Suitable (Table 12).

Table 12: Suitability class based on rainfall

Code	Rainfall range (mm)	Suitability level	Area coverage	
			Hectares (ha)	Proportion (%)
1	900 and 1400	Highly Suitable	61459.9	28.6
2	800 and 900	Moderately Suitable	69648.5	32.4
3	700 and 800	Marginally suitable	77307.2	35.9
4	500 and 700	Less Suitable	808.6	0.4
5	<500	Not Suitable	5981.9	2.8

At the landscape scale, the Mountain Nyala habitat is heavily reliant on rainfall/precipitation, which are known to have direct influences on vegetation structure and diversity (Tadesse, 2016). For instance, the plantation habitat which is relatively rich in palatable undergrowth plant species could serve as a foraging ground for Mountain Nyala during the wet season. In addition, the plantation habitat serves as a corridor and shelter from extreme weather for Mountain Nyala (Evangelista et al., 2007). The seasonal streams flowing across the plantation and the natural forest habitats serve as source of water for the species during the rainy season (Fanuel et al., 2014). This suggests that rain is important factor for Mountain Nyala that influences their habitat suitability (Gao et al., 2022).

### **Temperature suitability**

Species are more abundant in some habitats than others (Tadesse, 2016), with climatic (i.e., temperature) factors determining the presence or absence of Mountain Nyala species in a specific habitat. The importance of temperature was also highlighted by other researchers e.g. Hill, (2009); Mohammadi, (2022) and Gao et al., (2022). The temperature map (Figure 10) was reclassified into five classes ( $> 20^{\circ}\text{C}$ ,  $17.1\text{-}20^{\circ}\text{C}$ ,  $15\text{-}17.1^{\circ}\text{C}$ ,  $12.5\text{-}15^{\circ}\text{C}$  and  $10.5\text{-}12.5^{\circ}\text{C}$ ) and was ranked as 5, 4, 3, 2 and 1 with description ranging from not suitable, less suitable, marginally suitable, moderately suitable and high suitable respectively based on Mountain Nyala habitat suitability.

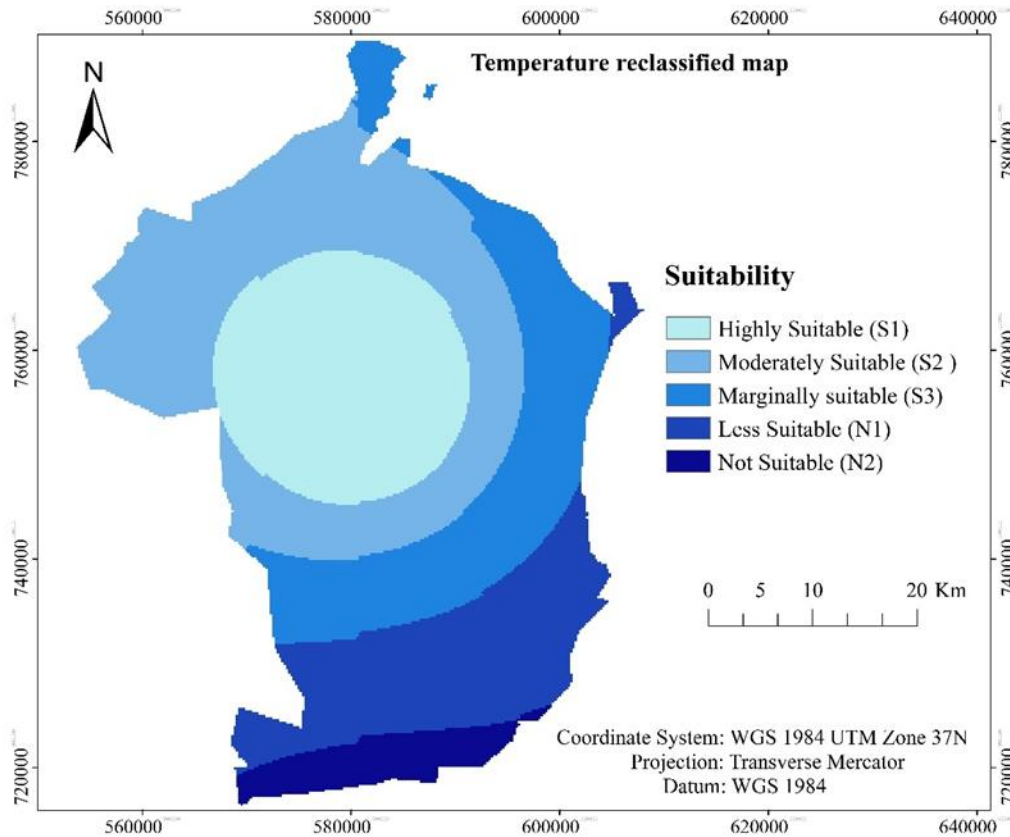


Figure 9: Reclassified temperature map in the study area

Out of the total percent of temperature class (Table 13), 21.9% (47207.6 ha) found highly suitable, whereas 33.7% (72596.1 ha) is moderately suitable, 21.4% (45996.7 ha) is marginally suitable, 18.1% (38884.8 ha) is less suitable and 4.9% (10599.2 ha) is found not suitable.

Table 13: Suitability class based on temperature

Code	Temperature range (°C)	Suitability level	Area coverage	
			Hectares (ha)	Proportion (%)
1	10.5-12.5	Highly Suitable	47207.6	21.9
2	12.5-15	Moderately Suitable	72596.1	33.7
3	15-17.1	Marginally suitable	45996.7	21.4
4	17.1-20	Less Suitable	38884.8	18.1
5	> 20	Not Suitable	10599.2	4.9

#### 4.1.5. Soil suitability

Based on the soil factor results, soil cover map was reclassified into five classes (Pellic Vertisols, Dystric Histosols, Eutric Cambisols, Eutric Nitisols and Chromic Luvisols) and was ranked as 5, 4, 3, 2 and 1 with description ranging from not suitable, less suitable, marginally suitable, moderately suitable and high suitable respectively based on Mountain Nyala habitat suitability (Figure 11).

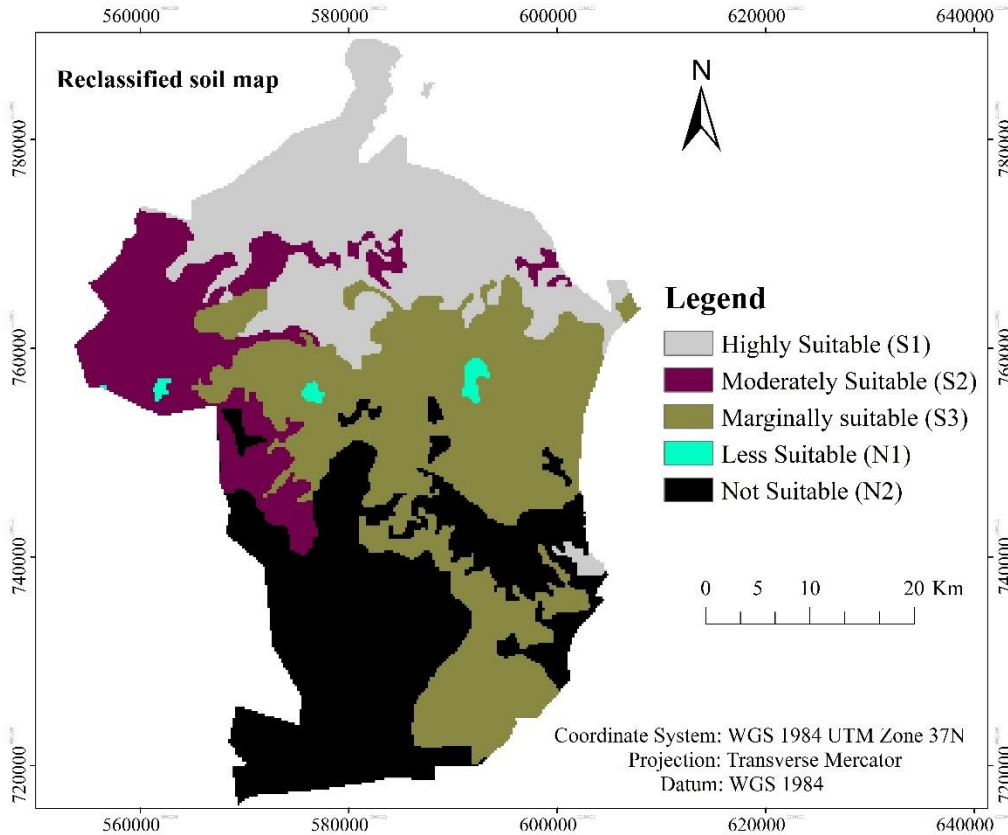


Figure 10: Reclassified soil map in the study area

About 23.5% or 50657.6 ha area of BMNP cover as highly suitable, 14.2% or 30557.6 ha moderately suitable, 33.1% or 71305.3 ha marginally suitable, 0.6% or 1231.6 ha less suitable and 28.6% or 61481.3 not suitable (Table 14).

