



**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES**

**ECOSYSTEM VIABILITY ASSESSMENT AND FRAGMENTATION ANALYSIS IN OF
BALE MOUNTAINS NATIONAL PARK
(Emphasis on Afro-Alpine Ecosystem)**

By: GETU ABDISSA

A THESIS SUBMITTED TO

THE SCHOOL OF GRADUATE STUDIES OF THE ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT FOR
THE DEGREE OF MASTER OF SCIENCE IN REMOTE SENSING AND GIS

June 2010

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF SCIENCE
DEPARTMENT OF EARTH SCIENCE

**ECOSYSTEM VIABILITY ASSESSMENT AND
FRAGMENTATION ANALYSIS IN BALE MOUNTAINS
NATIONAL PARK (*Emphasis on Afro-Alpine Ecosystem*)**

By: **Getu Abdissa**

ADVISOR:

Mohammed Umer (PhD)

APPROVED BY

EXAMINING BOARD:

1. Mekuria Argaw (PhD.) _____
2. Tenalem Ayenew (Prof.) _____

Chairman:

1. Balemual Atnafu (PhD.) _____

May 2010

Acknowledgements

I am highly grateful to my advisors Mohammed Umer(PhD) (AAU) and My Mentor Andre Nonguierma (UNECA) for their constructive guidance, suggestion and encouragement throughout this research work.

Special thanks to Dozie Ezigbalike (PhD) (UNECA) and Tesfaye Korme (PhD)(RCMRD), for their valuable and kind support throughout the course of the research. I wish to thank all ISTD staff members of particularly the Geo-team (Girum, Belen, Yosi and the three Merons) at the United Nations Economic Commission for Africa.

I would very much like to extend my gratitude to Anounska Kinhan and her husband (Ted) (FZS-BMNP-Technical Advisor) and Chris and Anne (from the EWCP) for the kind support and hospitality they rendered for me during my stay in Bale Mountains National Park.

And finally, my special thanks goes to my best friend Melakeneh Gelet (INSA) and Meron S/Mariam (UNECA) for helping me through all those moments of this research work.

Contents

Contents	ii
List of Tables	iv
List of Figures.....	iv
List of Acronyms.....	vi
ABSTRACT.....	viii
1. INTRODUCTION.....	1
1.1. Background	1
1.2. Statement of the Problem	3
1.3. Objectives.....	4
1.3.1. General objective	4
1.3.2. Specific objectives	4
1.4. Significance of the Study	5
2. LITERATURE REVIEW	7
2.1. Ecosystem Concepts and Definitions	7
2.2. Threats to Ecosystem.....	8
2.3. Landscape Ecology and Landscape Analysis	9
2.4. Fragmentation: Concepts and Definitions	9
2.5. Habitat Fragmentation and Heterogeneity	10
2.6. Effects of Fragmentation	12
2.7. Measuring Fragmentation-The Scale Problem	13
2.8. Fragmentation Metrics-Selection	13
2.9. Interpretation of Metrics-Limitations	14
2.10. Remote sensing –Beyond Vegetation Mapping and Integration.....	14
3. METHODS.....	16
3.1. Study Area.....	16
3.2. Geology and Landform.....	17
3.3. Hydrology	17
3.4. Vegetation and Wildlife	17
3.5. Climate and Altitude	18
3.6. Study Approach.....	19

3.7.	Methodology.....	20
3.7.1.	Image Processing	20
3.7.1.1.	Image geo-rectification	20
3.7.1.2.	Vegetation Type and Land use Mapping	21
3.7.1.3.	Accuracy assessment	24
3.7.1.4.	Fragmentation Analysis.....	24
3.7.1.6.	Ecosystem Viability Assessment	27
4.	RESULTS AND DISCUSSION.....	32
4.1.	Mapping of vegetation type and Land use	32
4.2.	Fragmentation.....	34
4.2.1.	Data Reduction.....	35
4.2.2.	Selection of class metrics	37
4.2.3.	Weighting factors.....	44
4.2.4.	Fragmentation.....	44
4.3.	Viability Assessment	47
4.3.1.	Data Reduction (Patch-level)	47
4.3.2.	Selection of patch metrics	48
4.3.3.	Weighting of factors.....	55
4.3.4.	Viability	56
5.	CONCLUSION AND RECOMMENDATIONS	59
5.1.	Conclusion	59
5.2.	Recommendations.....	60
6.	REFERENCES	61
	APPENDIX I: Ground Truth Data (FZS-BMNP, 2010)	67
	APPENDIX II: Codes for Vegetation/Land use Classes (FZS-BMNP, 2010)	73
	APPENDIX III: PCA Results After Varimax Rotation	74
	APPENDIX IV: PCA Results After Varimax Rotation (<i>Patch Metrics</i>).	75
	APPENDIX V: Contingency Matrix	77

List of Tables

Table 1: Description of Vegetation type and Land use	21
Table 2: Description of selected metrics (Class-level).....	38
Table 3: Components,Eigen values,weights(precent of variance) of selected metrics.	44
Table 4: Description of selected patch metrics.....	53
Table 5: components, Eigen values, and percent of variance (weights) of each representative metrics....	55

List of Figures

Figure 1: Habitat loss, habitat fragmentation and changes in habitat quality.	12
Figure 2: Location of the study area.....	16
Figure 3: Framework of the study approach	19
Figure 4: SPOT mosaic 2008 FCC, Bale Mountains National Park, Bale.	20
Figure 5: Flowchart of Methods	31
Figure 6: Vegetation type and Land use Map, BMNP.	33
Figure 7: percentage of the area of vegetation and land use types in BMNP.	34
Figure 8: Scree plot of components with their respective eigen values.....	35
Figure 9: Extracted components with Eigen values, percent of variation explained by each component and cumulative variance.....	36
Figure 10: Factor loadings of metrics representing each Component (axis).	37
Figure 11(a). Largest Patch Index.	41
Figure 11(b). Patch Density.....	49
Figure 11(C). Perimeter-Area Ratio Coefficient of Variation.....	50
Figure 11(d). Total Edge Contrast Index.....	50
Figure 11(e). Edge Contrast Coefficient of Variation.....	51
Figure 11(f) Mean Core Area Index.....	51
Figure 12: Linear Combination of factors LPI(a),PD(b),PARA_CV(c),TECI(d),ECON_CV(e) and CAI_MN(f).....	45
Figure 13: Fragmentation Index map.	46
Figure 14: Percent area under high, moderate and low fragmentation grades.	46
Figure 15: Scree Plot of PCA components with eigen values.....	47
Figure 16: Eigen values, percent of explained variance by each component and cumulative variance of Principal component axes	48
Figure 17: Factor loadings of selected metrics representing each component (axis)	49
Figure 18(a).Patch Elongation (Related Circumscribing Circle)	52
Figure 18 (b) Connectedness (Contiguity).....	61

Figure 18(C). Patch size (Area).....	62
Figure 18(d). Core area Index Class Percentile.....	62
Figure 18(e). Proximity Class Percentile.....	63
Figure 18 (f). Proximity Index.....	63
Figure 18 (g). Euclidean Nearest Neighbour.....	64
Figure 19: Linear combination of Circle standardized (a), Patch size (b), Contiguity (c), Core area index (d), Proximity class level percentile (e), Proximity index (f) and Euclidean nearest neighbour index.	57
Figure 20: Ecosystem Viability grades of the class <i>Helichrysum</i>	58
Figure 21: Percentage of the area under high, medium and low viability rankings.	58

List of Acronyms

EWNHS	Ethiopian Wildlife and natural History Society
PCA	Principal Component Analysis
WCMC	World Conservation Monitoring Center
BERSMP	Bale Eco-Region Sustainable Management Programme
BMNP	Bale Mountains National Park
CBD	Conservation of Biodiversity
EFAP	Ethiopian Forestry Action Program
WBISPP	Woody Biomass
EPA	Environmental Protection Agency
NFPA	National Forest Priority Area
GIS	Geographical Information System
BMNP	Bale Mountains National Park
GCP	Ground Control Points
RMS	Root Mean Square
UTM	Universal Transverse Merkator
WGS	World Geodetic System
FZS	Frankfurt Zoological Society
SPSS	Statistical Package for Social Science
MLC	Maximum Likelihood Classifier
SPOT	Sattellite Pour l'Observation de la Terre
FRAGSTAT	Fragmentation Statistics
LPI	Largest Patch Index

PD	Patch Density
PARA_CV	Perimeter Area Ratio Coefficient of Variation Index
TECI	Edge Contrast Index
ECON_CV	Edge Contrast Coefficient of Variation Index
CAI_MN	Mean Core Area Index
CONTIG	contiguity index
CAI_CPS	Core Area Index class percentile
PROX	Proximity Index
PROX_CPS	Proximity Index percentile proximity
ENN	Euclidean Nearest Neighbour Distance

ABSTRACT

Human population growth is fragmenting pristine ecosystems and impacting biological diversity worldwide. Like many National Parks forest fragmentation and degradation due to agricultural expansion are the greatest threats to biodiversity in BMNP. However, despite the presence of fragmentation, there are still opportunities for conserving the remaining ecosystem blocks (Patches) with information on the viable and fragmented Patches. Thus, the objective of this research is to suggest a ranking of ecosystem patches according to their degree of viability (i.e. their capability to preserve its integrity and host its original biodiversity). This study used Pearson correlation coupled with PCA for objective selection of representative metrics among 109 and 72 at Class and patch level, respectively. Pearson correlation ($|r| > 0.95$) reduced 56% of the class and 14% Patch metrics. Then PCA identified 6 and 7 components explaining 96% and 94% of the variance in class and patch metrics, respectively. Accordingly, patch elongation, patch size, core area, contiguity, proximity and Euclidean Nearest Neighbor were selected the 7 PCA components for ecosystem viability assessment. Weighted sum equations combining representative metrics using percent of variance explained by each axes of the PCA gave fragmentation Index and ecosystem viability map ranking classes and patches as high, moderate and low, respectively. This systematic approach of creating a fragmentation index and ecosystem viability assessment is not only a useful method that can be replicated in other regions, but the information provided in the form of maps can also be valuable guide to ecologists, natural resource managers, and planners to orient land use planning for optimal allocation of land resources.

Keywords: *Ecosystem fragmentation, Ecosystem Viability, PCA, Bale Mountains National Park.*

1. INTRODUCTION

1.1. Background

The majority of rural households in developing countries meet some part of their subsistence and income needs from the forests residing in natural ecosystems. Forests also provide a range of benefits in the form of goods that may be tradable, such as timber, fuel wood, non-timber forest products and services that arise from direct and indirect use. Forest resources are particularly important in bridging seasonal food gaps, and in helping households tide themselves over longer periods of food self sufficiency.

The importance of forests including non timber forest products to the quality of life even survival of very large numbers of poor rural people in tropical developing countries now seems indisputable. Forests are therefore very important as an economic buffer and safety net for poor households (Dien, 2004).

According to world conservation and monitoring center assessment WCMC, (2000), Ethiopia is rated 43 as Potential Natural World Heritage Site. The wide variations of geo-climatic features in Ethiopia have resulted in large biological diversity. The country hosts the fifth largest floral diversity in tropical Africa, is the richest in avifauna in mainland Africa and one of the eight Vavilov's centers of crop diversity (BERSMP, 2007). In addition to being an important regional centre for biological diversity, Ethiopia is one of the most important countries in Africa with respect to endemism of plant and animal species (EFAP, 1994; BERSMP, 2007). Thus, Ethiopia is among those countries that have already ratified the Convention on Biological Diversity (CBD). Ethiopia has been a party to the CBD since 1993 and has already submitted two reports (2nd and 3rd report and the 4th on the way). Meeting CBD's three objectives is a standing challenge since the country also needs to cope with the dual problems of poverty and environmental and natural resource degradation.

The natural resources of Ethiopia have been subjected to severe degradation owing to the long history of agriculture and poor cultural practices. According to EFAP (1994) the rate of deforestation estimated to be between 150,000 and 200,000 ha per annum for

the last five decades. On the other hand, WBISPP (2001) estimated 32,000 ha of forestland was converted to agricultural land in the Oromia region in 1995 alone. The current loss (between 2000 and 2010) is estimated to be more than 8.7%. It is further estimated that between 1990 and 2020, the region could lose 27% of its high forest resources from agricultural expansion (WBISSP, 2001; BERSMP, 2007).

As a result, disruption of natural ecosystems resulted in fluctuation of the normal hydrologic cycle and environmental equilibrium has been prevalent in the country. Moreover, uncontrolled population pressure with its increased demand for food crops, construction, feed and fuel wood induced massive removal of vegetation cover in the country (WBISSP, 2001). This destruction of the functioning of the natural ecosystem by small-scale farmers is largely driven by individual farmer's effort to escape poverty. However, these land use decisions that are made at an individual or local level accumulate to a degree in which their impacts are damaging at a broader scale. The additive natures of responses to individual land use behaviors therefore affect the ecological processes on a larger scale.

The Environmental policy of Ethiopia clearly stipulates the need to ensure that park, forest and wildlife conservation and management programmes which conserve biological diversity on behalf of the country allow for a major part of any economic benefits deriving there from to be channeled to local communities affected by such programme (EPA, 1997). In light of this fact, the Bale Mountains National Park (BMNP) which is established before 30 years ago has significant ecological importance in the region and world as one of the 34 world biodiversity hotspots (BERSMP, 2007). Nevertheless, ecosystems in BMNP are suffering from intensive pressures that are threatening the biodiversity and the short and long term persistence is very unlikely due to inadequate logging practices, agricultural expansion, illegal settlement, deliberate fire and plantation development. Thus, accurate inventory is required also to assess the extent, distribution and biological diversity of the forest resources. Otherwise the few remaining natural ecosystem will dwindle before our eyes and the Nation would suffer serious environmental degradation resulting in a loss of one of the world's 'Carbon Sink'.

1.2. Statement of the Problem

Like many national parks in the country, the problem of illegal settlement and agriculture has created an artificial matrix (fragmentation) affecting the continuum of the pristine natural ecosystem with largely negative implications on biodiversity in BMNP. The conversion from natural forest to small agricultural plots threatens the future of many endemic species, among them the Bale monkey, which relies almost solely on the bamboo patches found in the forest, as well as a number of known, and most likely unknown, amphibian and plant species. Burning of *Erica spp.* and Overgrazing in the Afro-alpine vegetation belt is causing a significant deterioration in the habitat quality for giant mole rats and other endemic rodents on which the Ethiopian wolves (*Canis simensis*) rely for food. Human settlers also bring with them domestic dogs, which, through disease transmission, pose a further threat to the Ethiopian wolf population. (BERSMP, 2007). However, despite the presence of fragmentation in the park, there are still opportunities for conserving the remaining ecosystem blocks (Patches).

1.3. Objectives

1.3.1. General objective

To suggest a ranking of ecosystem patches according to their degree of viability and therefore their suitability for informed Biodiversity Conservation, as an aid to planning and managing of areas prone to loss of biodiversity.

1.3.2. Specific objectives

- To identify a subset of class and patch metrics for ecosystem fragmentation and viability assessment , respectively.
- To assess spatial indicators for assessing viability of different ecosystem patches.
- To recommend or prioritize areas for biodiversity conservation (bio-prospecting).

1.4. Significance of the Study

The conservation value of Bale Mountains National Park (BMNP) is therefore essential because it does not only support the natural functioning of the ecosystems, but also is a very famous place for the beauty of its landscape, the diverse and varied nature of its ecosystems, as well as the value of cultural history. With such a high diversity of wildlife and endemism, the BMNP is a crucial protected area for a significant portion of Ethiopia's and the world's biodiversity.

Therefore, conservation and sustainable use of the biological resources is central to promoting sustainable development in the region or the country at large. The existing knowledge on the characterization of biodiversity, extent of the ecosystem, distribution, diversity of their constituent species (flora and fauna) as well as ecological requirements is very limited both in space and time. Although nothing replaces field surveys in the characterization of these ecosystems in terms of their composition, distribution and functioning they fall short for not keeping pace with the rate of change in land use and land cover and fragmentation.

Thus, Remote Sensing and GIS technologies will help in revealing patterns and analyzing processes that define and characterize the dynamics of natural resources and quantifying pattern of the landscape in spatially explicit ways. In addition, Remote Sensing and GIS technologies can be used for supplying and analyzing spatial information to support decision for the management of natural resources. It is also expected that they can be applied to integrate socio-economic and biophysical data to determine areas susceptible (prone) to biodiversity loss thereby making authorities aware of advances for making informed decisions.

Detailed knowledge of the landscape through indicator indices may allow managers to predict the effects of human disturbance and habitat modification on future resource use patterns, as well as the future success of a regional population in achieving sustainable development. Understanding the landscape using parameters such as fragmentation proximity and other patch characteristics and thereby suggest a ranking of the

ecosystems ability to preserve its integrity under existing pressure will help land use planners to optimize land allocation.

This study tries to provide the same information to Environmentalists, Researchers, Planners, Administrators and Local communities in form maps to provide them with sound, adequate and updated information on the status of Viability, thus supporting a holistic approach to planning of natural resource management.

2. LITERATURE REVIEW

2.1. Ecosystem Concepts and Definitions

An ecosystem can be defined as a naturally occurring, self-maintained system of varied living and non-living interacting parts that are self-organized into biophysical and social components. They are places where all plants, animals, soils, waters, climate, people and processes of life interact as a whole. These ecosystems/places may be small, such as a rotting log, or large, such as a continent or the biosphere. The smaller ecosystems are subsets of the larger ecosystems; that is, a pond is a subset of a watershed, which is a subset of a landscape, and so forth (Slocumbe, 1993; Golley, 1994). All ecosystems have flows of things, flows of organisms, energy, water, air, and nutrients moving within and through them. And all ecosystems change over space and time. Therefore, it is not possible to draw a line around an ecosystem and mandate that it stay the same or stays in place for all time (Botkin 1990, Kimmins 1992).

There are at least four broad concepts useful in understanding ecosystem process and function. Consideration of these concepts should aid in the development of information strategies and guide application development. These are as adopted from (Steffenson, 2000):

- Ecosystems are dynamic and evolutionary.
- It is useful to view ecosystems as being organized within a hierarchy, each level having a variety of time and space scales.
- Ecosystems have biophysical and social limits.
- There are limits to the predictability of ecosystem patterns and processes; conditions and events may be predictable at some scales but not at others.

2.2. Threats to Ecosystem

Deforestation of the Tropics, the conversion of continuous forest landscapes to ones with remnant forest patches in a matrix of non-forest vegetation is increasing at an alarming rate (Whitmore and Sayer, 1992). Destruction of the species-rich tropical forest is regarded as a major threat to global biodiversity (Turner 1996, Carlson and Hartman, 2001). The fragmentation of natural habitats is indeed the greatest single threat to the global biodiversity (Ghosh,2000). Community livelihood activities sometimes contribute to the degradation of the very natural systems they depend on. Almost all forms of human production and consumption have the potential to deplete, convert, pollute or otherwise degrade natural systems. Activities such as overgrazing, over-fishing, conversion of forest and wetlands to agriculture and unsustainable wildlife utilization all degrade and deplete natural systems directly. Other activities such as the use of destructive fishing or timber harvesting techniques slash and burn agriculture, open pit mining and the disposal of untreated agricultural and domestic wastes degrade natural systems as secondary effects of the technologies and methods they employ (Emerton, 1997)

The consequences of society's demands on natural resources residing in ecosystems may be reduced by increasing our understanding and consideration of ecological processes, including the role of biological diversity and natural disturbances in maintaining the health and resilience of ecosystems. Ecosystem Management therefore, can be described as the development of an integrated approach to managing the whole system (holistic approach) rather than each of the component pieces. (Costanza et. al., 1997).

Ecosystem management approach: *“a conservation planning approach that considers the composition, structure, functions, and processes of ecological communities occurring within a landscape. It uses a reference to the characteristics of ecological communities that occurred in an area historically, and strives to provide representation of these ecological communities while integrating human economic and social demands.”* (Bruce and Peter, 2008).

2.3. Landscape Ecology and Landscape Analysis

Landscape ecology, if not ecology in general, is largely founded on the notion that “environmental patterns strongly influence ecological processes” or “emphasizes broad spatial scales and the ecological effects of the spatial patterning of ecosystems” (Turner, 1989, McGarigal, 2002). A landscape is a mosaic of patches and a patch is a region that is more-or-less homogeneous with respect to a measured variable or a non-linear surface area that differs from its surroundings (Urban et al., 1987).

Landscape ecology research supports the application of spatial pattern metrics for quantifying environmental change. Several studies investigating the effects of human disturbances such as timber harvesting on forested environments have shown significant relationships between changes in landscape metrics and underlying ecological processes (Reed et al., 1996 and Sachs et al., 1998). The goal of landscape analysis is to develop an understanding of the landscape as an ecological system by exploring the relationship between structure and function. The purpose is to provide a basis for ecologically informed landscape planning and design (Bruce and Peter, 2008). Understanding the relationship between the spatial setting of the ecosystems and the conservation of their functions and biodiversity is one of the main challenges of landscape ecology. This discipline is deemed to provide a significant contribution to nature conservation practice in the near future (Burke, 2000).

2.4. Fragmentation: Concepts and Definitions

In order to fully comprehend fragmentation into a single workable definition, it requires the understanding of habitat since it is commonly confused as vegetation type. Habitat is defined as the resources and conditions present in an area that produce occupancy—including survival and reproduction by a given organism (Hall et al., 1997) or the subset of physical environmental factors that a species requires for its survival and reproduction Block and Brennan (1993) as cited in Carlson and Hartman (2001) or an area with the combination of resources (*like food, cover, water*) and environmental conditions (*temperature, precipitation, presence or absence of predators and competitors*) that promotes occupancy by individuals of a given species (or population)

and allows those individuals to survive and reproduce (Morrison et al., 1992). Whereas, vegetation type refers to vegetation an animal uses. The idea that habitat can be a specific combination and configuration of vegetation types can be extended further to different combinations and configurations representing different levels of habitat quality. Whereas, habitat quality *is* defined as the ability of the environment to provide conditions appropriate for individual and population persistence. Habitat quality is influenced by the mix and configuration of the two vegetation types that exist in an area (Hall et al., 1997).

2.5. Habitat Fragmentation and Heterogeneity

Habitat fragmentation is usually defined as a landscape-scale process involving both habitat loss and the breaking apart of habitat. It generally occurs through habitat loss; the sum of the fragments is less than the whole. For example, in a uniform landscape composed entirely of a single habitat, fragmentation is only possible if accompanied by habitat loss (Fahrig, 2003). Thus, fragmentation usually involves both a reduction in area and a breaking into pieces (Carlson and Hartman, 2001). Based on existing definitions, fragmentation can be viewed as both a process (that which causes fragmentation) and an outcome (the state of being fragmented) (Wiens, 1994). Second, the transition from being whole to being in pieces may lead to a change in quality of one or more of the fragments if habitat quality is a function of fragment size. For example, fragmentation of continuous forest (accompanied by an inescapable reduction in forest area) may change the quality of the fragments; habitat quality may increase for edge species and decrease for forest interior species (Bender et al. 1998).

An important consideration in both defining and understanding habitat fragmentation ultimately applies only to the species level because habitat is defined with reference to a particular species. Habitat is proximately linked to communities and ecosystems only because these levels are composed of species. There is no concept of community or ecosystem habitat.

In a broader sense, habitat fragmentation refers to the break-up of habitat expanses into smaller and more isolated units. The classic view of habitat fragmentation is the

breaking up of a large intact area of a single vegetation type into smaller intact units (Lord and Norton 1990). Fragmentation represents a transition from being whole to being broken into two or more distinct pieces. The outcome of fragmentation is binary in the sense that the resulting landscape is assumed to be composed of fragments (e.g., forest) with something else (the non-forest matrix) between the fragments. In contrast, *heterogeneity* implies a multi-state outcome from some disturbance process. For example, contiguous old-growth forest can be transformed into a mosaic of different seral stages by some natural or anthropogenic disturbance. If each seral stage, as viewed by a species, is a distinct habitat, then the result of the disturbance is an increase in habitat heterogeneity (Wiens, 1994).

In addition, if habitat is a combination of different vegetation types, then heterogeneity in vegetation types may influence habitat quality, but does not represent fragmentation. Habitat fragmentation is heterogeneity in its simplest form: the mixture of habitat and non-habitat. However, the effects of habitat fragmentation are also dependent on the composition of non-habitat. The matrix of non-habitat may have a positive, negative, or neutral effect on adjacent habitat.

The key point is whether intervening non-habitat affects the continuity of habitat with respect to the species. Therefore, it is arguable to say habitat fragmentation has not occurred when habitat has been separated by non-habitat but occupancy, reproduction or survival of the species has not been necessarily affected. Under this argument, key components in defining habitat fragmentation are scale, the mechanism causing separation of habitat from non-habitat (i.e., the degree to which connectivity is affected), and the spatial arrangement of habitat and non-habitat. Fragmentation arising from habitat loss un-avoidably leads to an increase in heterogeneity in habitat quality because the fragments may undergo a change in state either directly (through conversion) or indirectly through edge effects (Carlson and Hartman, 2001). Thus, the effect of fragmentation differs from species to species depending on the species behavior and hence should not be interpreted from human perspective.

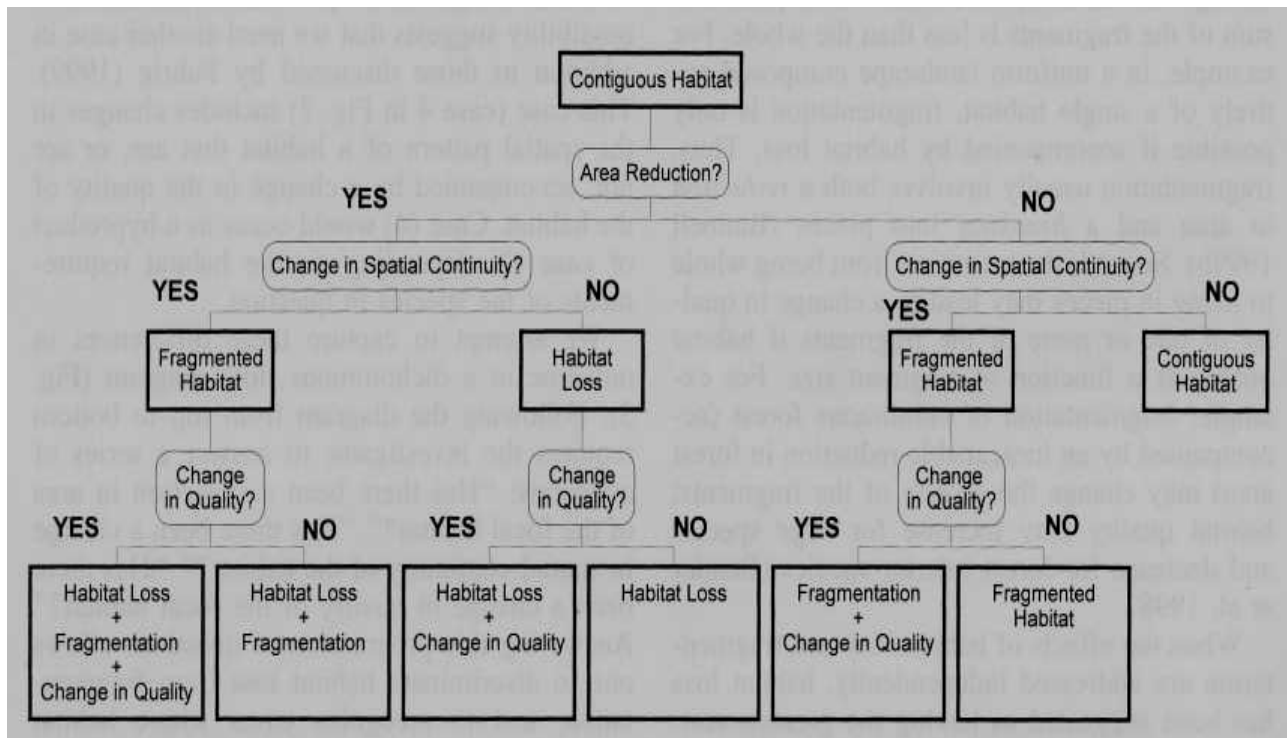


Figure 1: Habitat loss, habitat fragmentation and changes in habitat quality. (Source: - Carlson and Hartman, 2001)

2.6. Effects of Fragmentation

Fragmentation is a system level phenomenon. To estimate the effects of fragmentation, one should have a firsthand knowledge of how the entire system operates (Ghosh, 2000). When a habitat becomes fragmented and surrounded by another habitat this generally causes an increase in predation pressure at habitat transitions, often referred to as an edge effect. Edge effect in the form of enhanced nest predation intensities is one of the most cited explanations for bird population declines in fragmented landscapes. Fragmentation of an intact forest results in increased amount of edge (Hoover et al. 1995). This can have far reaching consequences for the native biota because generalized predators that are adapted to the edge habitats can more easily penetrate forest remnants (Whitcombe et al. 1981). A fragmented forest habitat is reduced in size but tends to retain ecological characteristics and organisms of the forest. Up to a point, in fragmentation, no species are lost. However, as the process continues, the remaining area is reduced to a critical size below which it will not support many of the original species and a number of them would disappear (Whitcomb et al., 1976; Robbins et al., 1989). Different components of an ecosystem can respond in different ways to habitat fragmentation (Robinson et al., 1992). The effects seen among populations can be hidden at the level of aggregated community variables. Therefore understanding the consequences of habitat fragmentation requires documenting the

system attributes that do not change as well as those that do. It has now become increasingly necessary to understand the consequences of the destruction and fragmentation of natural habitats. Habitat fragmentation can influence the entire suite of ecological processes, from individual behavior through population dynamics to ecosystem fluxes (Robinson et al., 1992).

2.7. Measuring Fragmentation-The Scale Problem

The pattern detected in any ecological mosaic is a function of scale and the ecological concept of spatial scale encompasses both extent and grain (Forman and Godron 1986, Turner 1989, Wiens 1989). Extent is the overall area encompassed by an investigation or the area included within the landscape boundary. From a statistical perspective, the spatial extent of an investigation is the area defining the population we wish to sample. *Grain* is the size of the individual units of observation. For example, a fine-grained map might structure information into 1-ha units, whereas a map with an order of magnitude coarser resolution would have information structured into 10-ha units (Turner et al. 1989 as cited in McGarigal, 2002). Extent and grain define the upper and lower limits of resolution of a study and any inferences about scale-dependency in a system are constrained by the extent and grain of investigation (Wiens 1989). From a statistical perspective, we cannot extrapolate beyond the population sampled, nor can we infer differences among objects smaller than the experimental units. Likewise, in the assessment of landscape pattern, we cannot detect pattern beyond the extent of the landscape or below the resolution of the grain (Wiens 1989).

2.8. Fragmentation Metrics-Selection

Landscape metrics can assist in quantifying the fragmentation process and in assessing the biological integrity of the remaining forest (Pfister, 2004). Landscape metrics are algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics. An overabundance of metrics has been developed to quantify categorical map patterns. These metrics fall into two general categories: those that quantify the *composition* of the map without reference to spatial attributes, and those that quantify the *spatial configuration* of the map, requiring spatial information for their calculation (McGarigal and Marks 1995, Gustafson 1998).

Although there are hundreds of metrics available, addressing several question using landscape metrics in assessment efforts is difficult depending on: (1) What are the objectives of the study (i.e. are the selected metrics related to the ecological processes being examined)? (2) What is the behavior of the metrics over a range of landscape configurations? (3) What are the effects of scale on the metrics? And (4) are the metrics correlated or redundant (Turner et al. 2001). The fragmentation index is a useful tool for measuring the level of disturbance and vulnerability of these forests (Abdullah, 2006). Metrics that are independent to represent landscape pattern (Turner, 2001)

2.9. Interpretation of Metrics-Limitations

McGarigal (2002), all landscape metrics need the user to define some parameters during the landscape analysis, including its extent and grain and the patches that comprise it, additional input parameters such as edge effect distance, edge contrast weights, and search distance before any of these metrics can be computed. Thus it is incumbent on the investigator to determine those parameters as they are deemed necessary for an application under consideration. The identification of patches reflects a minimum mapping unit that is chosen for practical or technical reasons and not for ecological reasons. Subjectivity in defining patches, surface pattern techniques can provide an objective means to help determine the scale of patchiness (Gustafson 1998). Additionally, the format (raster versus vector) and scale (grain and extent) of the data can have a profound influence on the value of many metrics (McGarigal, 2002). Furthermore, Jaeger (2000), failure to understand the theoretical behavior of the metric can lead to erroneous interpretations. Thus McGarigal (2002) advised to select a metric representing a landscape pattern in a manner and at a scale ecologically meaningful to the phenomenon under consideration to draw sound conclusions there from.

2.10. Remote sensing –Beyond Vegetation Mapping and Integration

Recent research on remote sensing/GIS integration supports a combination of data sources and techniques to provide a more comprehensive analysis of environmental change (Wilkinson 1996). Recent classification algorithms applied in remote sensing which take advantage of these integrated techniques include knowledge-based

classifiers. Decision tree classifiers represent a form of knowledge-based classification that provide important advantages over conventional methods. For example, the Hybrid Decision Tree algorithm described by Friedl and Brodley (1997) allows the incorporation of different data types and classification algorithms in a single approach

Recent advances in Remote Sensing and GIS have offered new opportunities for investigation at scales larger than in the past and contemporary research into processes and patterns. Recent developments in the spatial and temporal resolution has confirmed the importance of small scales which, in tracking back processes has allowed the understanding the environmental conditions of the past (Delcourt,1988). The availability of data across a large spectrum of scales has opened new possibilities for integrating patterns and processes, as recently stressed by Lubchenco et al (1991). Satellite images can be considered as a very convenient tool to measure landscape patterns since they provide digital mosaic of the spatial arrangement of land covers (Chuvieco, 1999, Coulson et al, 1990). Remotely sensed images can provide information beyond the Vegetation type or land use land cover images for landscape pattern analyses and the modeling capability of adds an extra advantage to model and simulate past patterns and forecast the future patterns (Turner and Gardner, 1990).

3. METHODS

3.1. Study Area

Bale Mountains National Park is located with bounding coordinates of 605132, 712380 and 551927, 789885 at the bottom-left and top-right, respectively. It covers an area of 247000 ha on the south-east Ethiopian plateau, in Bale Zone of Oromia Region. The zonal capital, Goba, is on the north-eastern side of the park. The park headquarters are on the northern border at Dinsho, 400 kilometers from the capital Addis Ababa.

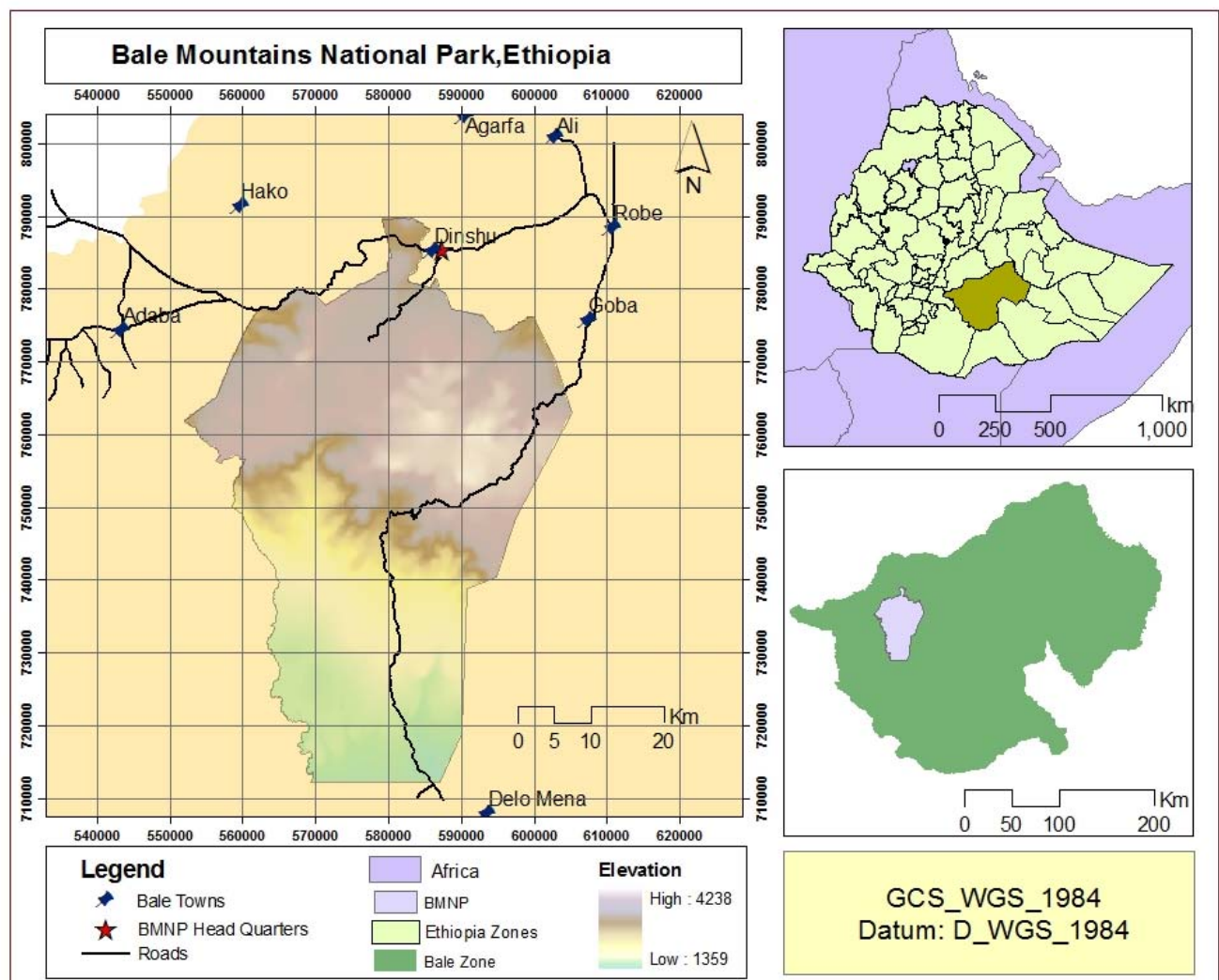


Figure 2: Location of the study area

3.2. Geology and Landform

The Bale Mountains are formed of ancient volcanic rocks that are now dissected by rivers and streams that have cut deep gorges, in some places resulting in beautiful waterfalls. The mountains rise from the 2,500-m plateau to the west, north and east of the park. The Sanetti plateau, which dominates the northern section of the park, reaches 3,800-4,200 m on top of the mountain block, and is broken by several peaks including Tullu Deemtu (4,377 m), the highest mountain in southern Ethiopia and second-highest in the country. The northern highland block is separated from the Hareenna forest by the Hareenna escarpment that runs diagonally from west to east across the middle of the park. The southern border of the park, at 1,600 m, represents the southern limits of the Hareenna forest, the largest intact forest block in the country.

3.3. Hydrology

Larger, permanent lakes like Garba Guracha, Hora Bacha and rivers such as Halla Wenz, are mostly found on the eastern side of the plateau. The northern section of the park covers the valleys of the Web and Danka rivers. The headwaters of four major rivers (Wabe Shebelle, Web, Dumal and Welemel) arise in over 40 streams. All this water eventually flows to the south of the mountains, passing through large areas of lowland Bale, Harerge, and Sidamo regions of Ethiopia, as well as the southern third of neighbouring Somalia (Hillman, 1988)

3.4. Vegetation and Wildlife

Bale Mountains National Park supports a wide range of habitats and encompasses the largest tract of Afro-alpine vegetation in continental Africa. The Hareenna forest increases in species-richness from the low-altitude, open-canopy dry forest at 1,500 m to the very moist, often cloud/mist-covered forest at and above 2,400 m. At these higher altitudes the trees support a high density of epiphytes and woody climbers and, as the canopy is not very dense, a rich herb layer is present.

Juniperus procera forest is found in the northern parts of the park and also on the east around and above Goba. Around Goba there are also patches of *Olea europaea cuspidata*. The tree-heathers *Erica arborea* and *Erica trimera* form a forest (up to 8 m tall) that replaces *Juniperus procera* at c.3,200 m. This vegetation continues up to the Afro-alpine moorland at 3,800 m. The Afro-alpine moorland in this park is extremely rich in endemic plants, with predictions of 30% highly plausible. The most striking plants are the giant *Lobelia spp.* and cushions of everlasting flowers *Helichrysum spp.*, particularly *Helichrysum citrispinum* and *Helichrysum splendidum*. A shrubby lady's mantle *Alchemilla haumannii* that is endemic to the mountains in southern Ethiopia is also present. The park is used for grazing domestic animals, and consequently fire is used to control the growth of woody vegetation (*Erica spp.*) and to stimulate new growth for grazing. (BirdLife International, 2009)

More than 50 wild mammal species are known occur in the Bale Mountains National Park area; over 20 percent of these species are endemic. The most significant remaining populations of two endemic large mammal species occur in the park Mountain Nyala (*Tragelaphus buxtoni*); Simen Fox (*canis simensis*) and were the main reason for the park's inception. Over 180 wild bird species are known from the park, of which 15 are endemic to Ethiopia making 62 percent of Ethiopia's endemic birds. Fourteen amphibian species are known from the area of which eleven (78 percent) are endemic to the country (Hillman, 1988; EWNHS, 1996).

3.5. Climate and Altitude

Rainfall is unimodal (8 months wet season) in the mountain massif, but grades to bimodal (5 months wet season) away from the mountains at lower altitudes. The highest rainfall (about 1,150mm/annum) is experienced in the northern slopes. This decreases to 800 mm/annum on the central plateau, and then apparently decreases all the way to south to 400mm/annum at Mena (1400 m). Extremes of

temperature occur at the highest altitudes on the plateau where dry season diurnal ranges of 40 c (-15 to +26) have been recorded (Hillman, 1986: 1988).