Table 14: Suitability class based on soil type

Code	Soil type	Suitability level	Area coverage	
			Hectares (ha)	Proportion (%)
1	Chromic Luvisols	Highly Suitable	50657.6	23.5

2	Eutric Nitisols	Moderately Suitable	30557.6	14.2
3	Eutric Cambisols	Marginally Suitable	71305.3	33.1
4	Dystric Histosols	Less Suitable	1231.6	0.6
5	Pellic Vertisols	Not Suitable	61481.3	28.6

Soils affect the kind and amount of vegetation that is available to wildlife as food and cover (Melese et al., 2014). The kind and abundance of wildlife depend largely on the amount and distribution of food, cover, and water. Wildlife habitat can be created or improved by planting appropriate vegetation, by maintaining the existing plant cover, or by promoting the natural establishment of desirable plants (Abel et al., 2022). Each species of wildlife is related to the availability of its choice foods, and each plant, in turn, is directly related to the kind of soil. The soils of BMNP support many different kinds of plants that provide food, cover, and protection for many species of wildlife including Mountain Nyala. Areas that are dominated by very deep soils were highly suitable for Mountain Nyala because such soils are good for plant and grass development. The major soil types in the BMNP include; fertile but poorly drained Pellic Vertisols and Chromic Luvisols is found on the low-lying plains. Subsequently, the higher elevation plains are relatively infertile well-drained Eutric Cambisols and Eutric Nitisols. On the gently sloping foothills below the southern escarpment of the park are relatively fertile Nitisols and Leptosols occasionally with high water tables. And, on the escarpment of the area are deep well drained Dystric Histosols of less fertility.

#### **4.1.6. Accessibility**

##### **River buffer estimation**

In this study, areas closer to water resource are considered as suitable and far from water points are considered as not suitable. Several studies Ganawa et al. (2015) in Tanzania, Ahmed, et al. (2018) in India, Mosissa, et al. (2021) in western Ethiopia, Baig et al. (2022) in northern Pakistan and Maiti et al. (2022) West Singhbhum emphasized the importance of “distance from water resources”. Based on the analysis of the criteria distance to the river, the study area was classified into 5 classes ranging from highly suitable to not-suitable (Figure 12).

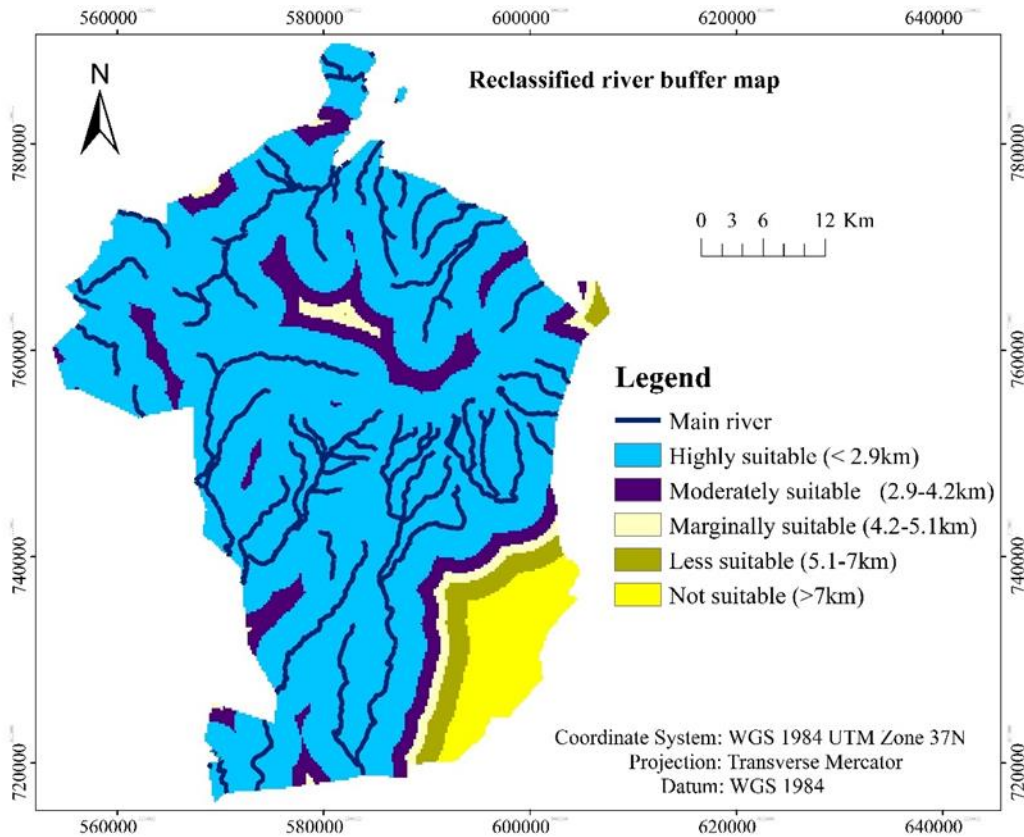


Figure 11: Reclassified River map in the study area

Area classed as highly suitable covers an area of 79.8% (171814.9 ha), areas classed moderately suitable covers an area of 9.5% (20442.6 ha), areas in marginally suitable class covers an area of 2.3% (4939.3 ha), areas in less suitable class covers an area of 2.7% (5895.9 ha), and areas classed as not suitable covers an area of 5.6% (12159.5 ha) (Table 15).

Table 15: Suitability based on distance to river in the study area

Code	Suitability	Proximity to river (km)	Area coverage	
			Hectares (ha)	Proportion (%)
1	Highly suitable	< 2.9	171814.9	79.8
2	Moderately suitable	2.9-4.2	20442.6	9.5
3	Marginally suitable	4.2-5.1	4939.3	2.3
4	Less suitable	5.1-7	5895.9	2.7
5	Not suitable	>7	12159.5	5.6

## Road buffer zone

The area closer to the major road crossing the park in the northern and southeast side less than 1.5 km classified as not suitable habitat, the area located 1.5 to 5 km far from the road has classified as less suitable habitat, and the area located greater than 5 km from the road are totally classified as suitable habitat (Figure 13).

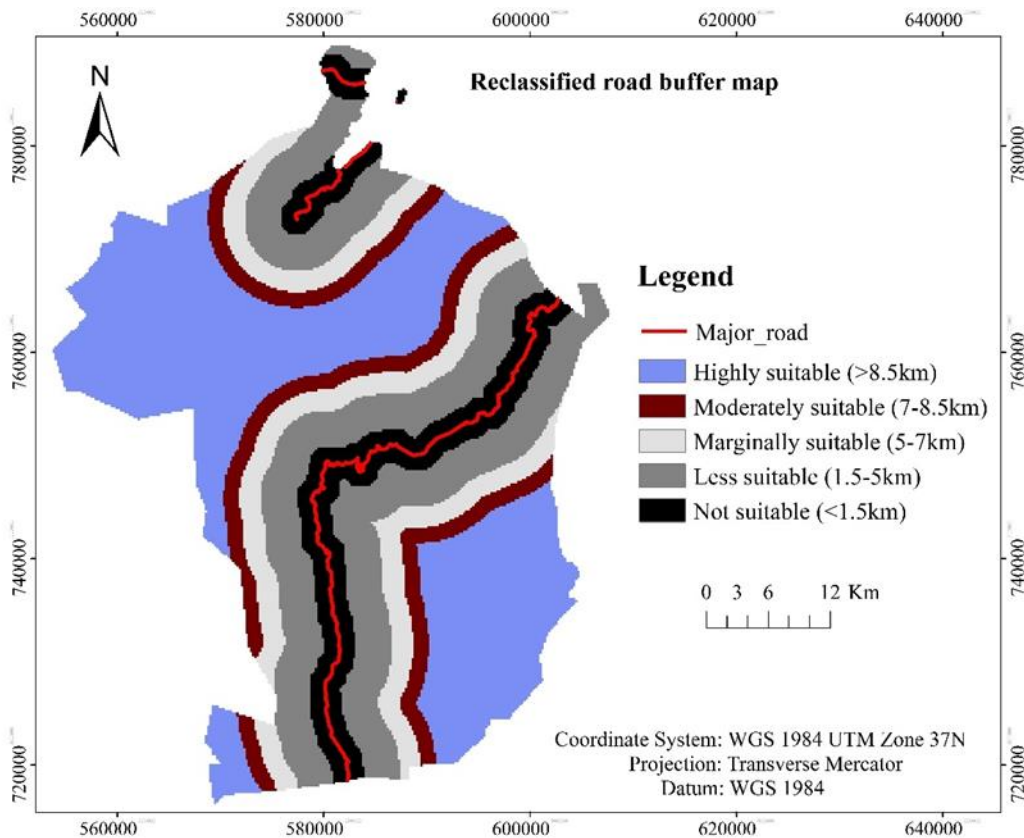


Figure 12: Reclassified Road map in the study area

Accordingly, the reclassification result showed that 38.3% (82514.7 ha), 9.7% (20919.3 ha) & 13.6% (29226.8 ha) of area found to be highly suitable, moderately suitable & marginally suitable habitat for Mountain Nyala and the rest 26.5% (57124.5 ha) and 11.8% (25469.8 ha) of area of land founds to be less suitable and not suitable habitat, respectively. The respective details are shown in tables 16.