3.6. Study Approach

This study followed a three phase approach: - *Pre-field activity*: involving formulation of the problem, framing objectives, research questions formulation and determination of data requirements. *Field work*: involving primary data collection. Post-field activity: multi-temporal image analysis, fragmentation measure analysis and ecosystem viability modeling. Figure 3 shows framework of study approach.

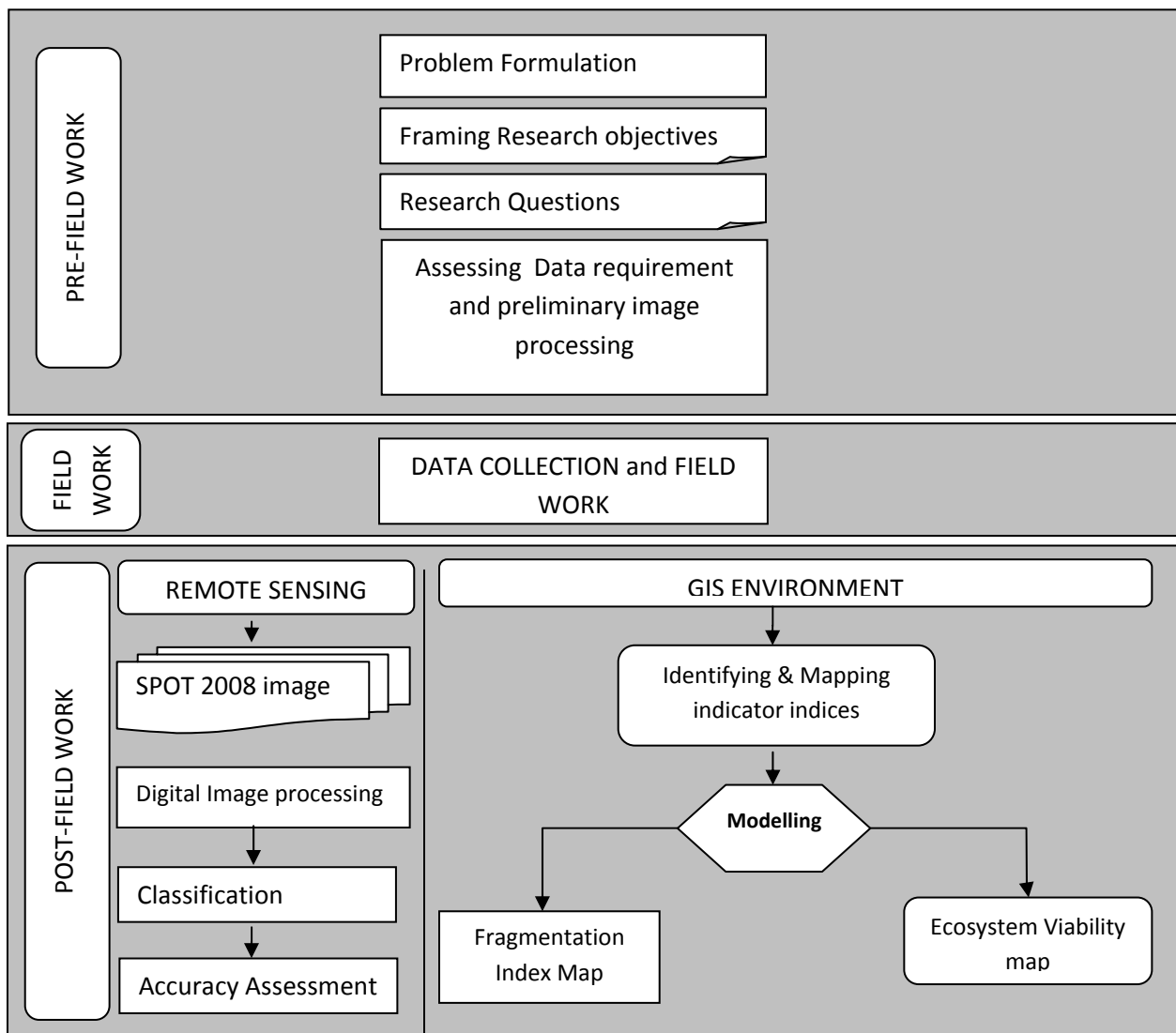


Figure 3: Framework of the study approach

3.7. Methodology

3.7.1. Image Processing

3.7.1.1. Image geo-rectification

The Satellite image obtained for this study had been already orthorectified by the image supplier. However, the model used for orthorectifying is too broad (global) to be in the state of usable precision (ERDAS, 2002). Therefore, it was essential to georeference the orthorectified images by using topographic map with the scale of 1:50000 and ground truthing GPS readings. The exact positions of these points were located on the 2008 image and were re-sampled using a 2nd order polynomial to a final raster. Final RMS error was less than 0.5 pixels were obtained. The image was projected to UTM_WGS84_Zone 37N system which is the country standard set by Ethiopian Mapping Agency (EMA). Since the study area did not lie within one scene, image mosaic was done using ERDAS Imagine mosaicing tool.

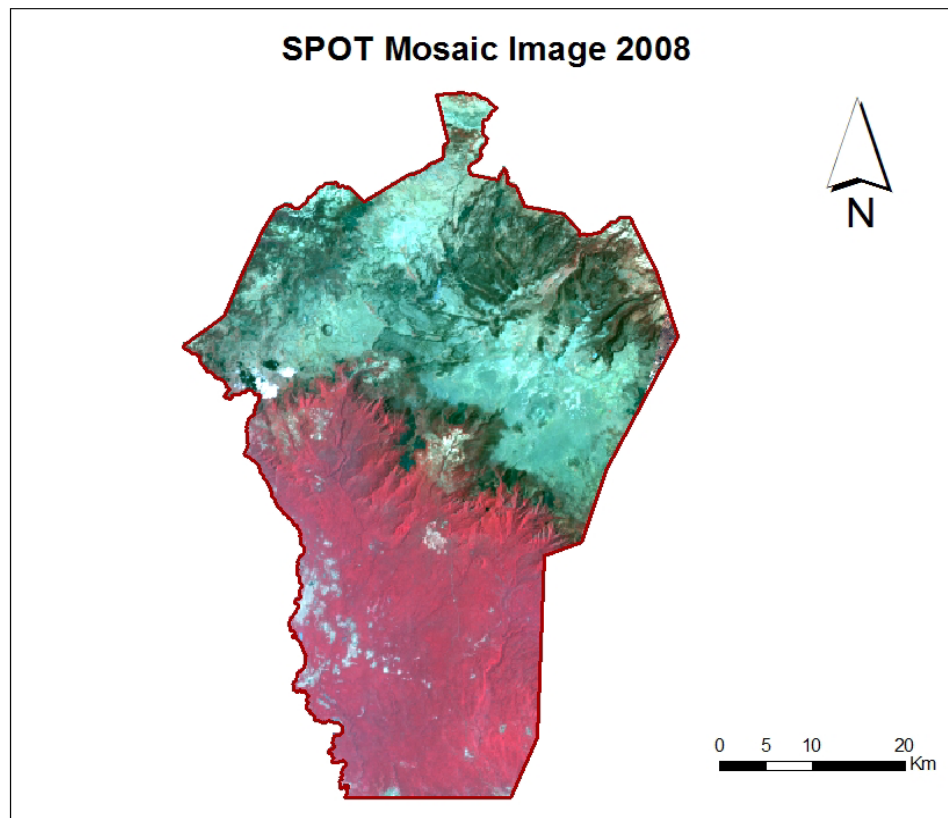


Figure 4: SPOT mosaic 2008 FCC, Bale Mountains National Park, Bale. (FZS-BMNP, 2010).

3.7.1.2. Vegetation Type and Land use Mapping

Land cover maps were prepared by classifying each of the pixels using a supervised classification Maximum Likelihood Classifier (MCL) decision rule. 40 GPS data out of 179 GPS control points (in Appendix I) were used to identify different features (as a training area) for supervised classification of pixels. Vegetation and Land use maps were produced by classifying the image into different vegetation/land use classes using supervised classification technique using 40 training samples out of 179 *ground truthing* data.

The vegetation type/ land use of the study site was categorized using supervised classification technique of Maximum Likelihood Classifier of the SPOT image of 2008. Description of each class is presented in Table 1 below. The first step in supervised classification is to select training (Area of Interest) within the study area (Lillesand and Keifer, 2004). Therefore, 40 training sample set were selected from 179 GPS points obtained from FZS-BMNP. Detailed classes were trained using Anderson et al., (1976) classification system (Level III but modified to suite the study area).

Table 1: Description of major Vegetation type and Land use

Vegetation/Land use type	Description
Agriculture settlement	A mixture Agricultural and settlement area. (Plate c)
Erica forest	Woodland of <i>Erica species</i> of height not more than 5m
Erica shrub	Patches of Erica shrubs of height less than 2m. (Plate b)
Pasture-Bare land	Very short, only composed of grass and <i>alchemilla spp.</i> , high bare ground (presence of <i>knifofia spp.</i> sometimes). Patches of higher type of vegetation (<i>Artemesia afra</i> , <i>Alchemilla johnstoni</i> , <i>Knifofia</i>), absent or very low bare ground because of overgrazing.
Shrubland	Ground mainly covered by dense type of vegetation (<i>Artemesia afra</i> , <i>alchemilla johnstoni</i> , and <i>Knifofia</i>), present when slope is high.
Montane forest	Characterized by the presence of different vegetation belts such

	as bamboo, <i>hypericum</i> belt, <i>hagennia</i> belt, <i>syzygium</i> belt and coffee belt with varying altitudes.(see photograph below) (Plate e and Plate f)
Grazing land	Ground mainly covered by small grasses if not bare soil indicating overgrazing. (Plate a)
Woodland	Includes both open and closed woodland with the dominant species <i>hypericum spp</i> , <i>hagennia spp.</i> , and Juniper spp.
Wetland	Wetlands, swamps and waterbodies
<i>helichrysum</i> and Grass land	Mixed <i>helichrysum spp.</i> with grassland.
<i>Afro-Alpine vegetation (Helichrysum spp.)</i>	Very small bushes with small white leaves and a common habitat for the Ethiopian wolf population. Dominated by <i>Helichrysum splendidum</i> , <i>Helichrysum formosissimum</i> , <i>H. cymosum</i> , <i>Helichrysum citrispinum</i> , <i>Lobelia rhynchopetalum</i> (Plate a)
Shrubland and grassland	A mosaic of mixed shrubland and grassland
Burnt area	Burnt areas in the year 2008



Plate (a)



Plate (b)



Plate (c)



Plate (d)



Plate (e)



Plate (f)

3.7.1.3. Accuracy assessment

The most common and typical method used by researchers to assess the correctness of classification (map reliability) is the use of an error matrix. It is also sometimes referred to as confusion matrix or contingency table. This was used to assess the errors of omission and commission resulting in misclassifying pixels. Producer accuracy, user accuracy, overall accuracy and kappa coefficient were used to indicate how much the classified image represented the actual features on the ground.

3.7.1.4. Fragmentation Analysis

After acceptable level of accuracy was attained through Maximum Likelihood Classifier (MLC) algorithm, the thematic map that derived from SPOT of 2008 was re-sampled to ARC grid format of 30mX30m cell size. The conversion was done at the detriment of the spatial resolution because it will be computationally intensive to extract fragmentation metrics covering the whole study area at 15mx15m spatial resolution. FRAGSTATS 3.3 software (McGarigal et al., 2002) was used for generating fragmentation measures. Class property files, similarity weight files and class properties were created for setting run parameters in FRAGSTATS 3.3. About 109 Class metrics and 72 patch level metrics were derived using constant edge depth of 30m and 200m search radius. Eight cell-Neighbor rule was used to execute standard analysis.

As many of the fragmentation pattern indices are correlated, it is advisable to use list number of indices to characterize the landscape. Therefore, the landscape metrics should be chosen that are relatively independent (less correlated) of each other, which are able to quantify the landscape change meaningfully (Turner et al., 2001).

Pearson correlation and Principal component analysis was done to select least correlated metrics using the statistical software Statistical Package for Social Science (SPSS 14.0). Principal Component Analysis (PCA) was then done to extract from a set of metrics a reduced set of components or factors that account to for most of the variance.

Spatial join was done to the tabular outputs of class level metrics to develop maps of these indices and use the resulting maps in further fragmentation index modeling. Fragmentation index map was created using a linear combination (Weighted sum) of these selected metrics weighted by their eigen values percent of variance. The resulting fragmentation index map was used to select the highly fragmented classes for additional patch level analysis (viability analysis). Selected patch level metrics were then spatially joined to the patch id image created and mapped accordingly.

A) Data Reduction of class Metrics

As many of the fragmentation pattern indices are correlated, it is advisable to use least number of indices to characterize the landscape (Turner, 2001). Therefore, the landscape indices should be chosen that are relatively independent of each other, which are able to quantify the landscape pattern meaningfully.

Pearson correlation and Principal Component Analysis was done to trim out highly correlated metrics using the statistical software SPSS. Principal component analysis (PCA) was then done to extract from a set of metrics a reduced set of components or factors that account to for most of the variance.

B) Selection of Metrics

Metrics were chosen to represent the seven factors based on criteria that:

- 1) The metric should be loaded highly (high value on the rotated component matrix table in presented in (Appendix II) on only one or very few axes or components
- 2) Primary or central tendency metrics were preferred, and
- 3) Easy to interpret metrics were preferred.

C) Factor maps of Fragmentation Index

Mapping of fragmentation metrics have enormous advantage in displaying the spatial distribution and patterns of indices for the conservation and management of resources within the landscape. Spatial join was done to the metric outputs of class level metrics

to develop maps of these indices and use the resulting maps in cartographic modeling of fragmentation index.

D) Standardizing the measurement value of factors

Because the measurement units of factors involved are different for all factors thus need to be converted into the same value so that they can be combined to determine the level of fragmentation. To do so, interval standardization method was used. By using this method, the original values of the selected factors have been converted to standardized scores. Principally the scores are normalized with a linear function between the absolute lowest value and the highest value with within the map. For this step each factor needs to be identified whether it is “cost” or “benefit” effect regarding the fragmentation index. For the benefit effect, the higher the better, and for the cost effect the lower the better. For example for the factor Largest Patch index the larger the value the more intact the patches are and therefore account to the benefit side in the fragmentation index analysis while for patch density, the higher the higher the fragmentation. For standardization of benefit and cost effects using the interval standardization method, the following formulas are used (Sharifi, 2003):

Benefit effect:

$$\frac{V_0 - V_{min}}{V_{max} - V_{min}} \dots\dots\dots (Eq. 1)$$

Cost effect:

$$1 - \frac{V_0 - V_{min}}{V_{max} - V_{min}} \dots\dots\dots (Eq. 2)$$

Where:

V_0 : original true value of the factor.

V_{min} : Lowest true value of the factor.

V_{max} : Highest true value of the factor.

The result of this standardization is a positive score for both the benefit and the cost effect. The standardized scores are exactly between 0 and 1.

E) Weighting of Factors

The use of a weighting method requires information on the relative importance of each factor involved. The weights of each factor need to be assigned. In the regime method, it is sufficient to order the factors from most, to least important. The methods then quantify weights for those factors (Saaty, 2002).

In this study, the percentage of the variance explained by each eigen value was used since it is an indication of each factor's importance, therefore, weighting according to this percentage is a logical method for representing each metric importance when creating fragmentation index map. Normally the weights will add up to one since it assumes all the factor maps play a significant influence in the output map.

F) Modeling Fragmentation

An Equation was created using a weighted linear combination of the selected metrics weighted by their eigen values respective percent of variance.

$$\text{Fragmentation} = e_1/F_1 + e_2/F_2 + e_3/F_3 + e_4/F_4 + \dots + e_n/F_n \dots \dots \dots (\text{Eq. 3})$$

Where: e_j is percent of variance explained by the j^{th} component

F_n is the selected fragmentation metrics on the n^{th} axis

Weighted sum analysis was chosen as a model since the factors involved exhibit compensatory behavior. The resulting fragmentation index map coupled with ecological relevance was used to select the highly fragmented ecosystem for patch level analysis.

3.7.1.6. Ecosystem Viability Assessment

One of the main objectives of ecological studies is to orient *land use* planning by providing clues for optimal ecosystem patterning to support natural conservation under conflict of interests. Spatial indicators are largely employed in landscape ecology to express ecosystem characteristics such as shape, isolation and heterogeneity.

Modeling ecosystem viability (i.e. the capability of an ecosystem to preserve its integrity and host its original biodiversity) is essential to prioritize area for conservation. In this study, selection of patch level metrics of a given class was done using the statistical software SPSS. Figure 4 depicts the flowchart of the methods.

A) Selection of class for patch level fragmentation Analysis

This was done to identify which patches of a given class are viable (could maintain their integrity) and which Patches have undergone extreme fragmentation and reclamation is the least management option. The highly fragmented class was then considered for viability analysis at patch level.

B) Data Reduction of Patch metrics

Pearson correlation analysis was done to reduce the original 72 metrics to a manageable size since. Principal component analysis (PCA) was then done to extract from a set of metrics a reduced set of components or factors that account to for most of the variance.

C) Selection of metrics

Only PCA components having Eigen values one and above were extracted. Then metrics were chosen to represent the axes based on criteria that:

- 1) The metric should be loaded highly (high value on the factor loadings table presented in Appendix III) on only one or very few axes or components
- 2) Primary or central tendency metrics were preferred, and
- 3) Easy to interpret metrics were preferred.

D) Mapping Patch metrics

Spatial Join the patch ID image created using 8 cell rule with metric data to create factor maps for viability analysis. The selected metrics were accordingly mapped for cartographic modelling of patches viability.

E) Standardizing the measurement value of factors

Because the measurement unit of factors involved is different for all factors thus need to be converted into the same value so that they can be combined. To do so, interval standardization method was used. By using this method, the original values of the selected factors have been converted to standardized scores. Principally the scores are normalized with a linear function between the absolute lowest value and the highest value with within the map. For this step each factor needs to be identified weather it is “cost” or “benefit” effect towards viability assessment. For the benefit effect, the higer the metric value the better, and for the cost effect the lower the metric value the better. For example for the factor Core Area Index, the largest the value the more viable the patches are and therefore account to the benefit side in viability analysis while for Proximity the higher the value higher the patch fragmentation. For standardization of benefit and cost effects using the interval standardization method, the following formulas are used (Sharifi, 2003):

Benefit effect:-

$$\frac{V_0 - V_{min}}{V_{max} - V_{min}} \dots\dots\dots (Eq. 4)$$

Cost effect:-

$$1 - \frac{V_0 - V_{min}}{V_{max} - V_{min}} \dots\dots\dots (Eq. 5)$$

Where:

V_0 : original true value of the factor.

V_{min} : Lowest true value of the factor.

V_{max} : Highest true value of the factor.

The result of this standardization is a positive score for both the benefit and the cost effect. The standardized scores are exactly between 0 and 1.

F) Weighting of Factors

Since the percentage of the variance explained by each eigen value is an indication of each factor's relative importance, therefore, weighting according to this percentage is a logical method for representing each metric importance when assessing the viability of patches. Normally the weights will add up to one since it assumes all the factor maps play a significant influence in the output map. However, in this particular study their sum equals the cumulative variance of the extracted axes.

G) Modeling Viability

Since the factors involved could compensate each other, weighted sum model was selected to assess the viability of patches.

$$\text{Viability}_i = e_1/F_1 + e_2/F_2 + e_3/F_3 + e_4/F_4 + \dots + e_n/F_n \dots \dots \dots (\text{Eq. 6})$$

Where: - Viability_i is the value of the index for the i^{th} patch

e_j is the percentage of variance of j^{th} eigen value

F_j is the factor for the j^{th} fragmentation metrics.