Table 16: Road suitability classes and area coverage

Code	Suitability	Distance from roads (km)	Area coverage	
			Hectares (ha)	Proportion (%)
1	Highly suitable	>8.5	82514.7	38.3
2	Moderately suitable	7-8.5	20919.3	9.7
3	Marginally suitable	5-7	29226.8	13.6
4	Less suitable	1.5-5	57124.5	26.5
5	Not suitable	<1.5	25469.8	11.8

Road accessibility is one of the important infrastructure considerations with regard to ecotourism development. In order to have good access for the tourist to visit or admire this endemic creature, suitable habitat of Mountain Nyala species preferably be situated near to all-weather road or access road. However, roads construction and tracks are being expanded in the study area through natural forests to link adjacent Kebeles (villages). Chaudhary et al. (2022) endorse that the presence of roads in the park area contributes to a deterioration of the landscape and reduces the obvious tourist values. On the other hand, noise pollution and hazards on the adjacent roads will a disturbing factor of wildlife habitat in the region. During FGDs, local people revealed that the pavement roads particularly in the northern part of park are doing major damage to Mountain Nyala species and its habitat.

It is, therefore, necessary to establish an area of lonesomeness for the species in accordance with the approved standards. Distance from roads influenced by the transport characteristics by access distance from the major road types (Khwanruthai, 2011). Thus, it was assessed by creating the buffer zones according to distance from the road types.

### **Settlement buffer zone**

Areas within greater than 13 km buffer around the settlement are ranked as highly suitable, and areas within less than 4 km and inside of any buffers around all settlement are ranked as not suitable. The proxy to the settlement analysis result shows that more than half of the study area is less suitable and not suitable for the habitat of Mountain Nyala (Figure 14).

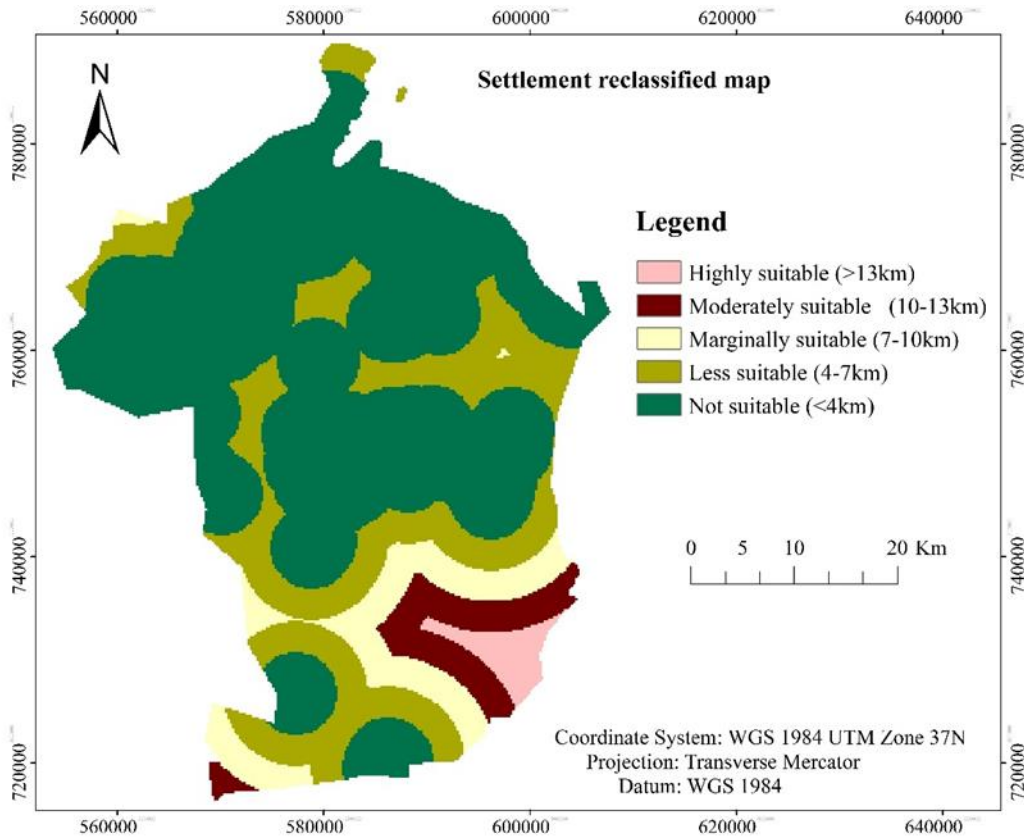


Figure 13: Reclassified settlement Map in the study area

Buffer zone to settlement in the study area is poor. Only 2.01 % (4333.32 ha) of the area has a score of 1 which is highly suitable, 5.19 % (11160.45 ha), 8.52 % (18329.03 ha), 22.3 % (47989.97 ha), and 61.99 % (133429.65 ha) has a score of 2, 3, 4 & 5 which are moderately suitable, marginally suitable, less suitable and not suitable, respectively (Table 17).

Table 17: Settlement suitability classes and area coverage

Code	Suitability	Distance from settlement (km)	Area coverage	
			Hectares (ha)	Proportion (%)
1	Highly suitable	>13	4333.32	2.01
2	Moderately suitable	10-13	11160.45	5.19
3	Marginally suitable	7-10	18329.03	8.52
4	Less suitable	4-7	47989.97	22.30
5	Not suitable	<4	133429.65	61.99

Settlement is considered an important parameter of disturbance leading to habitat fragmentation thus leads to change of landscape (Ahmad et al., 2018; Maiti et al., 2022). Worku et al. (2021) also found these parameters leading to change land use land cover of BMNP. Despite a new optimism for Mountain Nyala populations in the park, rapid loss of critical habitat due to increasing human land-use activities is a significant and immediate threat to the persistence of the species. There were settlements of small hamlets in a more dispersed way in the forest, where small farm operations were also seen. Different human activities such as deforestation, extension of croplands, built-up areas, and cattle grazing were observed on the edge of the natural forest. These can be gathered from field observations, which confirm that in the park especially some of these areas (e.g., Rira, Baluk, Fetcha Plains) the Mountain Nyala inhabited in these areas and that most of its habitat remains intact, however the species' habitat has threatened due to increased human activity in the area. Furthermore, in 1986, Hillman (1986) estimated that 2,500 people lived or used resources within BMNP. By 2017, it was estimated that 40,000 people inhabited BMNP residing in more than 3,000 settlements (BMNP, 2017). As human populations continue to grow at an alarming rate, so does the demand for agriculture, grazing lands, and natural resources (Atickem et al., 2011). These trends pose direct threats to the Mountain nyala and other wildlife species, primarily from habitat loss, fragmentation, and degradation. In this regard, Mountain Nyala habitat should be far from agriculture, settlements, towns, and fallow lands. Hence, the most suitable land use types exist far from settlement areas.

#### **4.2. Relative importance and weight of habitat controlling parameters**

To evaluate suitable habitat of Mountain Nyala 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 and the weight to each factors derived (Figure 15).

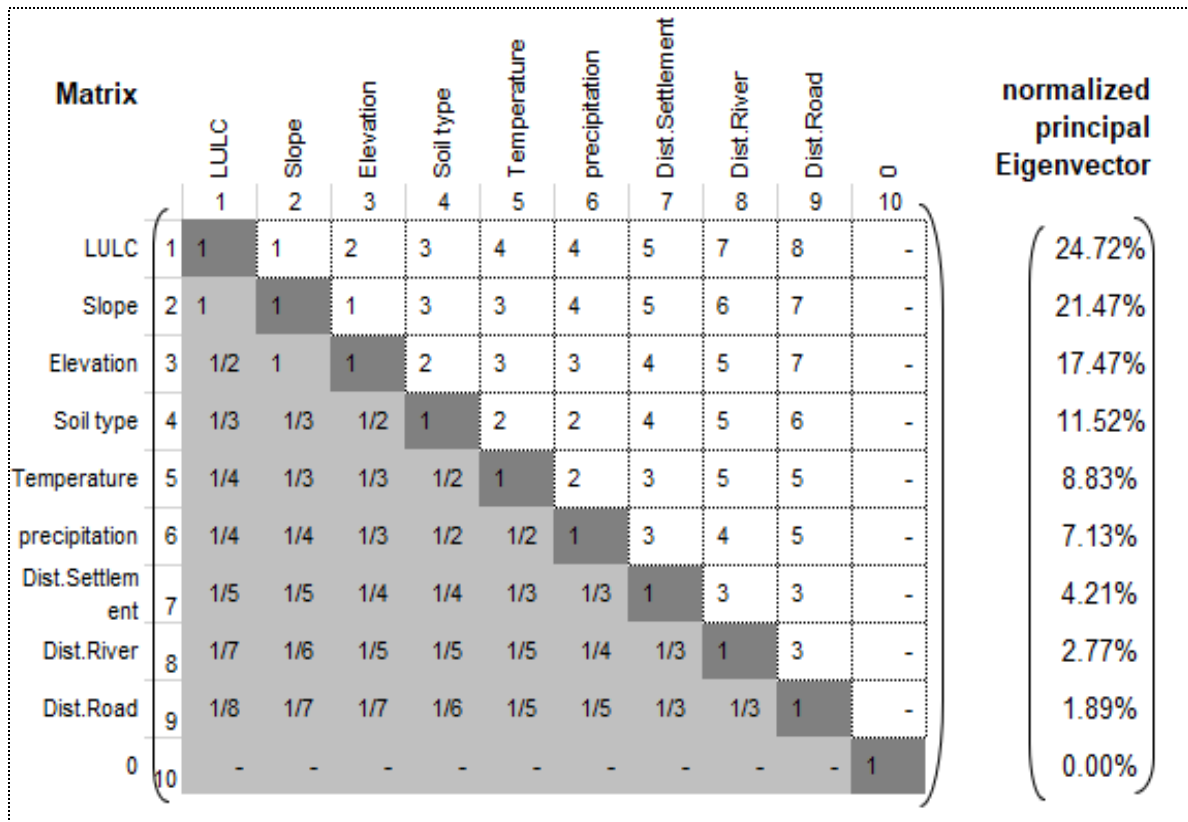


Figure 14: Showing Matrix calculation of weights of different criteria for Mountain Nyala habitat analysis.

As it was shown in figure 16 three predictor variables were the most important in having the greatest contribution to the habitat suitability model. Land use land cover and/or Vegetation cover (i.e., trees, shrubs, and herbs cover) was the strongest predictor, which should not be surprising given that Mountain Nyala needs such places to detect potential predators early enough to allow for easy escape. While road act as limiting factors for this reason Mountain Nyala significantly avoids the proximate area to the road for this matter they been assigned with low relative importance by the expertise. Consequentially, their influence in the model found to be lower.

The weight of Mountain Nyala habitat factors that had been derived through calculating Eigen vector of the factors relative importance that filled out in the pairwise comparison matrix (Figure 15). Based on this the respective weight of each habitat factor are shown in the following figure.

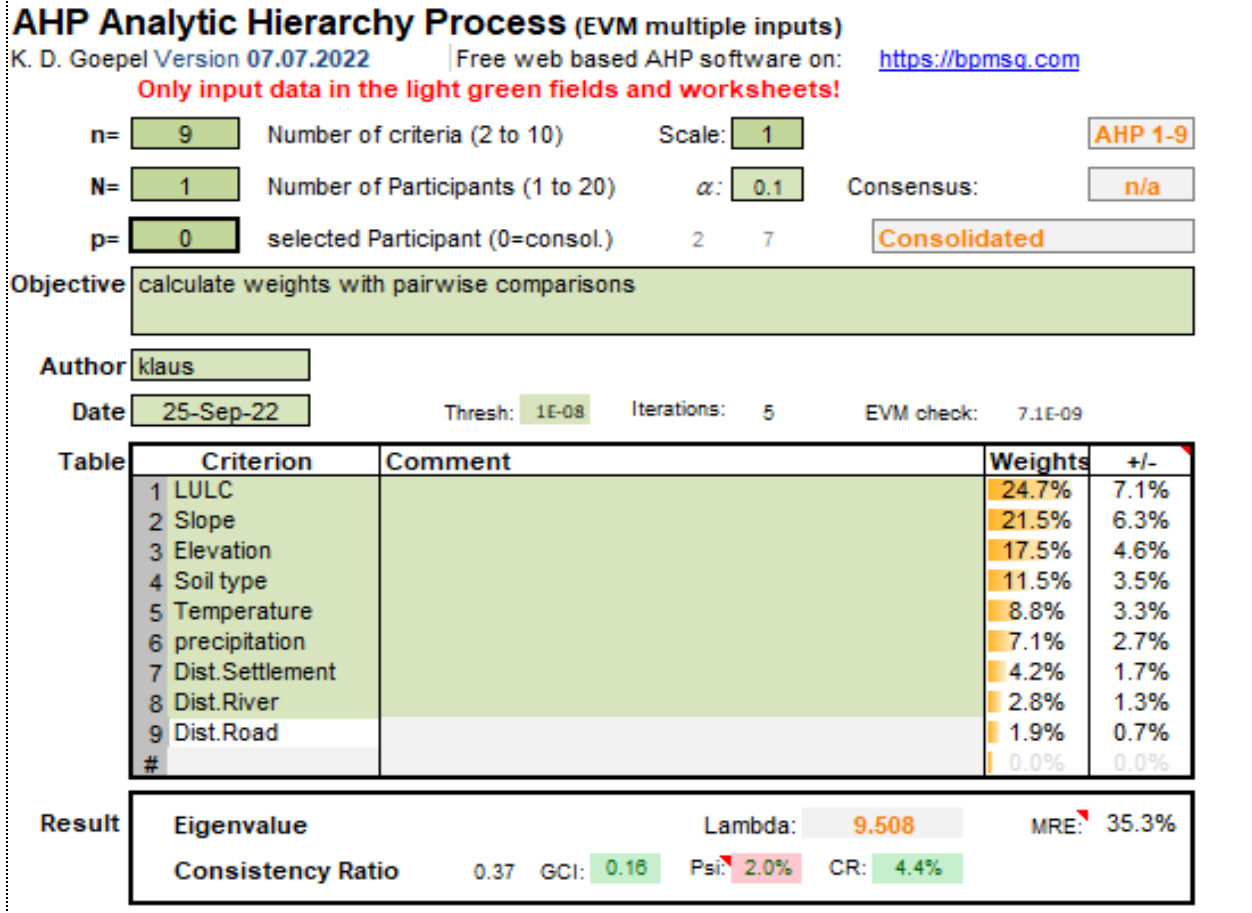


Figure 15: AHP analysis of 9 suitability criteria with their weight respectively

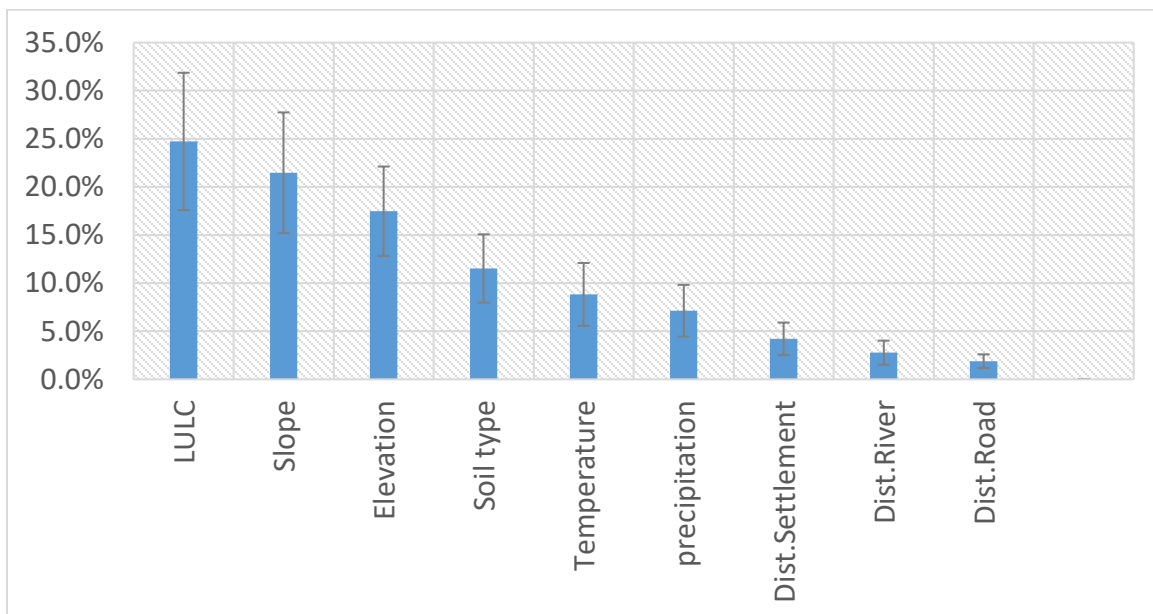


Figure 16: Criteria with calculated weights and errors

In this process, the CR was calculated and found to be 0.044, which is acceptable to be used in the suitability analysis as mentioned earlier. Subsequently, the habitat suitability map for Mountain Nyala was created based on the linear combination of the criteria and factors with their respective weights.