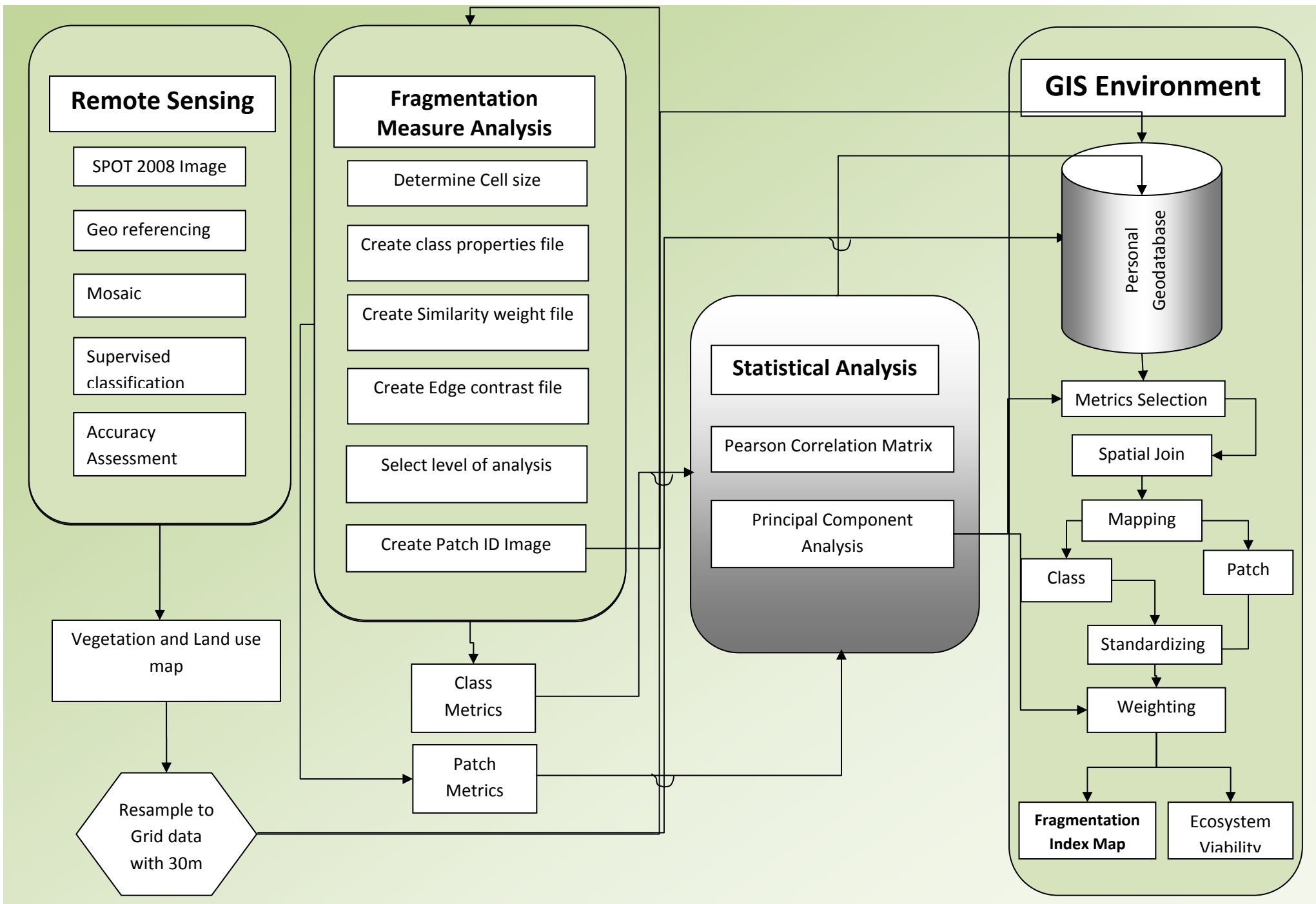


Figure 5: Flowchart of Methods

4. RESULTS AND DISCUSSION

4.1. Mapping of vegetation type and Land use

Thirteen vegetation type and landuses were trained using the 40 training GCP's for the Supervised classification of the SPOT 2008 (see Figure 5). Using the training sample set of 179 ground truth data (Appendix I), the overall accuracy and Kappa coefficient of the classification was found 88.33% and 0.8654, respectively. Map reliability assessment has showed that only 75% of shrubland on the map was correctly classified as shrubland. In addition, 20% of agriculture land use and 7% of Erica shrub class were misclassified as shrubland.

The user accuracy of grassland is quite low, at 60 %. In fact, it is not easy to select a homogeneous training sample, particularly when its spectral characteristic is quiet similar to the spectral characteristics of woodland. That is why 20% of woodland was misclassified as grassland (Appendix IV). The result of vegetation type and land use in the National park is shown in Figure 6 below.

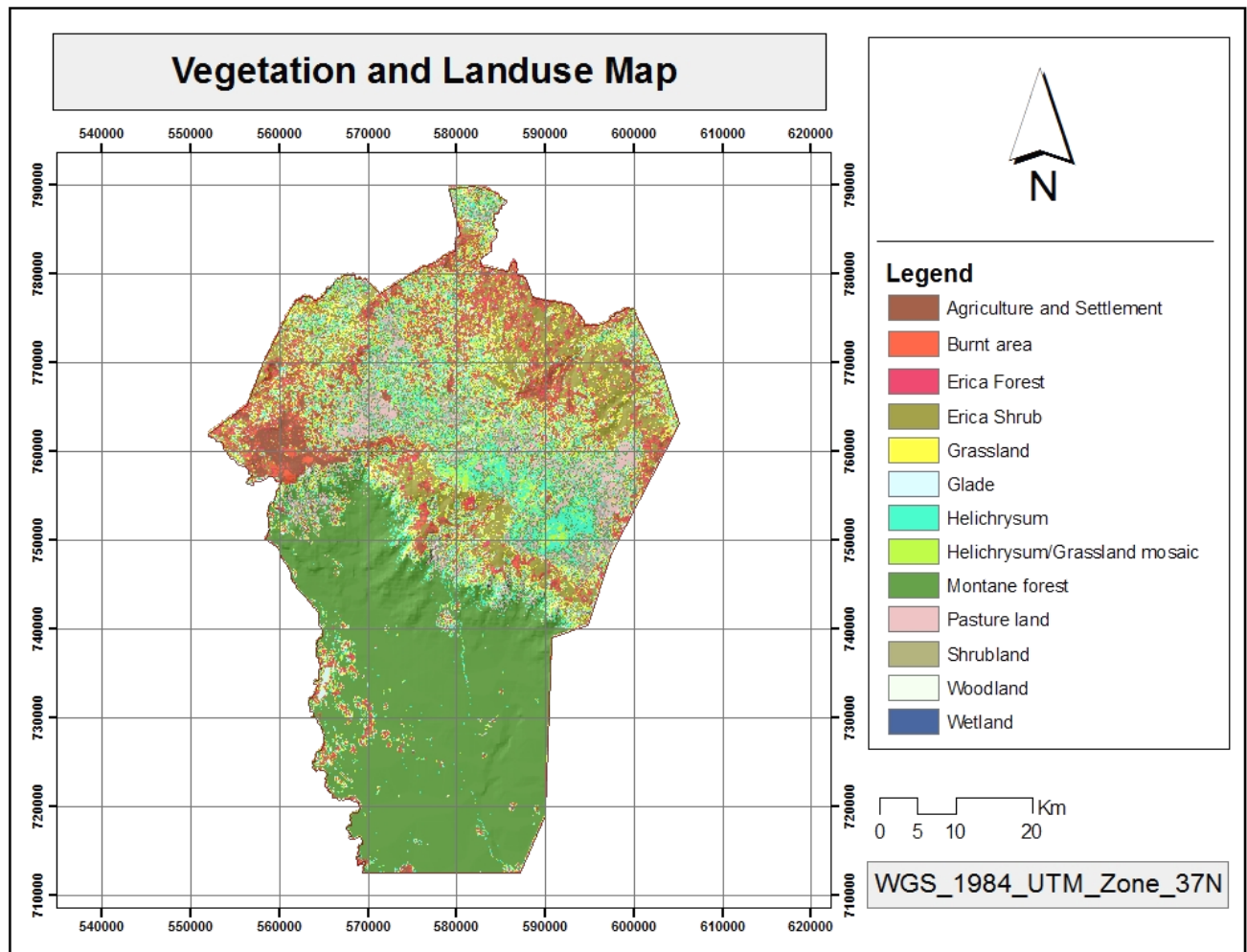


Figure 6: Vegetation type and Land use Map, BMNP.

As it can be seen from the Montane forest vegetation dominates the park area with above 40% followed by agriculture and settlement land use with around 16%. Erica shrub covers about 15 % of the park area (Figure 7).

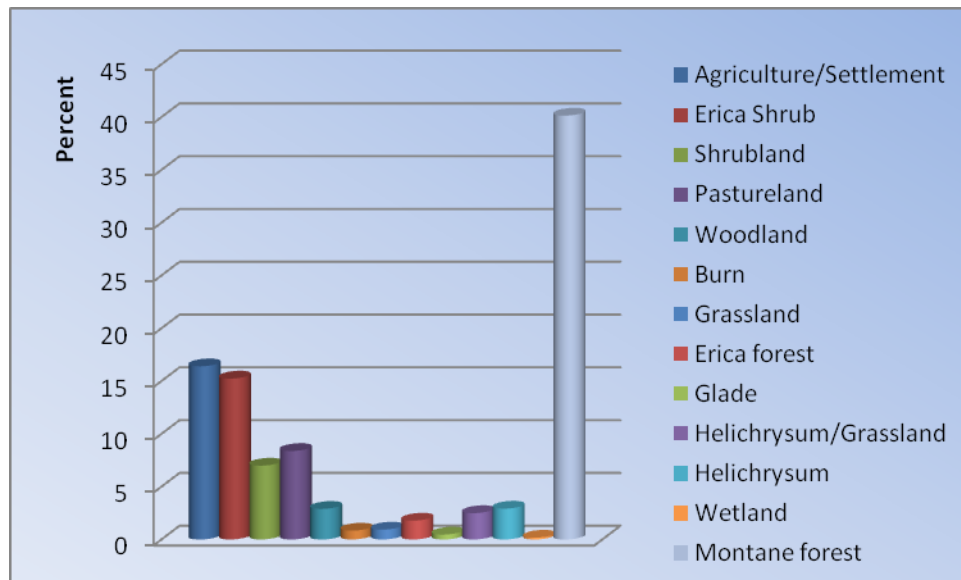


Figure 7: percentage of the area of vegetation and land use types in BMNP.

4.2. Fragmentation

Landscape metrics can assist in quantifying vegetation fragmentation and in assessing the biological integrity of the remaining vegetation (Fister, 2004). However, with literally hundreds of metrics available and usually many of the metrics are partially or completely redundant, measuring patterns of fragmentation has often remained ambiguous. A total of 109 fragmentation measures (at class level) were obtained from FRAGSTATS. Many of the metrics are partially or completely redundant; that is, they quantify a similar or identical aspect of landscape pattern. In most cases, redundant metrics will be very highly or even perfectly correlated (McGarigal, 2002). Therefore, reducing this number to a manageable size based on a statistically sound procedure was essential. It has been suggested that factors involved in fragmentation are often so complex that the use of one single measure is inadequate (Davidson, 1998). Bissonette and Storch (2002) have also suggested that agreement on appropriate measures of fragmentation metrics is a necessary step in order to draw conclusions from the results of the analysis. Turner et al. (2001), metrics are correlated and redundant and advised to use the least number of indices to characterize the landscape pattern.

4.2.1. Data Reduction

This study tried to use the matrix of Pearson correlation ($|r| > 0.95$) and reduced about 56% of the class level metrics. The Matrix of Pearson Correlation Coefficient indicated 59% of non-diagonal matrices were highly correlated with coefficient of correlation ($|r| > 0.95$). Through this analysis it was possible to reduce the original 109 class level fragmentation measures to 48. Then, the PCA analysis extracted from the remaining 48 metrics, a reduced set of components or factors that account for most of the variance. Outputs from PCA indicate that the first six components (having eigen value > 1) represent 96 % of the total variation (cumulative variance), (Figure 8 and Figure 9).

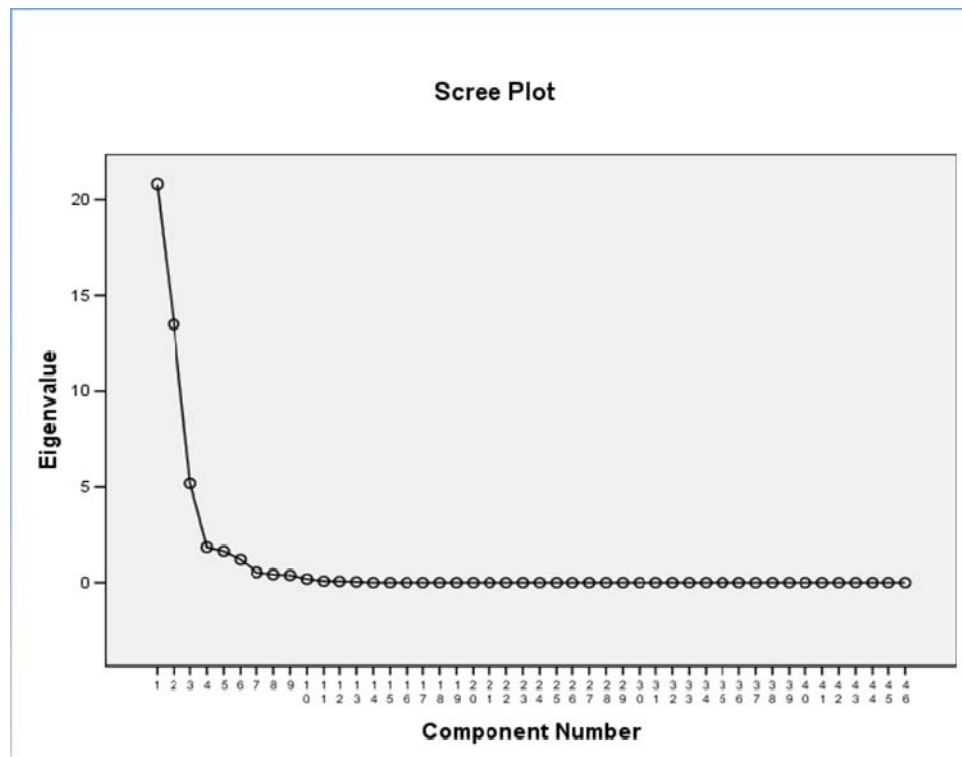


Figure 8: Scree plot of components with their respective eigen values

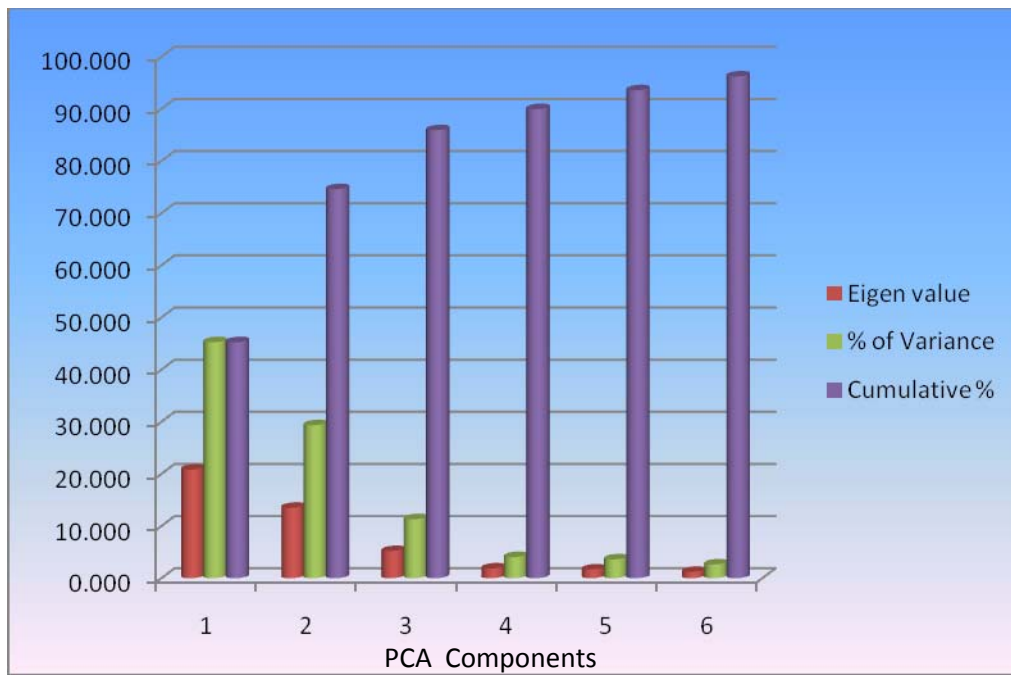


Figure 9: Extracted components with Eigen values, percent of variation explained by each component and cumulative variance

4.2.2. Selection of class metrics

Generally, Area/Density/Edge class level metrics loaded higher values on the factor loadings (in Appendix II) to represent the first and second axes of PCA that comprised 74% of the cumulative variation. From the available metrics, Largest Patch Index (LPI) and Patch Density (PD) were selected based on their relatively higher value (0.96 and 0.948) and relatively easy ease of interpretation to represent fragmentation in these axes, respectively.

Factor loading value on the third axis (explaining 10% of the variance) suggested that the shape metrics Perimeter to Area ratio Coefficient of Variation (PARA_CV=0.975) as a representative fragmentation measure. Factor loadings on the 4th and 5th component of the PCA showed that the contrast metrics (Total Edge Contrast and Edge contrast Coefficient of variation=0.758 and 0.931) to represent them as indicator of fragmentation respectively. Factor loadings in the last axis comprising (<1 % of the variation) indicated that Core Area metrics /Mean Core Area Index (CAI_MN) to represent it as a fragmentation factor. Figure10 present a summary of factor loadings of selected fragmentation measures.

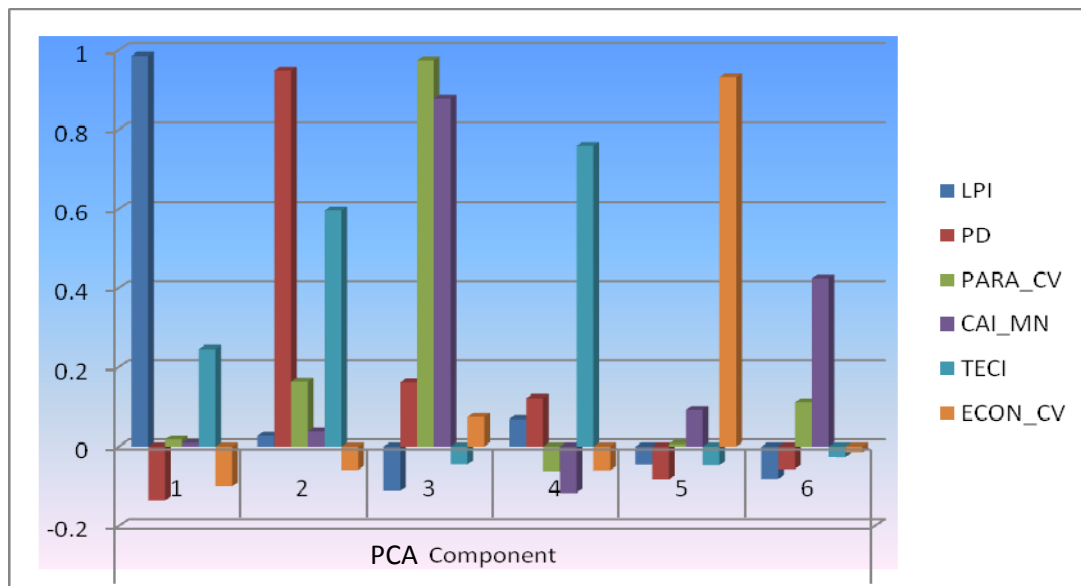


Figure 10: Factor loadings of metrics representing each Component (axis).

Table 2: Description of selected metrics (Class-level)

Class metrics	Description	Value Ranges	Remarks
LPI	Largest Patch index measures percentage of total landscape area comprised by the largest patch. It is a simple measure of dominance. (McGarigal,2002)	$0 < \text{LPI} < 100$	Benefit
PD	Patch Density equals the number of patches of the corresponding patch type divided by total landscape area. (McGarigal,2002)	$\text{PD} > 0$, constrained by cell size	Cost
PARA_CV	Perimeter Area Ratio coefficient of variation equals the standard deviation divided by the mean, multiplied by 100 to convert to a percentage, for the corresponding patch metric. Measures of overall shape complexity. (McGarigal,2002)	$0 < \text{PARA_CV} < 100$	Cost
TECI	TECI equals the sum of the lengths (m) of each edge segment involving the corresponding patch type multiplied by the corresponding contrast weight, divided by the sum of the lengths (m) of all edge segments involving the same type, multiplied by 100 (to convert to a percentage). (McGarigal,2002)	$0 < \text{TECI} < 100$	Cost
ECON_CV	Edge Contrast Coefficient of variation patch edge contrast for patches of a particular patch type (class level) or for all patches in the landscape. Equals the standard deviation divided by the mean, multiplied by 100 to convert to a percentage, for the corresponding patch metric. (McGarigal,2002)	$0 < \text{ECON_LPI} < 100$	Cost
CAI_MN	Mean Core Area Index equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric values, divided by the number of patches of the same type. (McGarigal,2002)	$0 < \text{CAI_MN} < 100$	Benefit

Therefore, six fragmentation indices representing each of the six PCA components for modeling of fragmentation were described in Table 2 above. Accordingly, these metrics were mapped to serve as factors maps in modeling of fragmentation (Figure 11 a-f).

Despite the confusing array of research on fragmentation, researchers have consistently identified key metrics although they differ in terms of scale, region and overall methodology. At the landscape scale, the factors of greatest importance appear to be measures of landscape diversity and texture first, with measures of shape and size being of lesser importance (Cain et al. 1997). At the class-level, measures of Patch area, Core area, Patch shape, and Patch isolation appeared rather consistently (Cumming and Vernier 2002, Abdullah & Nakagoshi, 2007). Specifically, Cumming and Vernier (2002), examined four classes of forest habitat and found in each case the first principal component, accounting for 50-67% of the variation was positively related to measures of patch shape, core area, and patch isolation and in general the second and third principal components describe additional aspects of patch shape, and mean distances between similar patches.