### 4.3. Mountain Nyala species habitat suitability analysis result

A multi-criteria decision making/analysis (MCDM/A)/AHP method was used to evaluate the priority weight of each criterion and the GIS is an integrated technique used to assess suitable habitat for targeted species (Mosissa & Yesus, 2021). According to the model generated by the weighted overlay analysis method in ArcMap the suitability map for Mountain Nyala species habitat was produced as shown in figure 18. Thus, habitat suitability modelling ‘‘HSM’’ for targeted species was obtained by integrating the various parameter given in the Eq 10. Which means;

$$HSM = \sum_1^n n = [(W_{LU} * S_{LU}) + (W_{SL} * S_{SL}) + (W_{EL} * S_{EL}) + (W_{SO} * S_{SO}) + (W_{TE} * S_{TE}) + (W_{PR} * S_{PR}) + (W_{SE} * S_{SE}) + (W_{RI} * S_{RI}) + (W_{RO} * S_{RO})]$$

Where  $S_{LU}$  is the land use land cover map,  $S_{SL}$  is the slope map,  $S_{EL}$  is the elevation map,  $S_{SO}$  is soil map,  $S_{TE}$  is the temperature map,  $S_{PR}$  precipitation map,  $S_{SE}$  is the settlement map,  $S_{RI}$  is river buffer, and  $S_{RO}$  is the road buffer. The  $W_{LU}$ ,  $W_{SL}$ ,  $W_{EL}$ ,  $W_{SO}$ ,  $W_{TE}$ ,  $W_{PR}$ ,  $W_{SE}$ ,  $W_{RI}$ , and  $W_{RO}$  are weightage values of each thematic layer used in the study are given in Figure 19.

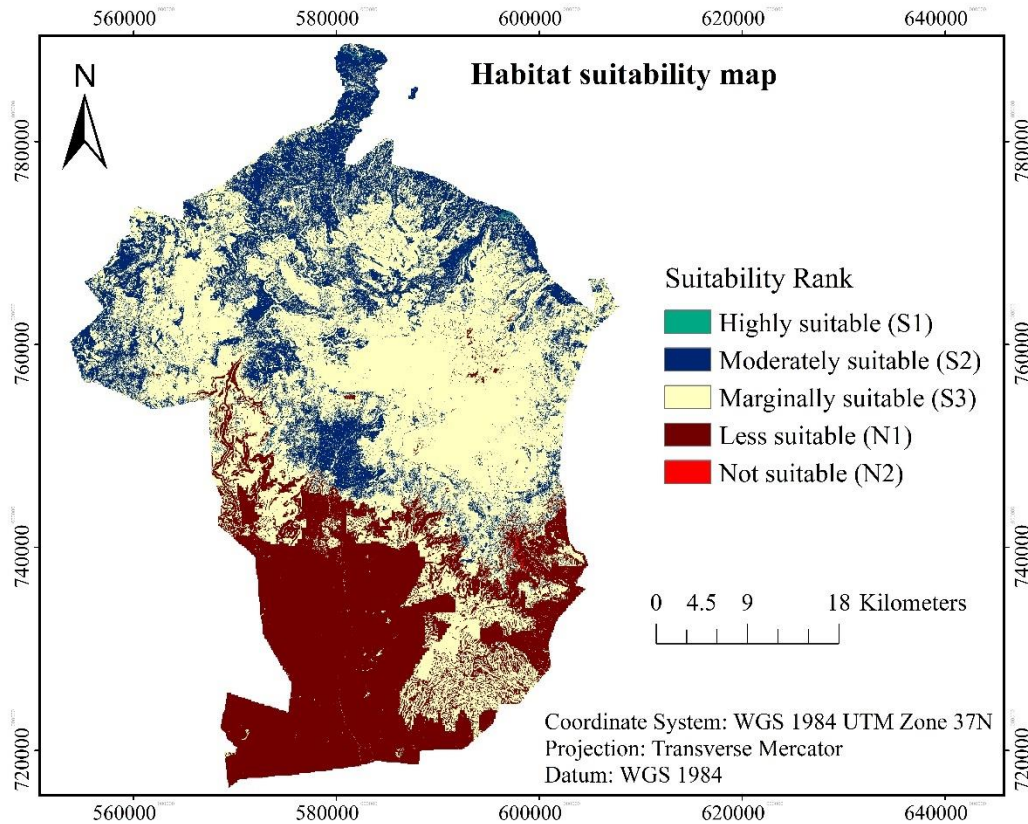


Figure 17: Map showing the Mountain Nyala habitat suitability map based on the weight sum tool. Based on the suitability output, only 0.06% (131.97 ha) is highly suitable (S1) for Mountain Nyala habitat located in the northern and north-east periphery of the park. The moderately suitable areas (S2) are confined mainly in the part of northern, north-west, north-east, and along the peak of Harrena forest and make up about 21.22% (45289.17 ha) of the region (Table 18 and Figure 19). The largest class of the study area is incorporated under the third class, the marginally suitable (S3) areas, which covers 51.14% (109143.50 ha) located at the central part of the plateau, Afro-alpine areas, north-western, and part of Harrena forest. Most of the southern Harrena forest-covered areas of the region are less suitable (N1), covering about 27.54% (58767.79 ha) and areas not suitable (N2) for Mountain Nyala habitat are also located at the part of Harrena forest, covering 0.04% (80.81 ha), which is a relatively small extent.

Table 18: Area coverage on classified habitat suitability

Code	Suitability Class	Area coverage	
		Hectares (ha)	Percentage (%)
1	Highly suitable	131.97	0.06
2	Moderately suitable	45289.17	21.22
3	Marginally suitable	109143.50	51.14
4	Less suitable	58767.79	27.54
5	Not suitable	80.81	0.04

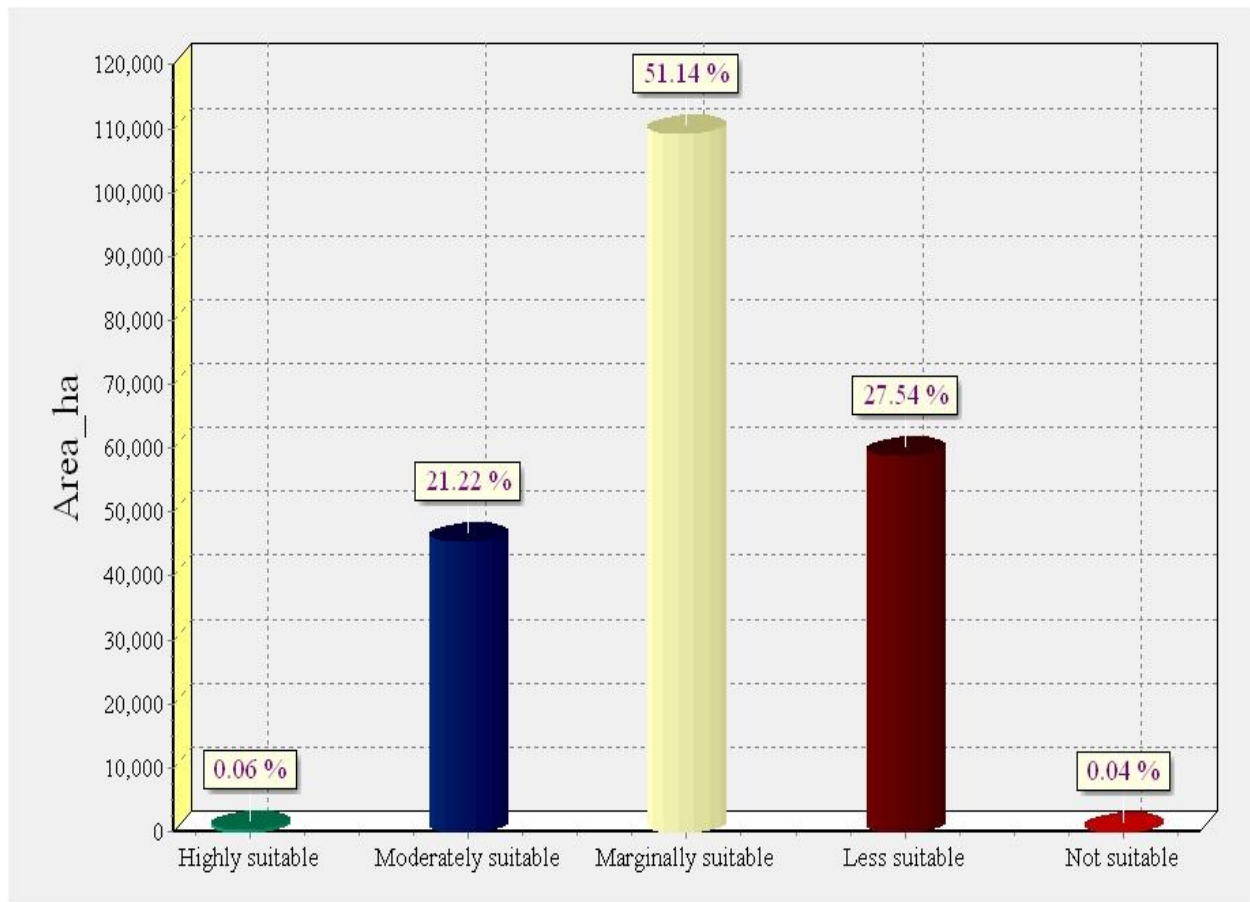


Figure 18: Graph depicting the classified suitability rank in percent

According to FAO, (1976), the habitat suitability map for Mountain Nyala species was classified based on 5 suitability classes as S1, S2, S3, N1 and N2 are seen in figure 18. The results are based

on the ranking of different sites according to the set criteria and thus identify those with the ‘best’ suitable habitat for the species. With regards to the typical and suitable sites for Mountain Nyala species, the following data were considered that are the results of analysis in particular, the results of the survey in order to examine of the species habitat of existing, present condition and future possibilities of suitable habitat in response to species sustainability and ecotourism development in the area. For purposes of identifying and prioritizing Mountain Nyala habitat, the typical and activities were proposed as follows:

#### **4.3.1 High suitable zone (S1)**

In this zone, where there was less anthropogenic disturbance and far away from the cultivated lands, temperate to cool climate, undulating and tough terrain, exhibited ample soil moisture, fall on less to no fire risk areas with sufficient clean perennial streams retained forest ecosystem with rich flora and fauna. In addition, the zone comprises the utmost favorite of endemic Mountain Nyala species habitats such as open woodland and grassland areas. Due to wealthy natural areas, it is crucial aspects that support this region for sustaining its suitability of the species habitat.

The site’s suitability falls in this class high and satisfies all the criterion conditions. Still, limitations need to follow for the sustainable conservation of species' habitats of protected regions. Moreover, the districts are characteristically endowed with lush green forests and abundances of wildlife and they are mainly located in parks. The destination has nature attractions and unique qualities for ecotourism. Therefore, these areas could serve as main ecotourism attractions and create a good opportunity to observe the Mountain Nyala species but with the use of certain limitations and guidelines. The example of guideline to be used to limit the number and duration of access to the areas is the code of conduct. These areas should be preserved or conserved and managed in a sustainable way unless the existing species' habitat in these areas is still usable.

The authorities responsible for monitoring environmental protection and conservation should spread awareness among tourists and stakeholders and the wildlife management addressing issues of environmental management and resource conservation. More specifically, the key element of wildlife management is sustainably managed and environmental responsibility is promoted (IUCN, 2017).

#### **4.3.2 Moderately suitable zone (S2)**

The S2 areas are those that satisfy most of the criteria set up, but some of the criteria are not satisfied. Grassland, heathland, and erica forests mostly cover these areas; therefore, areas or sites suitable for the species fall in this zone. Besides, these places are mostly free of semi-dense green for wild Mountain Nyala species habitats and great tourism potential with a spectacular natural landscape. However, the current ranges of Mountain Nyala and the predicted suitable habitats are fragmented, and various attractions and opportunities for ecotourism activities in these areas are still lagging. This could be ascribed to the various anthropogenic activities carried out in the area such as livestock grazing, illegal settlement, overgrazing, and higher concentration of farmland areas through shifting cultivation in the north-east edges. Likewise, some of the areas are inherited by afro-alpine vegetation; due to this do not allow and satisfy all the criteria for the targeted species habitat suitability in these areas of this zone.

The authorities which are actively involved and responsible for the conservation and protection of the habitats of these species', must manage and control the resources in order to retain their original conditions as far as possible, and confine travelling in sensitive regions, which are easily adversely affected and are difficult to rehabilitate. Unless human and livestock induced impacts are controlled and minimized, it is an inevitable fact that the predicted suitable habitats will be changed into marginal habitats for the Mountain Nyala species.

#### **4.3.3 Marginally suitable zone (S3)**

Areas circumscribed to this zone, are marginally suitable for Mountain Nyala species. The S3 areas which satisfy some of the criteria condition, but most of the criteria are not satisfied. Most of these areas are largely free from human built-ups with a unique natural resource, vegetation cover and great tourism potential. Notwithstanding, due to the other complex negative impacts of human and livestock disturbances including deforestation, agricultural land expansion, fire, the central and north-western ranges of Mountain Nyala species are highly fragmented.

Previous studies also suggested that the Mountain Nyala is currently distributed in both suitable and marginal habitats that are negatively affected by intensive human interference and livestock competition (Evangelista et al., 2007, 2012; Atickem et al., 2011; Mamo, 2015; Tadesse, 2016; Worku et al., 2021). Consequently, urgent conservation measures that could restore or rehabilitate

the habitats should be put in place in order to maintain these habitats and conserve the remnant, endangered and endemic Mountain Nyala species in BMNP.

#### **4.3.4 Less suitable zone (N1)**

This zone is an escarpment area which almost all of the criteria are not satisfied. This implies that while this escarpment area is less suitable for Mountain Nyala habitat, there would be the probability that for rehabilitation and treatment of scattered farmland and degraded land. Furthermore, areas circumscribed to this zone can be assumed to develop suitable habitats because, in upper parts, the escarpment contains a patch of tree heath (Erica Forest) – a shrub common to the western and eastern part that grows to staggering proportions in the region. In regard to this, wildlife management should be still considered the plenty of species in the region and any activities with minimal development or inference site include educational methods.

#### **4.3.5 Not suitable zone (N2)**

The final identified class is the not suitable site where all of the criteria are not satisfied. The category involves having limitations that may be appear, as severe as to preclude any possibilities of successful sustained use of the land in the given manner. Although this zone is not suitable for Mountain Nyala habitat, the area is typically endowed with wildlife reserves, rich cultural heritage, and dense-green forests. Besides, it is a high value of natural assets suitable for education and research-related activities as well as conservation of biodiversity and maintenance of the ecosystem in the area.

### **4.4. The contribution of habitat suitability modelling scenarios**

#### **For survival of the species – scenario I**

Habitat suitability modeling serves as a tool for a variety of wildlife management objectives (Kushwah, 2012). The information obtained through key informants assured that in the study area models that can predict suitability of wildlife habitat in a large-scale can be highly efficient and practical for wildlife managers. Therefore, to save Mountain Nyala species, it is important to identify the needs of these species and the type of habitat it prefers. In general, due to the irregular distribution of species in habitats, it is difficult and costly to determine the exact distribution of species (Naqibzadeh et al., 2021). Hence, such models are naturally static and probable because, statistically, the geographical distribution of species or communities is related to their current

habitats (Imam et al., 2013), so these models can perform well in describing the natural distribution of species (within their current range).

The information acquired from the KIIs further noted that the distribution and availability of suitable habitats for the Mountain Nyala in BMNP are crucial to enhance the conservation and management of the species and its habitats. It is important to accurately estimate the distribution of species to ensure that environmental protection planning efforts are more beneficial in managed areas (Baig et al., 2022). The result of this study also is consistent with the findings of Crawford et al., 2020; Mohammadi, (2022) who reported that the habitat models are also useful for predicting areas that may not currently be used by wildlife species. The basis of these models' work is to minimize the relationship between species distribution and biotic and abiotic environments (Naqibzadeh et al., 2021).

### **For development of ecotourism sector – scenario II**

Habitat suitability models of habitat-wildlife relationships are used to assess the potential of the area and to create habitat patterns for species that are introduced or present in the area (Naqibzadeh et al., 2021). Discussion with KIIs and FGDs confirmed that habitat suitability modelling or paying attention to the conservation of wildlife species and improvement of resources should be regarded as an important tool for the development of ecotourism activities in a study area. Hence, improving this modelling for the conservation of Mountain Nyala species and their habitats helps promote wildlife-based tourism in the region. Moreover, introducing and promoting community-based conservation activities that enable communities to derive economic benefits from ecotourism may promote conservation through addressing resource use conflicts. For example, FGDs confirmed that when tourists come to visit this endemic species, ecotourism activity can also improve and diversify the incomes of the local people through creating job opportunities, such as tourist guiding services, souvenir selling, horse renting, etc., all of which can help make ecotourism economically viable in BMNP. In this case, the support and participation of local people are essential to achieve sustainable ecotourism (Ahmadi et al., 2015).