The findings of this research are in agreement with many literatures. Results of the PCA extracted patch Largest Patch index (LPI), Patch Density (PD), Perimeter-Area ratio (PARA), Total Edge contrast Index (TECI), Contrast Index Coefficient of Variation (CI_CV) and Mean Core Area Index (CAI_MN) to represent its six respective components explaining 96% of the variation. Measures of area and shape represent the first three components of the PCA accounting to 85% of the total variance. Core area measures did not account for a large percent of the total variation, but represent a fairly unique measure that loaded highly on the sixth axis. Contrast metrics were other important factor that represented fragmentation index on the fourth and fifth axis of the PCA (see *Figure 10*). However, other studies found patch isolation/proximity measures to be important (Cumming and Vernier 2002).

Largest Patch Index (LPI) defined as the area of the largest patch divided by the land area of the entire landscape which measures of the percentage of a patch that is contained in the largest patch of a given class type. Moreover, McGarigal and Marks

(1995) mentioned the LPI as the measure of dominance in the landscape. Thus, this study showed land cover types of natural habitat such as Montane forest and pasture exhibit larger values of LPI. Hence, this study assumes the higher the LPI the more intact (the less the fragmentation) is the land cover types. On the other hand, lower value of LPI infers the presence of fragmentation in *helichrysum*, *woodland* classes. land cover class that shaded in green in the factor map (Figure 11(a)). Therefore, it is considered as a cost to have higher values (i.e. the higher the value of the LPI, the least is the fragmentation).

Large Patch Density (PD) expresses the number of patches per unit area. Since, maximum PD values are attained when every cell in raster grid is a separate patch (McGarigal, 2002), larger values generally suggest higher fragmentation; therefore it was considered a *benefit* to the fragmentation modeling. In relation to this, agriculture and settlement land use class exhibits higher PD values which shows higher fragmentation within the class (Figure 11(b)).

Perimeter-Area Ratio (PARA) is a simple shape complexity which measures the compactness of patches in the landscape. Higher values show higher shape complexity (irregularity). On the other hand, the smaller the value the higher the compactness, hence, the lesser the fragmentation, therefore it accounted to benefit in the fragmentation modeling. The Erica shrub class showed higher values of PARA index conveying intervention in the land cover class was present in the study site (Figure 11(c)).

Larger values of Edge Contrast Index Coefficient of Variation (ECON_CV) and Mean Core Area Index (CAI_MN) are generally regarded as high fragmentation therefore account to the benefit side of fragmentation modeling. Thus, Figure D and E indicate lower value of CI_CV and CAI_MN in *Montane forest* and *Helichrysum* vegetation classes. However, higher value of Total Edge Contrast Index (TECI) was observed which represent higher level of fragmentation (Figure 10(d)). As the result, ECON_CV, CAI_MN and TECI were considered as benefit, benefit and cost for fragmentation modeling, respectively.

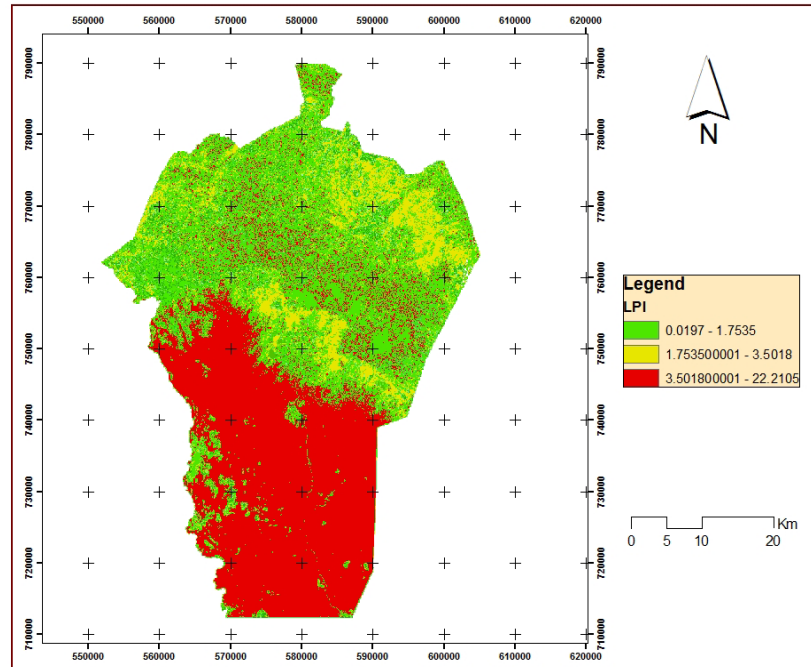


Figure 11(a). Largest Patch Index.

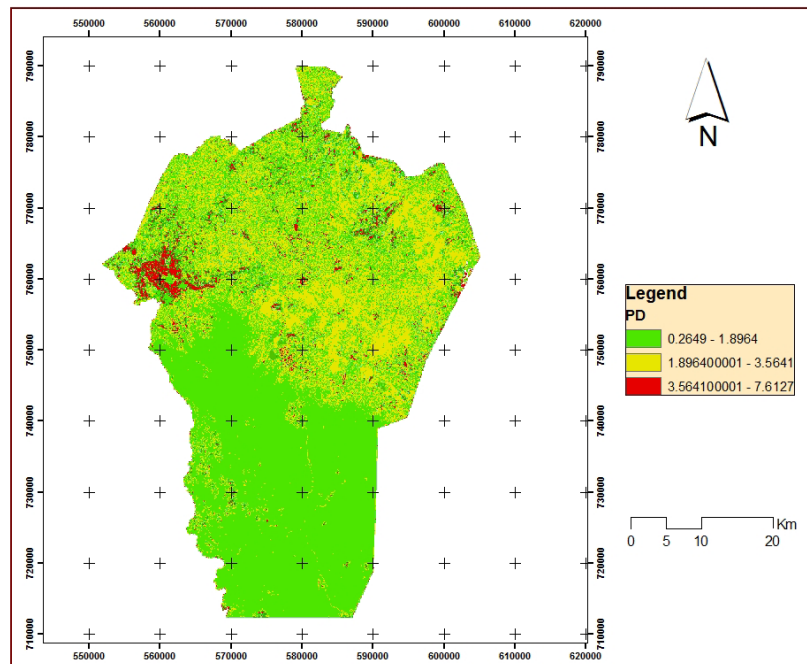


Figure 11(b). Patch Density.

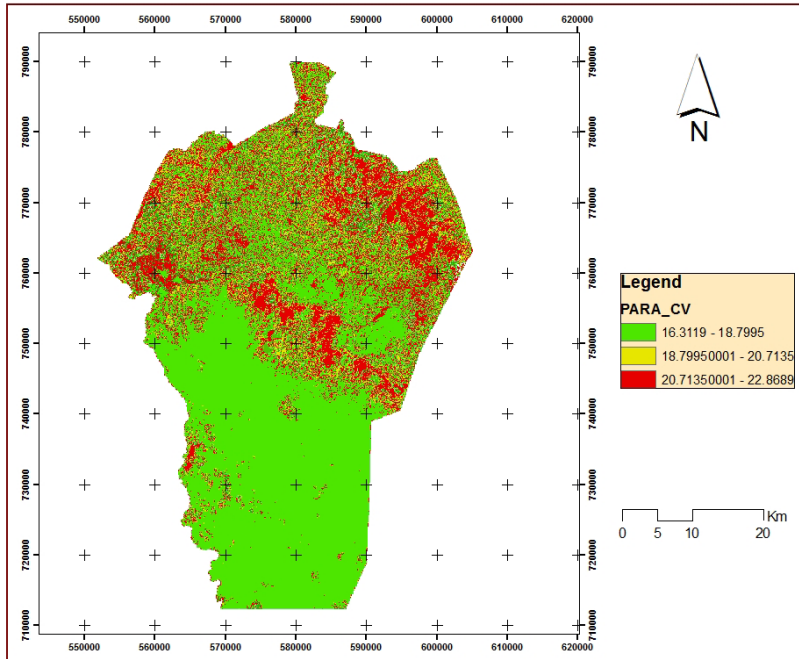


Figure 11(C). Perimeter-Area Ratio Coefficient of Variation

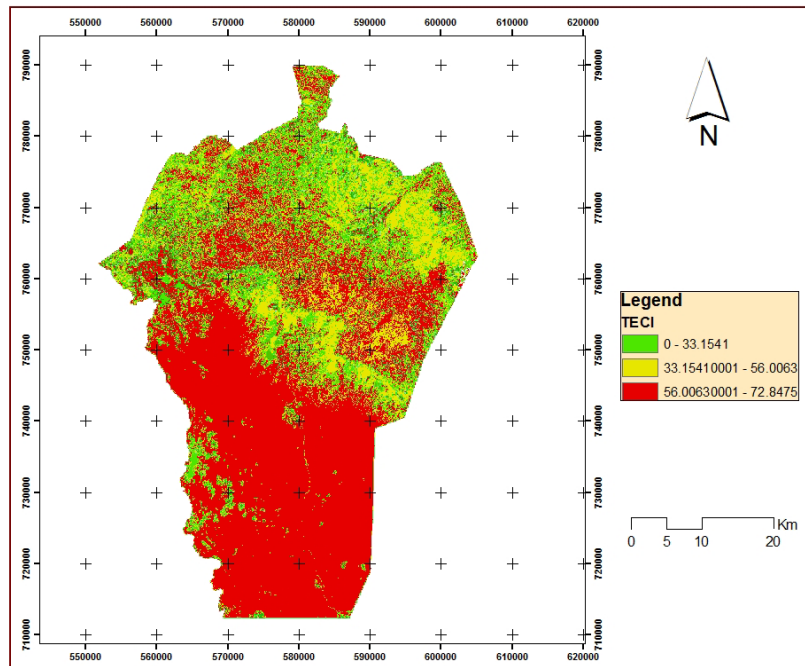


Figure 11(d). Total Edge Contrast Index.

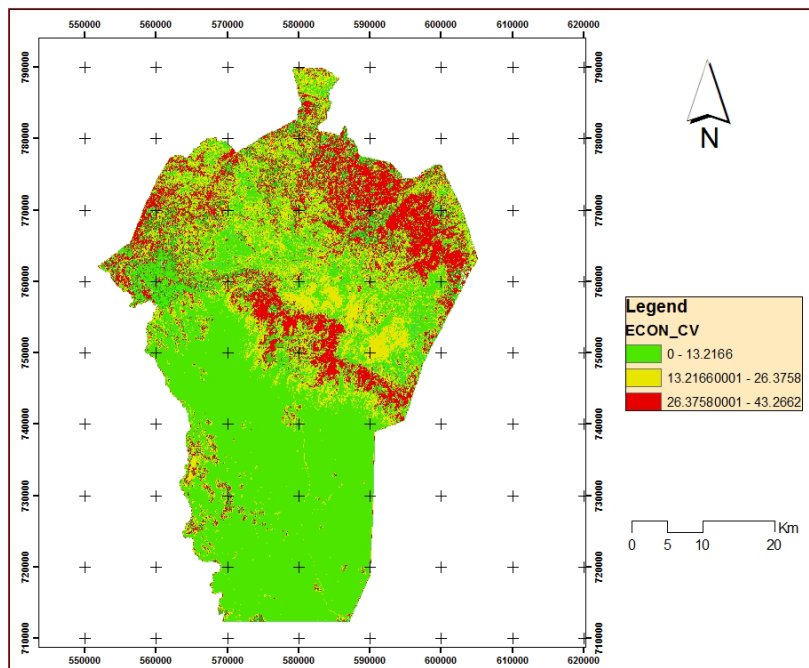


Figure 11(e). Edge Contrast Coefficient of Variation.

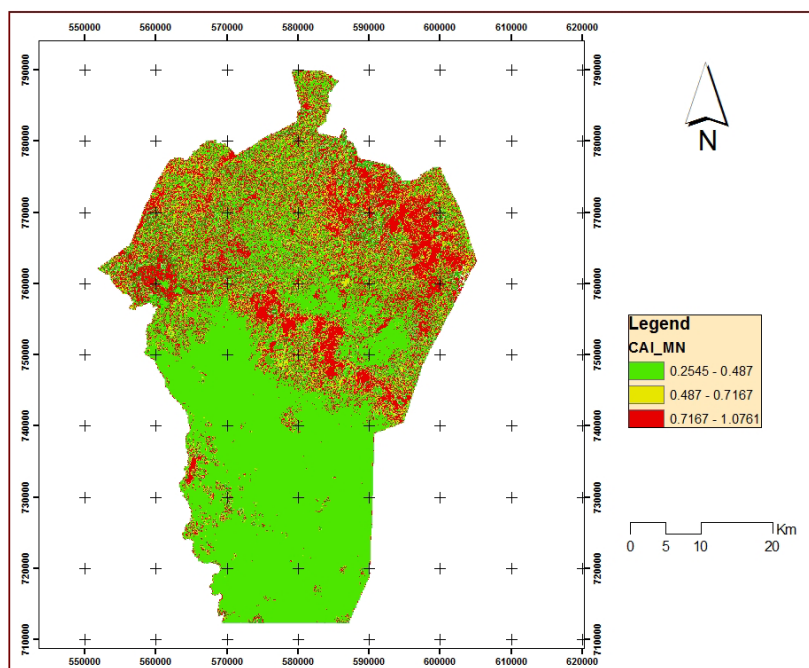


Figure 11(f) Mean Core Area Index

4.2.3. Weighting factors

The percentage of the variance explained by each axis is an indication of each factor's influence, therefore, weighting according to this percentage is a logical method for representing metric importance when creating fragmentation index model. Ideally, the weights will add up to one since it assumes all the factor maps play a significant influence in the output map. This study considers only those factors which have eigen values greater than one. Therefore, they sum to 0.96 unlike those techniques commonly used in many statistical softwares employing pair-wise comparison (Satty, 2002). Table 3 presents the weights (e_j) used for fragmentation modelling.

Table 3: Components,Eigen values,weights (percent of variance) of selected metrics.

Component	Eigen Values	Percent of Variance (e_j)	Representative Metrics
1	20.819	45.259	LPI
2	13.496	29.339	PD
3	5.204	11.314	PARA_CV
4	1.863	4.049	TECI
5	1.661	3.610	ECON_CV
6	1.214	2.638	CAI_MN

4.2.4. Fragmentation

The weighted sum model (linear combination) of the selected metrics in equation (7) produces a final map with a grade of classes according to their degree of fragmentation as high, medium and low. (Figure 13).The results indicate that about 20% of the BMNP is graded under high fragmentation rank particularly for the *Helichrysum* and *woodland* class (Figure 13). This study coupled the findings of the fragmentation index map with the ecological value to select classes for assessing viability of the remnant patches.

$$\text{Frag} = 0.45 \text{ LPI} + 0.29 \text{ PD} + 0.11 \text{ PARA_CV} + 0.04 \text{ TECI} + 0.036 \text{ ECON_CV} + 0.26 \text{ CAI_MN} \dots\dots(\text{Eq. 7})$$

Where:-Frag is the value of the fragmentation index

LPI is the Largest Patch Index (a)

PD is the Patch Density (b)

PARA_CV is the Perimeter Area Ratio Coefficient of Variation Index (c)

TECI is the Total Edge Contrast Index (d)

ECON_CV is the Edge Contrast Coefficient of Variation Index (e)

CAI_MN is the Mean Core Area Index (f)

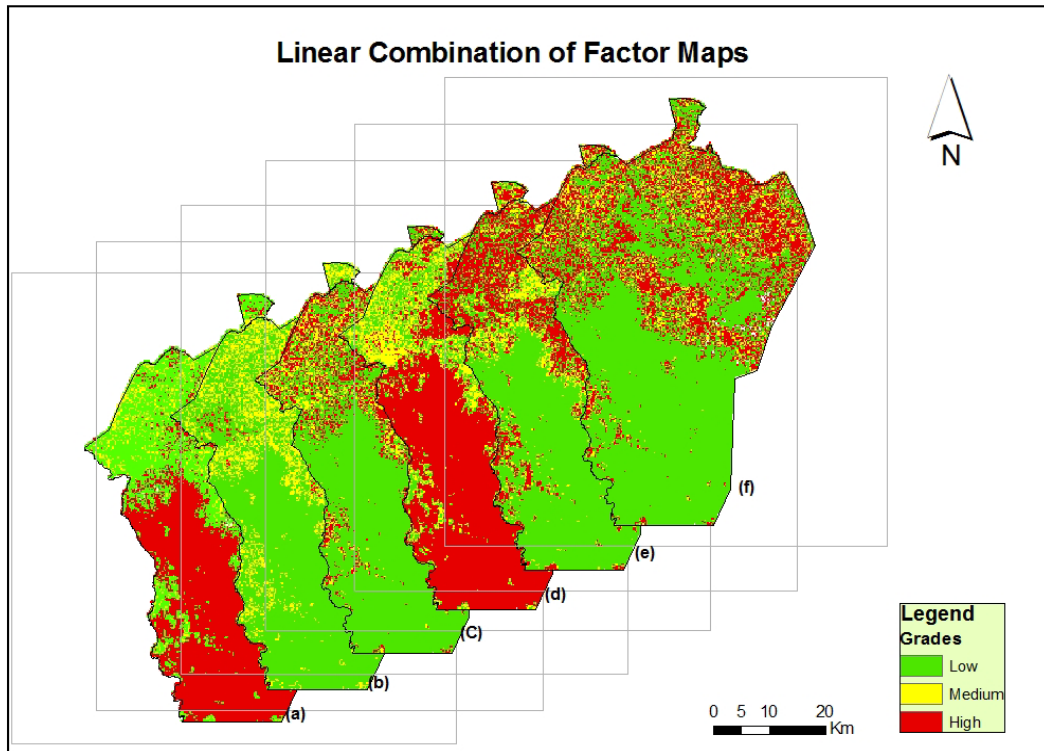


Figure 12: Linear Combination of factors LPI(a),PD(b),PARA_CV(c),TECI(d),ECON_CV(e) and CAI_MN(f)

Figure 13 shows ranks of fragmentation in the BMNP. The high level of fragmentation is characterized by the high values of those metrics stated as cost (see Table 2). On the other hand, those metrics which are standardized as benefit in Table 2 above contributed for the low fragmentation scaling of the study area. In relation to this, percentage of area coverage for the respective level of fragmentation is presented in Figure 14. Thus, most of the study area falls under low fragmentation class which accounted to 54.7%, while 20.6 % of the study area is graded as high fragmented. Visually, it could be seen that the vegetation class *helichrysum* and woodland falls

under the high fragmentation class while the montane forest is intact (low fragmentation).

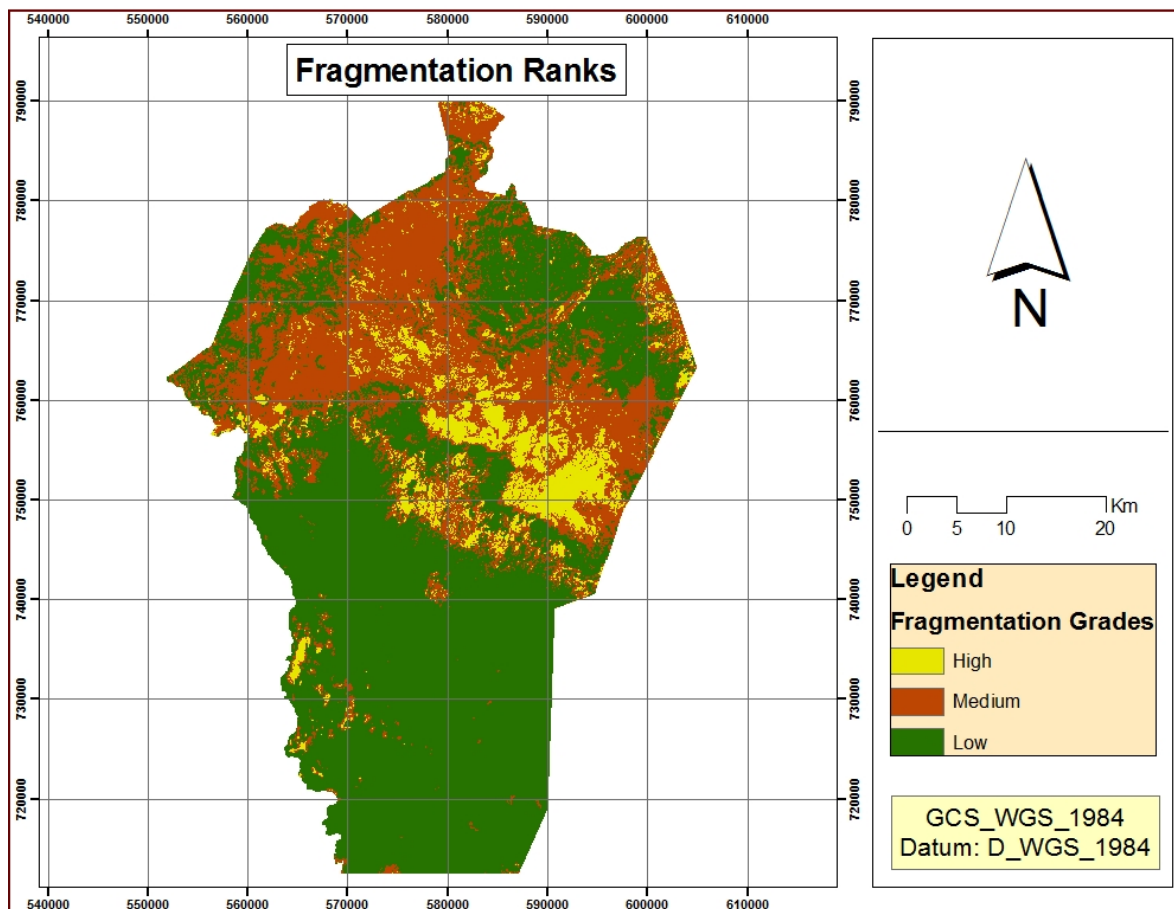


Figure 13: Fragmentation Index map.