Digital distribution maps of species for wildlife and ecotourism study based on powerful statistical software and Geographic Information System (GIS) tools, depending on the environmental needs of the species and their geographical distribution, lead to the development of habitat modeling (Naqibzadeh et al., 2021). For some species, there is information about presence and absence that

allows the use of a variety of standard statistical methods. Geospatial-based habitat suitability models are commonly used to predict species occurrence and also identify critical habitats in response to sustainable ecotourism development therefore, they have been popular among wildlife managers.

## CHAPTER FIVE

### 5. CONCLUSION AND RECOMMENDATION

#### 5.1. Conclusion

Geospatial technologies are used to gather information about the physical parameters of wildlife habitats and geospatial modeling for wildlife habitat suitability evaluation. The habitat suitability model may serve as a basis for promoting the conservation and management of the populations of the endangered Mountain Nyala and its natural suitable habitats. This plays an important role in the protection and sustainability of this valuable species and development of ecotourism in the BMNP. A weight base Mountain Nyala suitability habitat model is consistent with the strategies used to develop habitat suitability indices. The mathematical operation has been applied to achieve overall suitability scores. The GIS software enabled rapid development of a weight base prototype model and naturalized the use of proficient knowledge and understanding to determine the optimal location of Mountain Nyala habitats.

The applied suitability model within the scope of this study achieved relatively reliable results regarding the prediction of habitat that are highly suitable or favorable and unsuitable or most unfavorable for Mountain Nyala in BMNP with respect to vegetation cover, topography (e.g., slope and elevation), soil type, climatic conditions, and accessibility of road and water, and human disturbance. We conclude that the northern part of BMNP was found to have a large extent area are not likely in danger for Mountain Nyala species due to their spatial locality, elevations, sufficient food and water and alternative escaping routes to cope with the adverse impacts posed by local hunters, climate change or environmental degradation. Specifically, highly suitable habitats for this flagship species are concentrated in the north and northeast edges of the park. Moreover, the result of the study revealed that most parts of the study area were moderately, marginal and less suitable habitat for Mountain Nyala whereas very few areas of the park were highly suitable and not suitable, respectively. Generally, the study confirmed that the different habitat and vegetation types utilized by the Mountain Nyala were getting deteriorated. This suggested that habitat fragmentation is a common problem for the survival of the Mountain Nyala throughout its ranges of distribution in BMNP.

Thus, to safeguard the endangered and endemic Mountain Nyala species from foreseeable extinction, future conservation and management action should gear towards solving the problem of habitat fragmentation by designing appropriate corridors that help connect the fragmented suitable habitat patches over the whole ranges of the Mountain Nyala in BMNP. Corridors can also help Mountain Nyala species to expand in their ranges of distribution or even be reintroduced. The distribution and abundance of Mountain Nyala species are negatively affected by the impacts of human and livestock disturbances. It is, therefore human and livestock encroachments should be controlled or minimized from affecting the suitable habitats of the Mountain Nyala species throughout its ranges of distribution in BMNP.

## **5.2. Recommendation**

**Considerable revising the whole thesis paper is recommended the following:**

- The Mountain Nyala habitats suitability maps should be used by the agents, decision-makers, wildlife management agencies, and other related organizations of interest to aid in wildlife conservation and programmers' awareness
- The results show that forests, grasslands, woodlands, and heathlands are under persistent pressure and threats, it is therefore, highly recommended to monitor and manage this landscape in well manner and proper
- The current situation of the Mountain Nyala at Bale Mountain National Park is under high threat therefore its recommended that further research should be carried out by considering more criteria and more techniques for properly conserving these species
- A follow-up study that will check the limitations of this study and make the field visit to validate and make verification the results obtained in this case study
- Conducting further research and studies on Mountain Nyala movements and distributions at Bale Mountain National Park using web-based GIS for emergency and response and quick patrol

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# ANNEXES

## ANNEXES 1: QUESTIONARIES FOR KEY RESPONDENT

As part of my MSc research thesis at the Jimma University I am conducting a study that investigate on, *Mountain Nyala species habitat suitability modelling in response to species sustainability and ecotourism development using geospatial technologies: The case of Bale Mountains National Park, Ethiopia*. This will help the park management and the concerned bodies to seek possible solutions for the problems which hinder the park habitat suitability for the Mountain Nyala species. So you are kindly requested to fill this questioner.

Dear Participant, I appreciate if you could fill in the required information which remains confidential and any information obtained in connection with this study that can be identified with you will only be used for academic purposes.

### Section A: General Information (Tick where appropriate).

#### Respondent details

1. Name \_\_\_\_\_

2. Your gender? Male  Female

3. Age bracket? 18- 25  26- 35   
36 – 45  above 45

4. Education level?

Elementary  High school  Diploma

Undergraduate  Postgraduate (MA/MSC)

Postgraduate (PHD)

5. Organization (work place)?

Government  Nongovernment

Private  Other

6. Organization Name? \_\_\_\_\_

7. Your occupation? \_\_\_\_\_

8. Working experience \_\_\_\_\_ year.

**Section B: Guiding question for key informant interviews (expertise)**

Semi-structured interview used to evaluate the relative importance and classification effects of Mountain Nyala habitat defining parameters from expertise value judgments.

1. How do you evaluate the habitat type of Mountain Nyala species in Bale Mountain National Park? If you say that the habitat type of Mountain Nyala is on risky, what do you think the major reasons behind?
2. What is the role of habitat suitability modelling for the survival of the species and ecotourism development of the park?
3. Does the lack of a suitable habitat for Mountain Nyala have an impact on the ecotourism development of the park? If yes, what do you think should be done?
4. What do you suggest to be done to conserve and manage the Mountain Nyala and their habitats in Bale Mountain National Park?
5. Kindly provide your overall opinion about the Mountain Nyala in regard to sustainability and ecotourism development?
6. How do you rate the relative importance of Mountain Nyala habitat factors in defining the species habitat use? The following is to do Pair-wise comparisons, where each criterion is compared with the other criteria relative to its importance on a scale from 1 to 9. So, I appreciate if you could fill in the required information by circling.

C1: Slope    C2: Elevation    C3: Land use land cover    C4: Temperature    C5: Precipitation  
C6: Soil type    C7: Distance to River    C8: Distance to Road    C9: Distance to settlement

Factor	Factor weighting score																Factor	
	More importance than								Equal	Less importance than								
C1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C2

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C3
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C4
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C5
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C6
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C7
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C8
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C9
C2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C3
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C4
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C5
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C6
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C7
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C8
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C9
C3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C4
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C5
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C6
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C7
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C8
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C9
C4	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C5
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C6
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C7
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C8
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C9
C5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C6
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C7
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C8
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C9
C6	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C7

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C8
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C9
C7	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C8
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C9
C8	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C9

Thank you in advance for your cooperation

### **Section C: Guiding question for focus group discussions**

Guiding questions was used for focal group discussions to assess the attitudes and indigenous knowledge of local people about Mountain Nyala and their habitats in Bale Mountain National Park.

1. What do you know about Mountain Nyala and their habitats in Bale Mountain National Park?
2. What are the main challenges that faced Mountain Nyala in Bale Mountain National Park?
3. What needs to be done to survive Mountain Nyala species?
4. How do you see the habitat type of Mountain Nyala in the park?
5. What are the major factors defining Mountain Nyala suitable habitat in Bale Mountain National Park?
6. What are the impact on the ecotourism development of the park due to the lack of a suitable habitat for Mountain Nyala?
7. What is the contribution of Mountain Nyala habitat suitability modelling in terms of ecotourism development and the benefits to the local community around the parking area?
8. What is your recommendation about the conservation of Mountain Nyala and the development of ecotourism in the park?