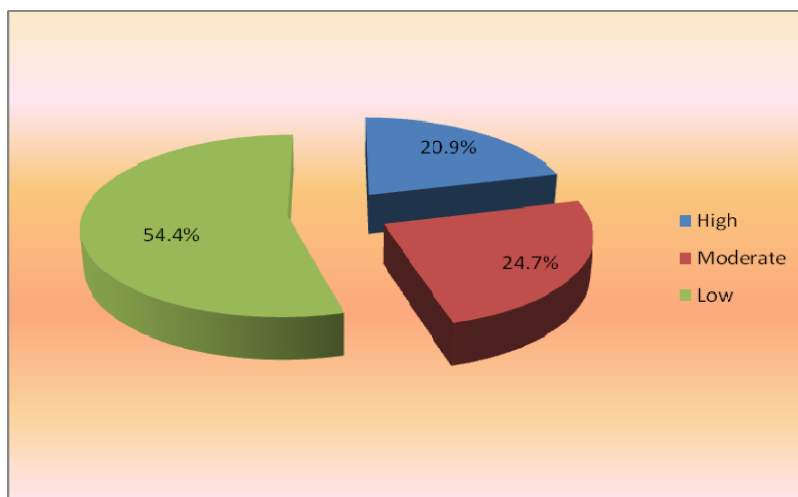


Figure 14: Percent area under high, moderate and low fragmentation grades.

4.3. Viability Assessment

Prioritizing vegetation classes to assess the integrity of remaining patches was based on the level of fragmentation exhibited and ecological relevance of the class. From the results of fragmentation above (see Figure 13 above) the *helichrysum* vegetation class was selected the assessment of viability of the fragmented patches.

4.3.1. Data Reduction (Patch-level)

The Pearson Correlation matrix ($|r| > 0.95$) reduced the original 72 metrics to 62 (by 14%). Then results from PCA identified seven components (having eigen values > 1.0) comprising the largest percentage of the variation (about 94% of the cumulative variance). (Figure 15 and Figure 16)

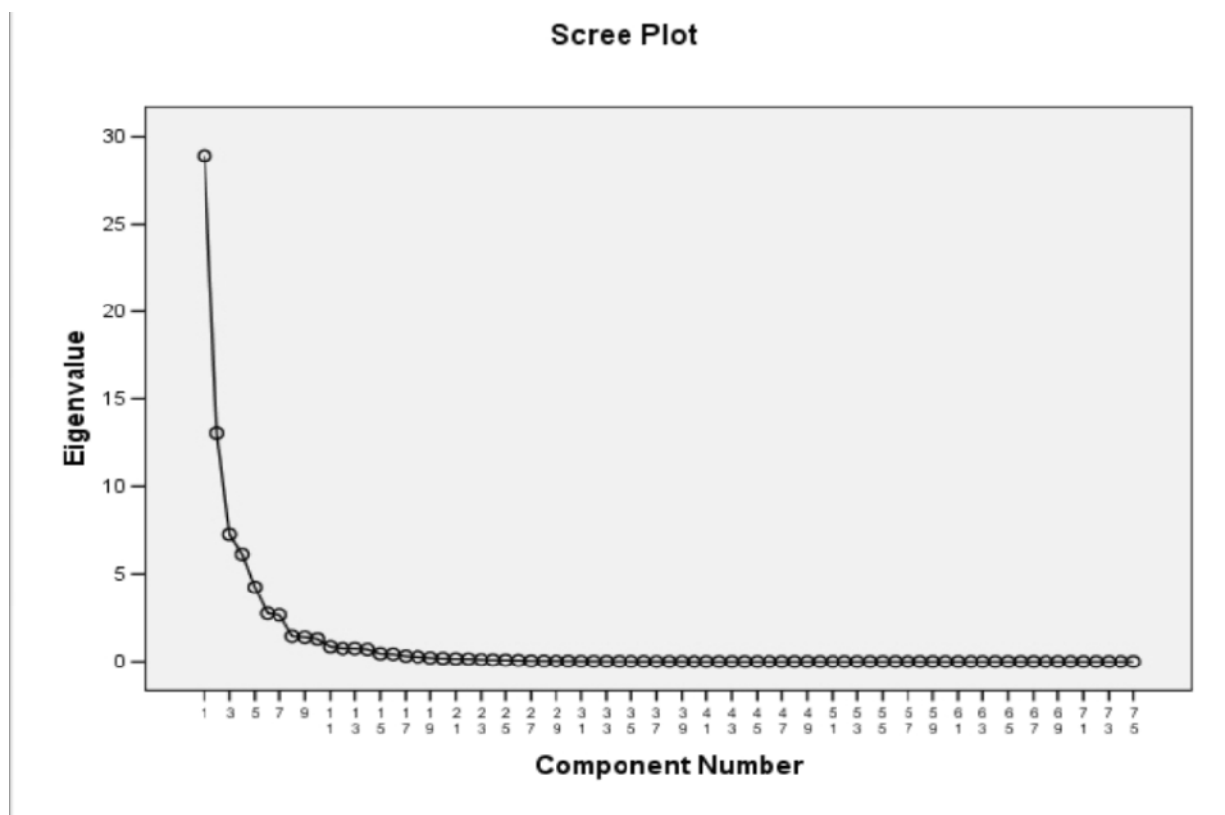


Figure 15: Scree Plot of PCA components with eigen values.

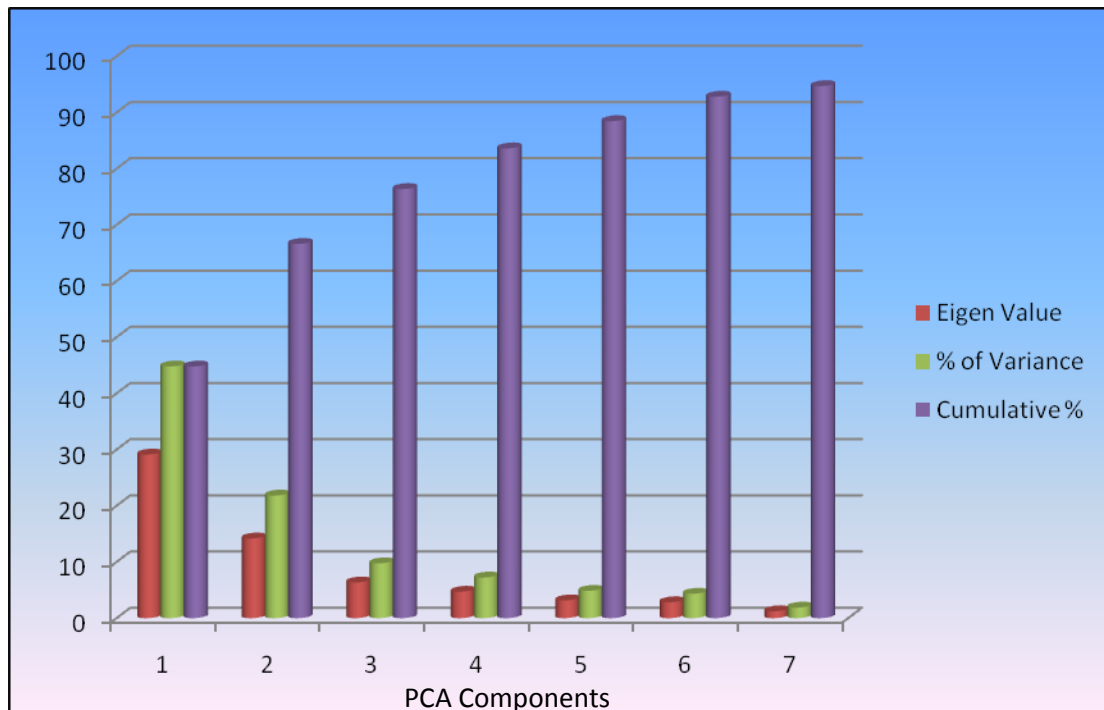


Figure 16: Eigen values, percent of explained variance by each component and cumulative variance of Principal component axes

4.3.2. Selection of patch metrics

Factor loading on the first component of PCA shows with the value of (>0.92) for shape metrics as a representative for the viability model. On the other hand, the factor loading on the second axis showed higher loading values (>0.961) for Area/Perimeter metrics to represent it as a factor for modelling ecosystem viability. In the third component, Core Area metric loaded higher value, hence, represented this axis for modelling. In the fourth axis of the PCA, the shape metrics Contiguity has shown a relatively higher value. Factor loadings on the fifth, sixth and seventh axis showed relatively higher values for Proximity/Isolation metrics (Appendix III).

Finally, Based on the set criteria related circumscribing circle (elongation), patch size, core area index, contiguity, proximity class level percentile, proximity index and Euclidean nearest neighbour were selected to represent the seven axes, respectively. Figure 17 shows a result of factor loadings of the selected metrics on each component (axis).

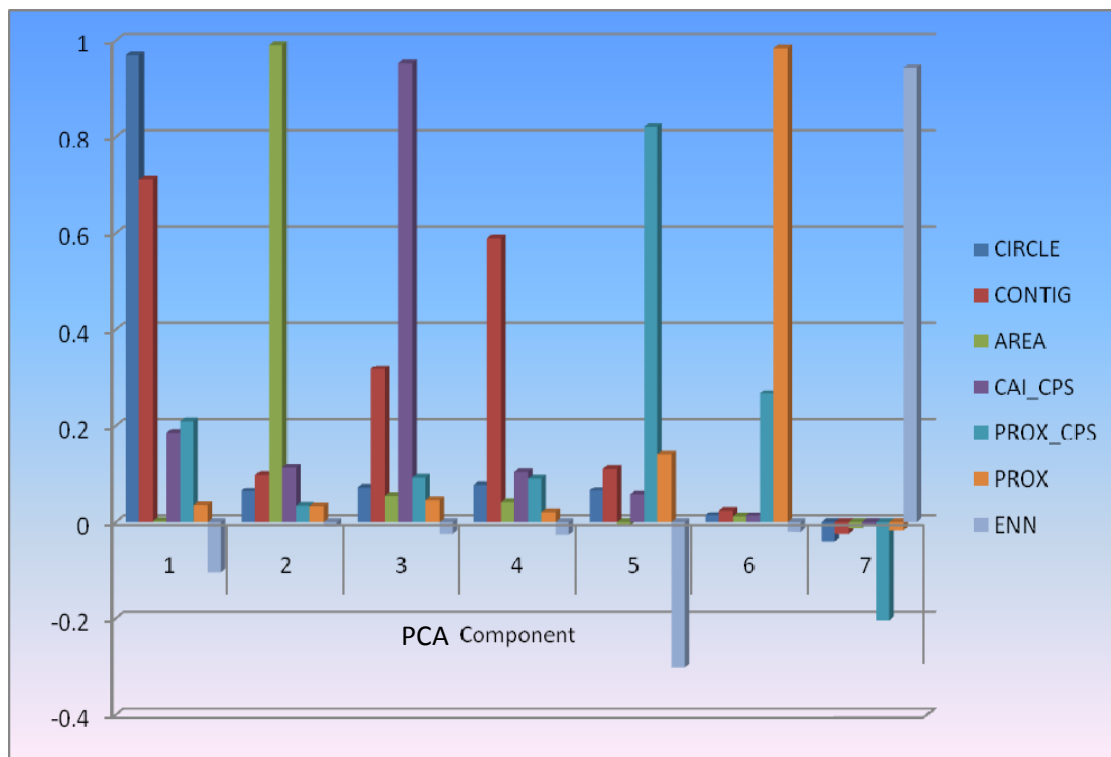


Figure 17: Factor loadings of selected metrics representing each component (axis)

Table 4: Description of selected patch metrics

Patch metrics	Description	Value Ranges	Standardized as
CIRCLE	<i>Related circumscribing circle</i> (CIRCLE) uses the smallest circumscribing circle to measure the overall patch elongation. This index may be particularly useful for distinguishing patches that are both linear (narrow) and elongated	$0 \leq \text{CIRCLE} < 1$	benefit
CONTIG	<i>Contiguity index</i> assesses the spatial connectedness, or contiguity, of cells within a grid-cell patch to provide an index of patch boundary configuration and thus patch shape (LaGro 1991, McGarigal, 2002).	$0 \leq \text{CONTIG} < 1$	Benefit
AREA	The <i>area</i> of each patch comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape (McGarigal, 2002).	AREA > 0, without limit.	Benefit
CAI_CPS	A derivative of <i>Core area index</i> is a relative index that quantifies core area as a percentage of patch area (i.e., the percentage of the patch that is comprised of core area). (McGarigal, 2002).	$0 \leq \text{CAI_CPS} < 100$	Benefit
PROX_CPS	Is a comparative index measuring the distance between the focal patch and each of the other patches within the search radius ((McGarigal, 2002).)	PROX ≥ 0	Benefit
PROX	Has similar interpretive value as PROX increases as the neighborhood (defined by the specified search radius) is increasingly occupied by patches of the same type and as those patches become closer and more contiguous (or less fragmented) in distribution.	PROX ≥ 0 , The upper limit of PROX is affected by the search radius and the minimum distance between patches.	Benefit
ENN	Euclidean Nearest neighbor equals the distance (m) to the nearest neighboring patch of the same type, based on shortest edge-to-edge distance	ENN > 0, without limit. Minimum and maximum values are constrained by cell size and landscape extent.	Cost

Seven patch metrics representing the seven PCA components for modeling of ecosystem viability are described in Table 4. Accordingly, these metrics were mapped to serve as factors maps in modeling of ecosystem viability (Figure 18 a-f).

For Viability assessment, the PCA extracted Patch elongation (Circle), Patch size (area), Core area Index, Contiguity, two Proximity measures and Euclidean Nearest Neighbour to represent its six respective components explaining 94% of the cumulative variance. Proximity index and proximity index class level percentile distinguishes sparse distributions of small habitat patches from clusters of large patches (Gustafson, Eric J.; Parker, George R. 1994). In the context of this study it was taken as a benefit since higher values for this index means patches are large and clustered and viable. CAI measures the percentage of the patch that is comprised of Core Area. The largest the value, the more likely it supports ecological functions.

Thus, while a patch may be large enough to support a given species, it still may not contain enough suitable core area to support the species. It is generally regarded a benefit towards viability modelling considering its benefit to interior species. In the context of the viability , isolation (Euclidean Nearest Neighbour) can be regarded as a cost since the further a patch is from another patch of the same type, the more likely is extinction and the more difficult re-colonization will be.(See Figure 18 a-g)

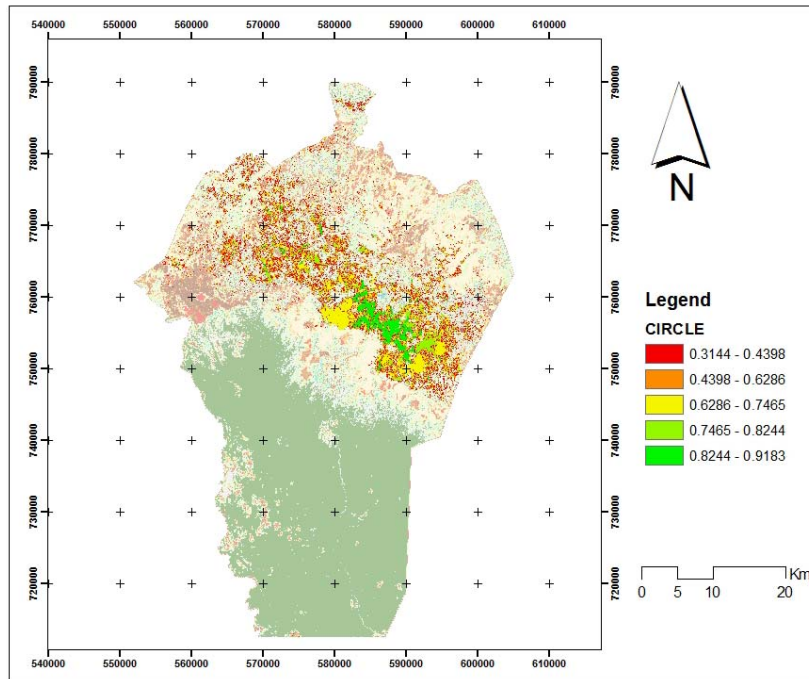


Figure 18(a).Patch Elongation (Related Circumscribing Circle)

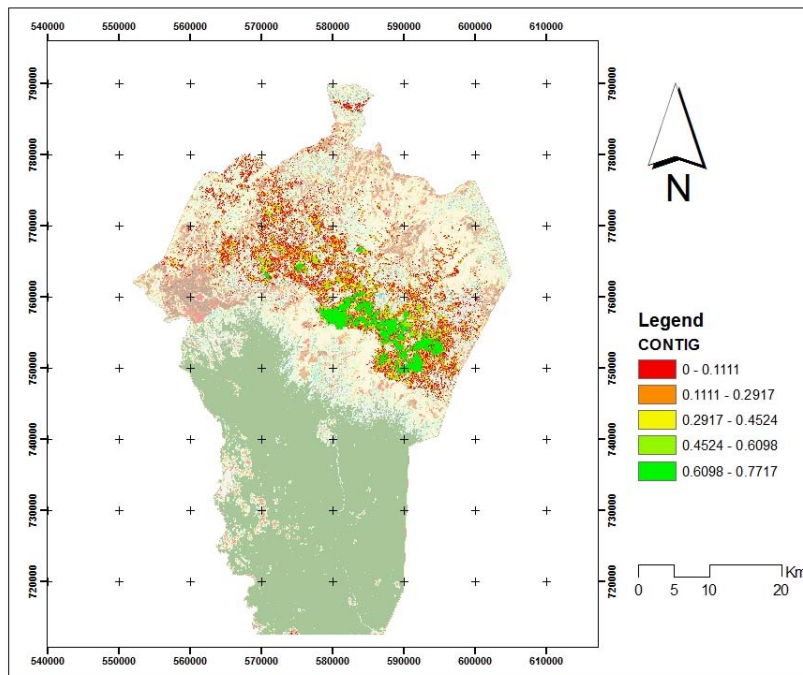


Figure 18 (b) Connectedness (Contiguity)

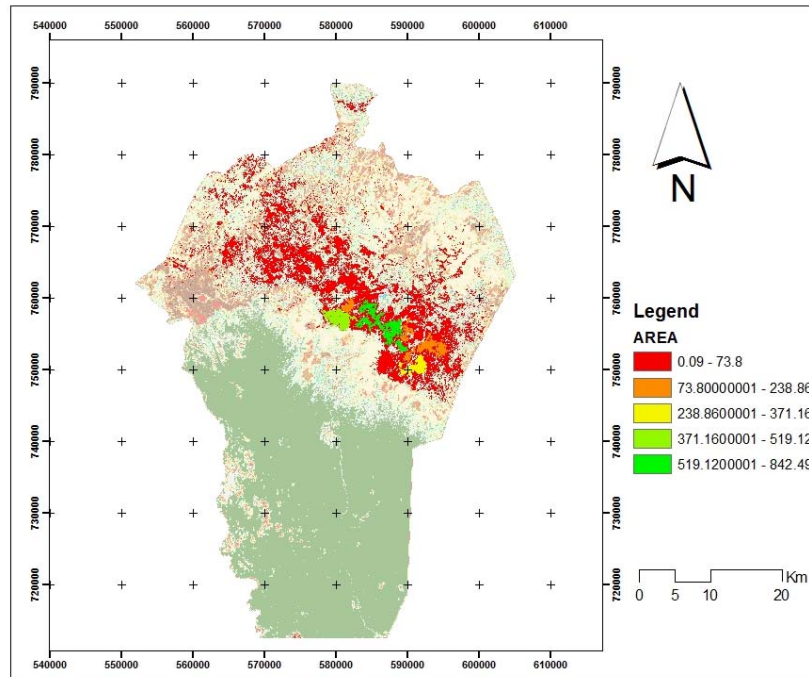


Figure 18(C). Patch size (Area)

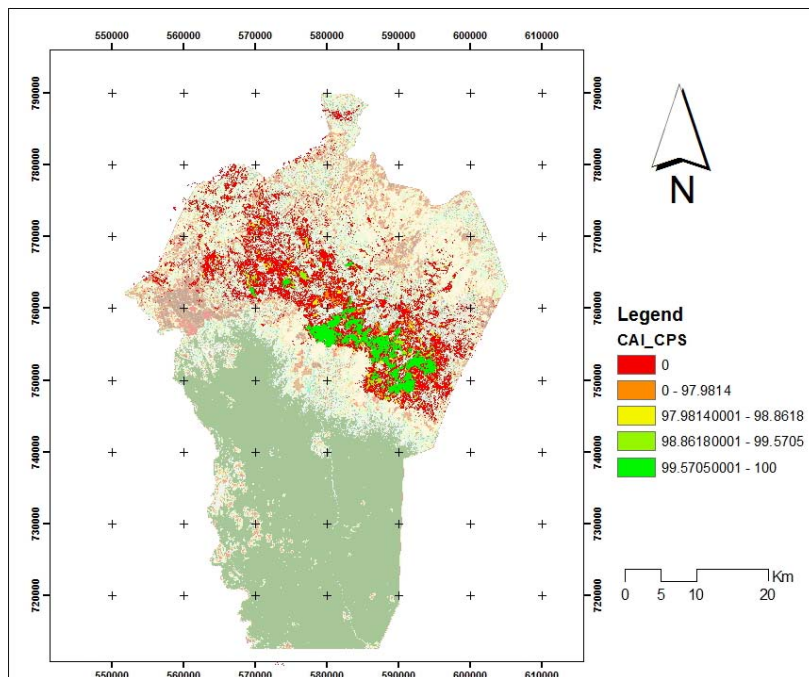


Figure 18 (d). Core area Index Class Percentile

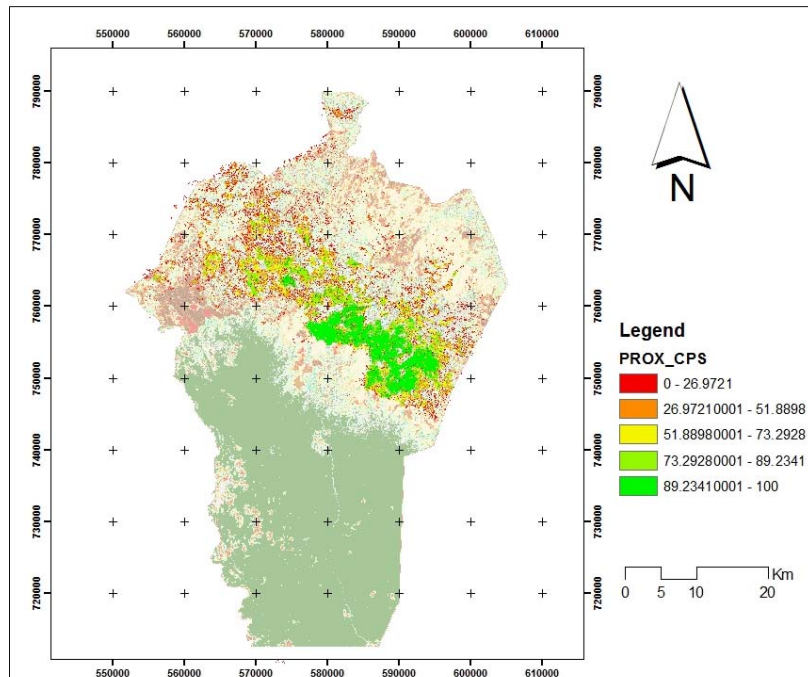


Figure 18 (e). Proximity Class Percentile

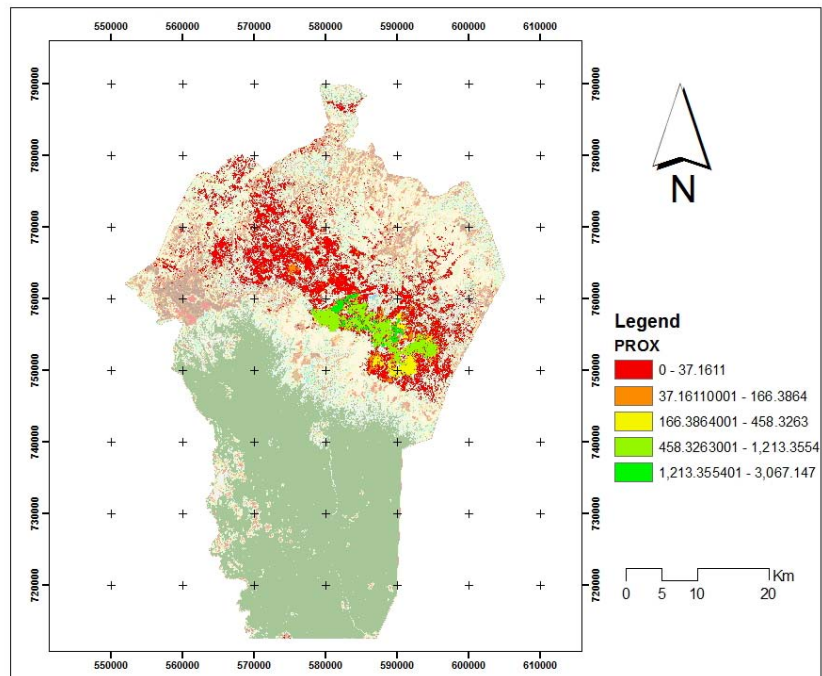


Figure 18 (f). Proximity Index

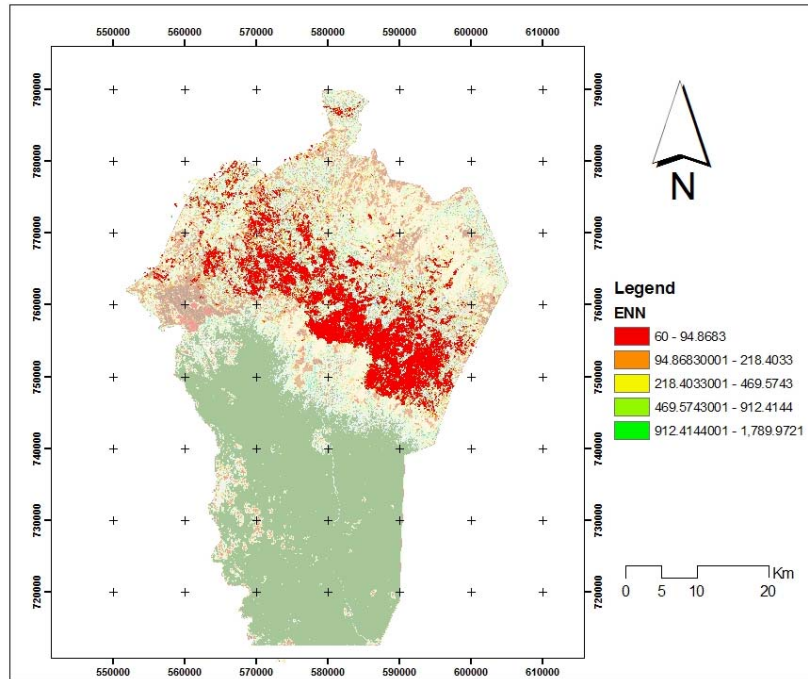


Figure 18 (g). Euclidean Nearest Neighbour

4.3.3. Weighting of factors

The final Viability model is the weighted sum (linear combination) of the seven measures weighted by the corresponding variance explained by each eigen value from the PCA analysis. Table 9 presents the result of extracted components, eigen values and percent of variance (weights) each factors.

Table 5: components, Eigen values, and percent of variance (weights) of each representative metrics

Component	Eigen Values	Percent of Variance (Weights)	Representative Metrics
1	29.112	44.788	CIRCLE
2	14.181	21.817	AREA
3	6.346	9.764	CAI
4	4.7	7.23	CONTIG
5	3.155	4.854	PROX_CPS
6	2.826	4.348	PROX
7	1.224	1.884	ENN

4.3.4. Viability

The weighted sum model (linear combination) the selected metrics in Equation (8) below produces a final map with a ranking of ecosystem patches according to their degree of viability. Ecosystem patches (shown in brown red in the map) have higher capability to preserve their integrity and host its original biodiversity. Ecosystem Patches (yellow in the map) are within a lower ranking.

$$\text{Viability}_i = 0.45 \text{CIRCLE}_i + 0.22 \text{AREA}_i + 0.10 \text{CAI}_i + 0.07 \text{CONTIG}_i + 0.05 \text{PROX_CPS}_i + 0.04 \text{PROX}_i + 0.02 \text{ENN}_i \quad \text{..... (Eq. 8)}$$

Where: - Viability_{*i*} is the value of the index for the *i*th patch

e_j is the percentage of variance of *j*th eigen value

CIRCLE_{*i*} is the standardized related circumscribing circle (Patch Elongation) for the *i*th patch

AREA_{*i*} is the standardized Patch Area for the *i*th patch

CONTIG_{*i*} is the standardized contiguity index for the *i*th patch

CAI_CPS_{*i*} is the standardized Core Area Index class percentile for the *i*th patch

PROX_{*i*} is the standardized proximity Index for the *i*th patch

PROX_CPS_{*i*} is the standardized class level percentile proximity index for the *i*th

ENN_{*i*} is the standardized Euclidean nearest neighbor distance of the *i*th patch with patch of the same type.

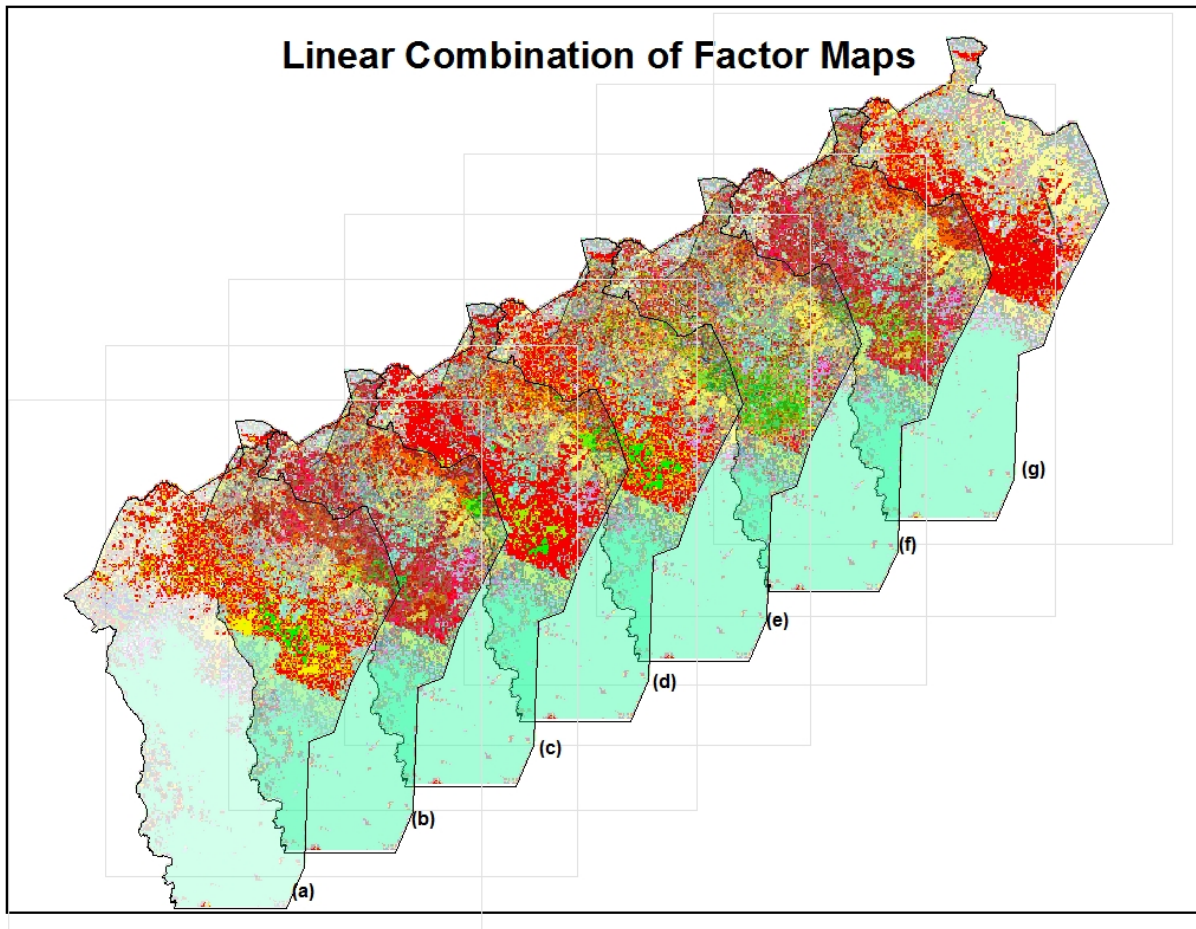


Figure 19: Linear combination of Circle standardized (a), Patch size (b), Contiguity (c), Core area index (d), Proximity class level percentile (e), Proximity index (f) and Euclidean nearest neighbour index.

Figure 20 shows ranks of fragmentation in the BMNP. The high level of viability is characterized by the high values of those metrics stated as benefit (see Table 4). On the other hand, those metrics which are standardized as cost (see Table 4) contributed for the lower viability grades of the study area. In relation to this, percentage of area coverage for the respective level of fragmentation is presented in Figure 21. Thus, most of the study area falls under low viability class which is accounted to 57.5%, while 19.76 % of the study area is graded as high viability.

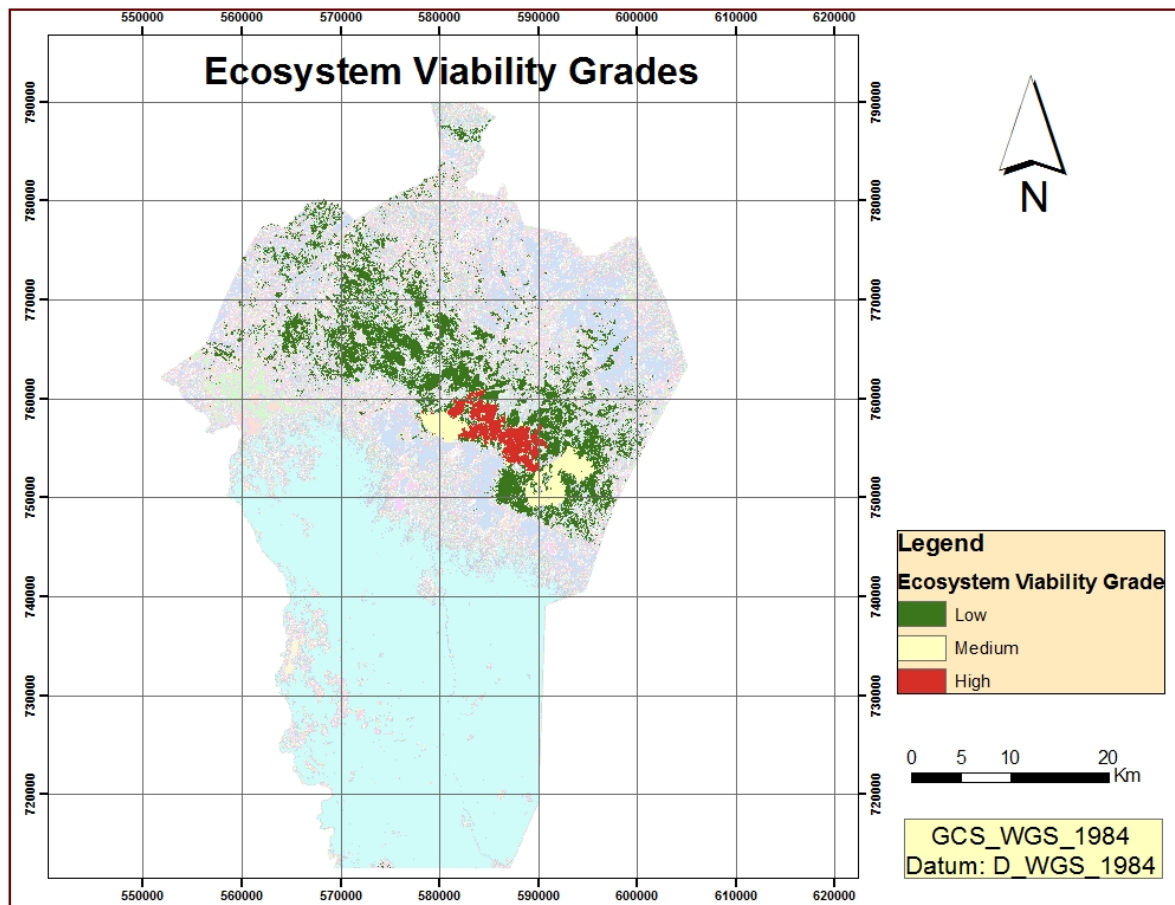


Figure 20: Ecosystem Viability grades of the class *Helichrysum*. Vegetation and land use type map was overlaid at 80 % transparency for display purpose.

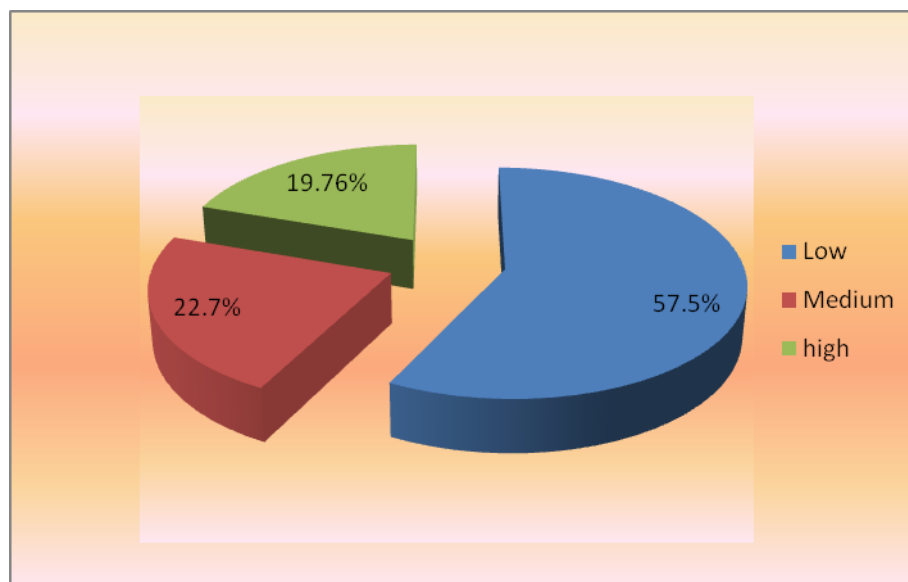


Figure 21: Percentage of the area under high, medium and low viability rankings.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Understanding the relationship between the spatial settings of the ecosystems and the conservation of their functions and biodiversity is one of the main challenges of land use planning. This study used Class and Patch metrics to come up with a quick and replicable model for assessing fragmentation and viability, respectively.

Despite the hundreds of metrics available to quantify patterns of Ecosystem fragmentation and assess viability, objectively selecting a small set of metrics that are representative of ecosystem patterns within the class and patch, standardizing, weighting, and finally combining these metrics, it was possible to create a GIS-based fragmentation index and viability model of the remaining patches at class and patch level, respectively.

At class level, grading classes according to the level of fragmentation as high, medium and low indicated the classes *Helichrysum* and woodland were found to be within the high fragmentation rank. This study considered the *Helichrysum* vegetation class for further research at patch level assessment of viability its fragmented Patches. The findings could be extended to steer specific management decisions for specific classes.

Finally, assessing the viability of remaining patches of *helichrysum*, found about 58 % of the area covered under the *Helichrysum* vegetation is under low viability meaning it is less likely to maintain its integrity and host its biodiversity. This has an immense importance in land use planning in bio-prospecting (prioritizing) areas for conservation.

In order for the result obtained to effectively support land-use planning, the viability assessment is to be integrated with an analysis of the ecological value of the different ecosystems. The viability map could also be used to support the design of ecological networks. Highly viable ecosystems, for example, may represent the backbone of ecological corridors. Another application is in the context of Environmental Impact Assessment (EIA) to assess the impact of different development projects on the ecosystem.

5.2. Recommendations

- Ecosystem Patches that are both valuable and graded viable play a key role for biodiversity conservation and therefore deserve protection. On the other hand, valuable ecosystems with low viability require specific care to guarantee their conservation (e.g. relieving the pressure exerted from surrounding land uses by planning buffer areas or nature restoration interventions). This allows one to obtain a complete picture of the relevance of the different ecosystem patches for nature conservation under competing cost implication.
- A systematic approach of creating a fragmentation index and ecosystem viability assessment is not only a useful method that can be replicated to other regions, but the information provided in the form of maps can also be valuable tool to ecologists, natural resource managers, and planners.
- Viability assessment could provide a on the shelf Decision Support System (DSS) to objectively direct development projects toward highly fragmented regions (i.e. have little chance of reclamation) and steered away from regions of low fragmentation. Measuring the geographic extent and the patterns of fragmentation within landscapes is a key step of understanding the impacts and basis for making wise and informed decisions.
- *Viability maps* can serve as a quick guideline for optimal allocation land and land resources which can aid conservation efforts. It also provides invaluable information to orient conservation endeavours in prioritizing (bio-prospecting) areas (patches) under different cost implication. It also serve as an important application in Environmental Impact Assessment (EIA) studies to evaluate the impact of different development projects on the ecosystem.