**Thank you for your participation!**

ANNEXES 2: ERROR MATRIX RESULTING FROM CLASSIFYING TEST PIXELS (2022)

LULC type	Reference (GCP) Data									Row total	User accuracy (%)	Producer accuracy (%)
	AV	MMF	EF	HL	WL	GL	WB	BL	CL			
AV	12	0	0	1	0	1	0	0	0	14	85.7	85.7
MMF	0	11	0	0	1	0	0	0	0	12	91.6	84.6
EF	0	2	19	0	0	0	0	0	0	21	90.4	95
HL	0	0	0	14	0	0	0	0	1	15	90.3	82.3
WL	0	0	1	0	8	0	0	0	0	9	88.8	88.8
GL	1	0	0	0	0	12	0	0	0	13	92.3	80
WB	0	0	0	1	0	0	4	0	0	5	80	100
BL	1	0	0	0	0	0	0	7	0	8	87.5	100
CL	0	0	0	1	0	2	0	0	3	6	50	75
<b>Column total</b>	<b>14</b>	<b>13</b>	<b>20</b>	<b>17</b>	<b>9</b>	<b>15</b>	<b>4</b>	<b>7</b>	<b>4</b>	<b>103</b>	Overall accuracy = 87%; <b>KC = 0.85</b>	

**Note:** AV: Afroalpine vegetation, MMF: moist montane forest, EF: erica forest, HL: heath land, WL: woodland, GL: grassland, WB: waterbodies, BL: bare land, CL: cultivated land; KC: Kappa coefficient

ANNEXES 3: SUPPORTING CALCULATIONS OF AHP ANALYSIS

Supporting calculations										
Decision Matrix A				participant 1						
	LULC	Slope	Elevation	Soil type	Temperature	precipitation	Dist.Settlement	Dist.Rive	Dist.Ro	
	1	2	3	4	5	6	7	8	9	10
1	1	1	2	3	4	4	5	7	8	0
2	1	1	1	3	3	4	5	6	7	0
3	1	1	1	2	3	3	4	5	7	0
4	0	0.33333	0.5	1	2	2	4	5	6	0
5	0	0.33333	0.33333	0.5	1	2	3	5	5	0
6	0	0.25	0.33333	0.5	0.5	1	3	4	5	0
7	0	0.2	0.25	0.3	0.33	0.3333	1	3	3	0
8	0	0.16667	0.2	0.2	0.2	0.25	0.3333	1	3	0
9	0	0.14286	0.14286	0.2	0.2	0.2	0.3333	0.3333	1	0
10	0	0	0	0	0	0	0	0	0	1
col sum	4	4.42619	5.75952	11	14.2	16.783	25.667	36.333	45	1

Ln(A) for calculation of RGMM										RGGM			
1	-	-	0.69315	1.1	1.39	1.3863	1.6094	1.9459	2.079	-	3.11	24.9%	26.1%
2	-	-	-	1.1	1.1	1.3863	1.6094	1.7918	1.946	-	2.7	21.6%	22.6%
3	-1	-	-	0.7	1.1	1.0986	1.3863	1.6094	1.946	-	2.21	17.7%	18.4%
4	-1	-1.0986	-0.6931	-	0.69	0.6931	1.3863	1.6094	1.792	-	1.44	11.5%	12.1%
5	-1	-1.0986	-1.0986	-1	-	0.6931	1.0986	1.6094	1.609	-	1.08	8.7%	9.2%
6	-1	-1.3863	-1.0986	-1	-0.7	-	1.0986	1.3863	1.609	-	0.88	7.0%	7%
7	-2	-1.6094	-1.3863	-1	-1.1	-1.0986	-	1.0986	1.099	-	0.51	4.1%	4%
8	-2	-1.7918	-1.6094	-2	-1.6	-1.3863	-1.0986	-	1.099	-	0.33	2.6%	3%
9	-2	-1.9459	-1.9459	-2	-1.6	-1.6094	-1.0986	-1.0986	-	-	0.23	1.9%	2%
10	-	-	-	-	-	-	-	-	-	-	1	-	-
										12	9.411	#####	

Consistency Error Matrix										
1	1	1.15136	1.4235	1.4	1.4	1.1318	1.2087	-	-	-
2		1	1.22028	1.6	1.21	1.3031	1.0498	1.3584	-	-
3			1	1.3	1.47	1.1926	1.0753	1.3359	-	-
4				1	1.51	1.2203	1.4273	1.1489	1.038	-
5					1	1.6199	1.421	1.5251	1.066	-
6						1	1.7544	1.5064	1.316	-
7							1	1.9319	1.35	-
8								1	2.096	-
9									1	-
10										1

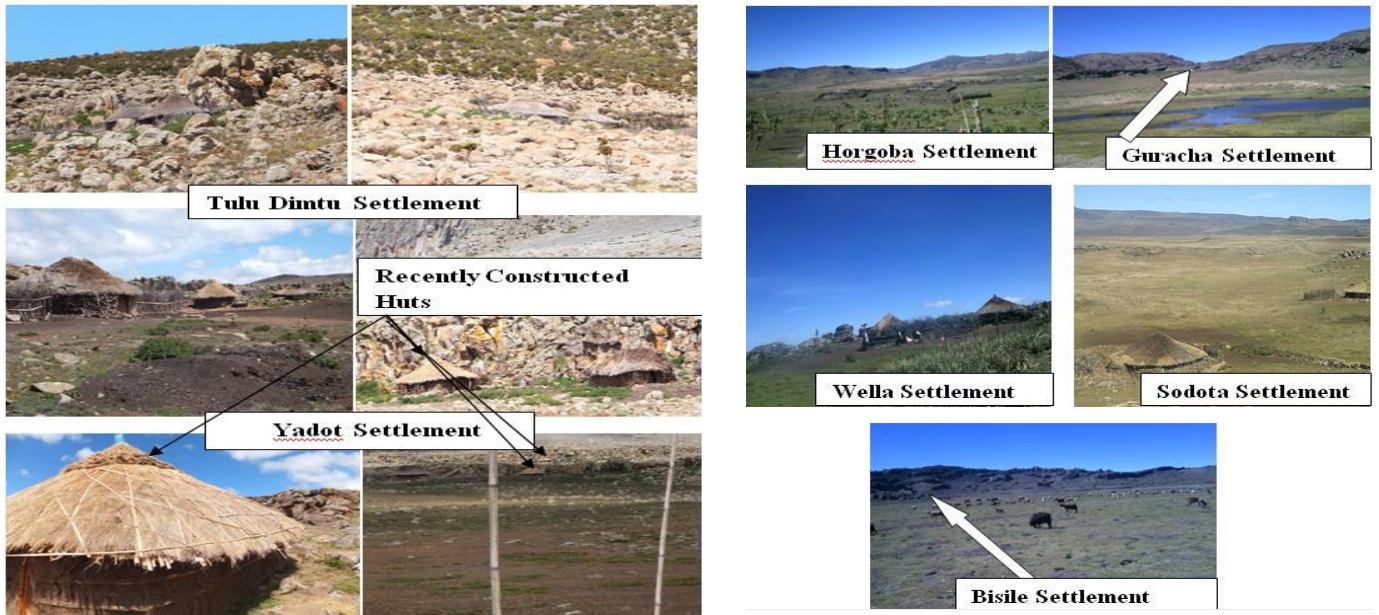
pj/pi										
1	1	0.86854	0.71175	0.5	0.35	0.283	0.1655	0.1066	0.074	0
2		1	0.81948	0.5	0.4	0.3258	0.1905	0.1227	0.086	0
3			1	0.7	0.49	0.3975	0.2325	0.1497	0.105	0
4				1	0.75	0.6101	0.3568	0.2298	0.161	0
5					1	0.8099	0.4737	0.305	0.213	0
6						1	0.5848	0.3766	0.263	0
7							1	0.644	0.45	0
8								1	0.699	0
9									1	0
10										1
	1	2	3	4	5	6	7	8	9	10
1	1	A1	A1	A2	A3	A4	A6	A9	A9	
2		1	A1	A2	A2	A3	A5	A8	A9	
3			1	A2	A2	A3	A4	A7	A9	
4				1	A1	A2	A3	A4	A6	
5					1	A1	A2	A3	A5	
6						1	A2	A3	A4	
7							1	A2	A2	
8								1	A1	
9									1	
10										1

Error calc	1	2	3	4	5	6	7	8	9	10
0.31	0	0.02	0.125	0.109	0.112	0.015	0.036	0.086	0.268	0
0.305	0.02	0	0.04	0.222	0.035	0.07	0.002	0.094	0.261	0
0.274	0.125	0.04	0	0.07	0.15	0.031	0.005	0.084	0.097	0
0.307	0.109	0.222	0.07	0	0.168	0.04	0.127	0.019	0.001	0
0.354	0.112	0.035	0.15	0.168	0	0.233	0.123	0.178	0.004	0
0.344	0.015	0.07	0.031	0.04	0.233	0	0.316	0.168	0.075	0
0.376	0.036	0.002	0.005	0.127	0.123	0.316	0	0.434	0.09	0
0.449	0.086	0.094	0.084	0.019	0.178	0.168	0.434	0	0.548	0
0.41	0.268	0.261	0.097	0.001	0.004	0.075	0.09	0.548	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

**ANNEX 4: PHOTO DURING KEY INFORMANT INTERVIEWS AND FOCUS GROUP DISCUSSIONS IN THE STUDY AREA**



**ANNEX 5: PHOTO DURING FIELD OBSERVATION IN THE STUDY AREA**



One of the magnificent areas while livestock's grazing in Bale Mountain National Park