6. REFERENCES

- Abdullah, S. A., & Nakagoshi, N. (2007). Forest fragmentation and its correlation to human land use change in the state of Selangor, Peninsular Malaysia. *Forest Ecology and Management* 241, 39-48.
- Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (1976). A Land Use And Land Cover Classification System For Use With a Remote Sensor Data. *A Revision of Land use Classification System* . United States of America: United States Government Printing Office.
- BERSMP-Bale Eco-Region Sustainable Management Programme. (2007). *The significance of the Bale Mountains, South Central Ethiopia*. Addis Ababa: BMNP.
- BirdLife International. (2009). *Important Bird Area factsheet*. Bale Mountains National Park, Ethiopia: Downloaded from the Data Zone at <http://www.birdlife.org> on 31/12/2009.
- Bissonette, J., & I., S. Fragmentation: Is the Message Clear? *Conservation Ecology* 6(2).
- Botkin, D. (1990). *A New Ecology for the Twenty -first Century*. New York: Oxford University Press.
- Bourgeron, P. S.; Jensen, M. E. (1994). An Overview of Ecological Principles for Ecosystem Management. In: Jensen, M.E.; Bourgeron, P.S., tech. eds. *Eastside Ecosystem health assessment--Volume II: Ecosystem Management: Principles and applications*. General Technical Report. Portland, OR: USDA, Forest Service, Pacific Northwest Research Station. 119-130.
- Burke, V. (2000). Landscape ecology and Species Conservation. *Landscape Ecology* 15, 1-3.
- Cain, D., K., R., & K., O. (1997). A Multi-Scale Analysis of Landscape Statistics. *Landscape Ecology* 12 , 199-212.

- Carlson, A., & Hartman, G. (2001). *Tropical forest fragmentation and Nest Predation- An Experimental Study in the Eastern Arc Montane Forest, Tanzania*. Kluwer Academic Publishers .
- Chuvieco, E. 1999, Measuring changes in landscape pattern from satellite images: short-term effects of fire on spatial diversity, *International Journal of Remote Sensing*, 20 (12):2331-2346.
- Constanza, R., d'Arge, R., Groot, R. d., Faber, S., Grasso, M., Hannon, B. (1997). The Value of the World's Ecosystem Services and Natural Capital. *Nature* 387 , 253-260.
- Coulson, R.N., C.N. Lovelady, R.O. Flamm, S.L. Spradling & M.C. Saunders. (1990). *Intelligent geographic information systems for natural resource management*, In: M.G. Turner and R.H. Gadner, eds., Quantitative methods in landscape Ecology, pp. 153-172. Ecological Studies 82 New York: Springer-Verlag.
- Cumming, S., & Vernier, P. (2002). Statistical Models of Landscape Pattern Metrics, With Applications to Regional Scale Dynamic Forest Simulations. *Landscape Ecology* 17(5).
- Davidson, C. Issues in Measuring Landscape Fragmentation. *Wildlife Society Bulletin* 26.
- Delcourt, H.R. & P.S. Delcourt. 1988, Quaternary landscape ecology: relevant scales in space and time. *Landscape Ecology*, 2: 23-44.
- EFAP-Ethiopian Forestry Action Program. (1994). *The challenge for Development, Volume II*. Addis Ababa: MNRDEP.
- Emerton, L. (1997). Using Economic Incentives for Biodiversity Conservation in Eastern Africa. In *paper Presented at Second Sub Regional Biodiversity Forum*. Nairobi.

- EPA-Environmental Protection Authority. (1997). *Environmental Policy of Ethiopia*. Addis Ababa.
- ERDAS.(2002) *ERDAS Field Guid,sixth edition*. Atlanta Georgia.
- EWNHS-Ethiopian Wildlife and natural History Society. (1996). *Important Bird Areas of Ethiopia:A First Inventory* . Addis Ababa, Ethiopia: Samayata Press.
- Fahrig, L. (2003). Effects of Habitat Fragmentation on Biodiversity. *Annual review of Ecology and Systematics* 34 , 487-515.
- Forman, R. T. T., and M. Godron. 1986. *Landscape ecology*. Wiley, New York.
- Gardner, R.H., R.V. O'Neill, M.G. Turner & V.H. Dale. 1989, Quantifying scale-dependent effects of animal movement with simple percolation models. *Landscape Ecology*. 1:19-28.
- Ghosh, P. (2000). Forest Fragmentation:A Threat to Global Biodiversity. ENVIS Bulletin Vol 12(2): *Himalayan Ecology* . Uttaranchal, Kosi-Katarmal: G.B. Pant institute of Himalayan Environment and Development.
- Golley, F. (1994). Development of Landscape Ecology and its Relation to Environmental Management. In M. Jensen, & P. Bourgeron, *Eastside Forest Ecosystem Health Assessment-Volume II: Ecosystem Management Principles and Applications.Gen.Tec.Rep.* (pp. 34-41). Portland: U.S Department of Agriculture,Forest Service.
- Gustafson, Parker, E. J., & R, G. (1994). Using an Index of Habitat Patch Proximity for Landscape Design. *Landscape and Urban Planning* 29 (1994) , 117-130.
- Hillman. (1988). The Bale Mountains National Park Area, Southeast Ethiopia, and Its Management . *Mountain Research and Development*, Vol. 8,No.2/3 .
- Kimmins, H. (1992) *Balancing act: Environmental issues in forestry*. Vancouver, B.C.: University of British Columbia Press.

- L.Pfister, J. (2004). *Using Landscape Metrics to Create an Index of Forest Fragmentation*. Towson, Maryland: Towson University.
- Lillesand, T., Keifer, R., & Chipman, J. (2004). *Remote Sensing and Image Interpretation*, Fourth Edition. New York: Wiley.
- Lubchenco, J., A.M. Olson & L.B. Brudbaker. (1991). The sustainable biosphere initiative: an ecological research agenda. *Ecology*, 72: 371-412.
- M, T. (1996). Species Loss in Fragments of Tropical Rain Forest: A Review of the Evidence. *Journal of Applied Ecology* 33 , 200-219.
- M.A, F., & C.E, B. (1997). Decision Tree Classification of Land Cover from Remotely Sensed Data. *Remote Sensing of the Environment* 61 , 399-409.
- McGarigal, K., and Marks, B. J., 1995. Fragstats: Spatial Pattern Analysis Program for Quantifying Landscape Structure. Gen. Tech. Rep. PNW-GTR-351. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, 122p.
- McGarigal, K., Cushman, S., Neel, M., & Ene, E. (2002). Spatial Pattern Analysis Program for Catagorical Maps. In *Computer Software Program Produced by the Authors at the University of Massachusetts*. Amherst: Available at the following website:
www.umass.edu/landeco/research/fragstats/fragstats.html.
- Neily, P., & B.Stewart. (2008). *Procedural Guidelines for Ecological landscape Analysis*,. Nova Scotia: Nova Scotia Dept. of Natural Resources, Forestry Division.
- Reed, R., Barnard, J., & Baker, W. (1996). Fragmentation of a Forested Rocky Mountain Landscape. 1950-1993. *Biological Conservation* 75 , 267-277.
- Riquene, A. (2002). Mapping of Woody Vegetation in Arid Zones: A multi-sensor Analyses, A case study in the serowe area, Botswana, Forest Science Division,. Enschede, The Netherlands: The International Institute for Geoinformation Science and Earth Observation.

- Robbins, C. S., Dawson, D. K. and Dowell, B. A.(1989). *Wildlife Monographs*, 103, the Wildlife Society
- Robinson, G. R., Holt, R. D., Gaines, M. S., Hamburg, S. P., Johnson, M. L., Fitch H. S. and Martino, E.A.(1992). *Science*,257, 524-526.
- Saaty .(2002). Forecasting the resurgence of the US economy in 2001: An expert judgement approach. *Socio-Economic Planning Sciences*, 36(2), 77-91.
- Sharifi .(2003). *Spatial decision Support system*.ITC, Enschede.
- Slocombe, D. (1993). Environmental Planning, Ecosystem Science, and an Ecosystem Approach for Integrating Environment and Development. *Environ. Manage.* 17 , 289-303.
- Steffenson, J. (2000). *Ecosystem Characterization and Assessment in the Interior Columbia River Basin*. Portland: USDA.
- Tien, D. V. (2004). Susceptibility to Forest Degradation: International Institute for geoinformation Science and earth Observations. ITC.The Netherlands
- Turner, M. (1986). Landscape Ecology:The Effect of Pattern On Process. *Ann. Rev. Ecol. Syst.* 20 , 171-197.
- Turner, M. (1996). Species Loss in Fragments of Tropical:A Review of the Evidence. *Journal of Applied Ecology* 33 , 200-219.
- Turner, M. G. & R.H. Gardner. (1990). Quantitative Methods in Landscape Ecology. *The Analysis and Interpretation of Landscape Heterogeneity*. Ecological Studies Series, Springer-Verlag, New York.
- Turner, M., Gardner, R., & O'Neill, R. (2001). *Landscape Ecology in Theory and Practice:Pattern and Process*. New York: springer.
- UNEP-WCMC-World Conservation Monitoring Center. (2000). A Contribution to the Global Theme Study of World Heritage Natural Sites. In *A Global Overview of protected Areas on the World Heritage List of Particular Importance for Biodiversity*. UK: Cambridge.

- Urban, D., O'Neill, R., & Shugart, H. (1987). Landscape Ecology: A Hierarchical Perspective can help Scientists Understand Spatial Patterns. *Bioscience* 37(2) , 119-127.
- Whitmore, T., & Sayer, J. (1992). Deforestation and Species Extinction in Tropical Moist Forest, *Tropical Deforestation and Species Extinction*. London: Chapman & Hall.
- Whitecomb, R.F., Lynch, J.F., Opler P.A and. Robbins, S.C.(1976). *Science*, 193, 1030-1032.
- Wiens, J. (1976). Population Response to Patchy Environments. *Annals of Rev. Ecological Systems* 7 , 81-129.
- Wilkinson, G. (1996). a review of Current Issues in the Integration of GIS and Remote Sensing Data. *International Journal of Geographical Information Systems* 10(1) , 85-101.

APPENDIX I: Ground Truth Data (FZS-BMNP, 2010)

	UTM X	UTM Y	alt(m)	Cat	Scat	DS
1	584909	785500	3074	GZL	GZL	gra
2	582337	784532	3431	ESH	ESH	esh, gra
3	582056	783983	3415	ESH	ESH	esh, gra
4	583241	783834	3174	WL	WLO	gra
5	583682	784067	3132	WL	WLO	gra
6	584301	784713	3062	WL	WLO	gra
7	579191	787476	3072	GZL	GZL	gra
8	579049	788208	3084	GZL	GZL	gra, art
9	579326	788699	3083	GZL	GZL	gra, alc
10	581316	789715	3327	WL	WLO	hyp
11	581646	789547	3449	ESH	ESH	esh
12	584576	785894	3066	GZL	GZL	gra
13	581992	789027	3322	WL	WLO	hyp, rs
14	582431	788729	3297	ESH	ESH	esh
15	582779	788426	3099	WL	WLO	hag
16	583635	788409	3064	GGL	GL	gra, alc
17	583411	787558	3061	GGL	SHR	art
18	583007	787679	3068	GGL	GL	gra, alc
19	582611	787313	3067	GGL	SHR	art
20	582169	787589	3061	GGL	GL	gra, alc
21	581326	787386	3066	GGL	SHR	art
22	566404	752024	2642	MF	HAG	sch vol
23	565795	751575	2567	MF	HAG	sch vol
24	567357	751458	2492	MF	HAG	hag
25	562823	752911	2782	MF	HAG	hag, sch
26	584312	786036	3047	GZL	GZL	gra
27	582472	742996	2489	MF	HAG	bb - gra -rub
28	579717	743095	2402	MF	HAG	hag
29	584163	786120	3047	GGL	SHR	gra, art

	UTM X	UTM Y	alt(m)	Cat	Scat	DS
30	577682	765018	3859	AFR	PAS	roc, hel,gra
31	582281	764337	3997	AFR	HEL	hel, gra
32	600807	763935	3775	AFR	SHR	esh, alc, hum
33	596823	756705	4138	AFR	PAS	gra
34	583441	768901	3957	ESH	ESH	esh, hel, gra
35	585542	749832	3877	AFR	HEL	hel, gra
36	582454	767695	3913	ESH	ESH	esh, hel, gra
37	580540	766958	3868	AFR	PAS	hel, kni, gra
38	583846	765653	3968	ESH	ESH	esh
39	583736	786163	3048	GGL	SHR	gra, art
40	571875	763026	3654	AFR	HEL/PAS	hel - alc
41	567216	762072	3723	AFR	SHR	alc -gra - hel
42	571597	761921	3697	AFR	SHR	gra - alc - hel
43	565725	761897	3736	AFR	PAS_M	alc - gra - hel - x
44	570604	763747	3671	AFR	PAS_M	gra
45	563391	760166	3734	AFR	PAS_M	alc - gra - hel
46	566448	758307	3563	ESH	ESH	esh - gra
47	566950	758358	3555	ESH	ESH	esh - gra
48	567425	766714	3642	AFR	SHR	alc - art - hel - x
49	570653	766605	3658	AFR	PAS	kni - gra
50	567041	765965	3698	AFR	PAS	alc - gra
51	569998	765838	3619	AFR	PAS	alc
52	567098	764929	3725	AFR	PAS	alc - gra
53	570162	763338	3676	AFR	HEL	gra - hel
54	583145	785808	3068	GGL	SHR	gra, art, hel
55	575283	777674	3544	AFR	PAS	alc - gra
56	577593	776804	3499	AFR	PAS	gra
57	574304	775528	3530	AFR	PAS_M	gra - alc
58	577905	774400	3500	AFR	PAS	gra - alc
59	575577	773669	3506	AFR	WET	x

	UTM X	UTM Y	alt(m)	Cat	Scat	DS
60	574292	771755	3536	AFR	PAS_M	gra
61	583160	785548	3163	WL	WLC	rap, jun, hyp, gra
62	583055	784958	3304	WL	WLC	rap, jun, hyp, gra
63	582925	784884	3316	WL	WLC	hyp, rap, gra
64	583895	743074	2818	MF	BB	bb - gra
65	580416	742657	2389	MF	BB	bb - gra
66	580499	742722	2391	MF	BB	bb - rub
67	580509	742805	3297	MF	BB	bb
68	580415	742870	2401	MF	BB	bb - gra
69	580297	742669	2388	MF	GZL	gra - phor - alc
70	580255	742556	2379	MF	GZL	gra - alc
71	580165	742500	2378	MF	GLA	gra - alc
72	579850	741988	2378	MF	GLA	gra - alc
73	579286	741494	2310	MF	AG	all - x - y
74	579204	741439	2285	MF	AG	x - ery
75	580596	741468	2360	MF	HAG	sch.vol. - bb
76	579006	741507	2269	MF	STL	budd - x
77	578873	741529	2258	MF	STL	all - x
78	565207	731326	1740	MF	GLA	gra
79	565039	732676	1748	MF	GLA	gra
80	565204	734675	1752	MF	GLA	gra
81	572215	739505	1838	MF	SYZ	pol
82	576498	739553	2034	MF	SYZ	syz
83	570240	729744	1717	MF	AG	x
84	573425	739121	1856	MF	GLA	gra
85	575275	739121	1964	MF	SYZ	syz
86	583851	742742	2840	MF	BB	bb - gra
87	568629	737064	1830	MF	SYZ	pou
88	567023	730531	1714	MF	COF	pol
89	580241	742468	2399	MF	GLA	hag

	UTM X	UTM Y	alt(m)	Cat	Scat	DS
90	580661	742745	2434	MF	HAG	hag
91	580873	742906	2447	MF	HAG	bb
92	579903	742529	2392	MF	HAG	sch.abby
93	582249	749248		EF	EF	
94	582967	749470		ESH	ESH	
95	583444	748399		ESH	ESH	
96	584855	750402		ESH	ESH	
97	583802	742097	2508	MF	BB	bb - all - gra
98	586247	750913		AFR	HEL	
99	595955	753936		AFR	HEL	
100	583737	741504	2457	MF	HAG	all - sch.vol.
101	583402	741183	2304	MF	BB	bb - sch.vol.
102	581210	737536	2014	MF	SYZ	syz - cass
103	581914	736324	1934	MF	SYZ	syz -cass - gra
104	580373	742624	2380	MF	BB	bb - gra
105	569588	733889	1750	MF	SYZ	pou
106	565667	728226	1700	MF	SYZ	oco
107	565256	729658	1721	MF	X	figus sur
108	567566	728771	1720	MF	X	pou
109	581413	766470	3889	AFR	HEL	hel, alc
110	595628	755731	4149	AFR	HEL	hel, lob
111	595013	755500	4109	AFR	HEL	hel
112	594207	754863	4105	AFR	HEL	hel
113	594032	754112	4199	AFR	HEL	hel
114	594532	753769	4101	AFR	HEL	hel
115	595285	753556	4060	AFR	HEL	hel
116	595871	753489	4063	AFR	HEL	hel, lob
117	596397	753406	4071	AFR	HEL	hel
118	597148	754022	4107	AFR	HEL	hel, lob
119	597584	754368	4094	AFR	HEL	hel, lob

	UTM X	UTM Y	alt(m)	Cat	Scat	DS
120	583222	765486	3887	AFR	WET	gra
121	598699	758548	4075	AFR	HEL	kni, lob
122	600122	762225	3956	AFR	SHR	alc, hum
123	600101	762512	3922	AFR	SHR	esh, alc, hum
124	600303	763136	3859	AFR	SHR	esh, alc, hum
125	600542	764185	3757	ESH	ESH	esh, alc, hum
126	601024	764363	3725	ESH	ESH	esh, alc, hum
127	577208	764608	3841	AFR	ESH	hel,esh,alc
128	579312	763075	3858	AFR	ESH	esh,gra
129	578406	763397	3805	AFR	HEL	hel, gra
130	581454	764297	4013	AFR	HEL	hel, gra
131	582443	765011	3979	AFR	HEL	hel, alc
132	582812	768100	3918	ESH	ESH	esh, hel
133	583303	768386	3814	AFR	WET	gra
134	595382	760717	3962	AFR	WET	gra
135	595897	760429	3954	AFR	WET	gra
136	598624	757742	4062	AFR	WET	gra
137	598945	756403	4046	AFR	WET	gra
138	598382	756809	4094	AFR	WET	gra
139	581920	766965	3880	ESH	ESH	esh
140	581577	767982	3826	AFR	WET	gra
141	581502	768951	3813	ESH	ESH	esh
142	581047	769150	3748	AFR	WET	gra
143	595846	757155	4149	AFR	HEL	hel, lob
144	595464	756645	4164	AFR	HEL	hel, lob
145	571427	763212	3658	AFR	BS	none
146	569693	767209		AFR	SWA	
147	570715	769186		AFR	SWA	
148	571515	762263		AFR	SWA	
149	568381	761144		AFR	SWA	

	UTM X	UTM Y	alt(m)	Cat	Scat	DS
150	568754	764794		AFR	SWA	
151	568876	760081	3606	ESH	ESH	esh
152	575949	773578	3504	AFR	PAS	gra - alc
153	569210	760836	3721	AFR	SHR	hel - alc - gra
154	577429	772934	3521	AFR	SHR	art
155	575653	777356	3554	AFR	SHR	art
156	577372	772820	3510	AFR	SWA	gra
157	576493	777238	3510	AFR	SWA	gra
158	568389	765124		AFR	SWA	
159	584120	748170		ESH	ESH	eri
160	582383	749177		EF	EF	eri
161	582413	749070		EF	EF	eri
162	581607	748990		EF	EF	eri
163	580697	749001		MF	HAG	hag
164	581076	733856		MF	GLA	gra
165	580965	733860		MF	MF	
166	581083	733695		MF	GLA	
167	581074	733579		MF	MF	
168	581140	733644		MF	MF	
169	582951	749374		ESH	ESH	
170	583304	749344		ESH	ESH	
171	560390	763735	3756	ESH	ESH	eri
172	558214	766421	3560	ESH	ESH	eri
173	560152	768933	3529	AFR	PAS	gra
174	561938	772691	3355	ESH	ESH	eri
175	557408	761656	3666	ESH	ESH	eri
176	555174	762010	3564	ESH	ESH	eri
177	556075	759390	3730	ESH	ESH	eri
178	556194	757084	3757	ESH	ESH	eri
179	558213	758949	3726	AFR	WET	x

APPENDIX II: Codes for Vegetation/Land use Classes (FZS-BMNP, 2010)

CODE	Vegetation and land use
AGST	Agriculture settlement
AFR	Afro Alpine
EF	Erica forest
Esh	Erica shrub
GL	grassland
GLD	GLADE
Hel	<i>helichrysum</i>
HELGL	MIXED <i>helichrysum</i> and GRASSLAND
MF	Montane forest
PAS	Pastureland
SHL	Shrubland (usually artemisa shrub)
SHLGL	mixed shrubland and grassland (mosaic)
WL	Woodland
WT	Wetland

APPENDIX III: PCA Results After Varimax Rotation

	Component					
	1	2	3	4	5	6
LPI	0.986	0.027	-0.113	0.069	-0.047	-0.082
AREA_MN	0.981	-0.022	-0.123	0.084	-0.053	-0.100
AREA_AM	0.974	-0.040	-0.151	0.085	-0.069	-0.116
PROX_MN	0.972	-0.046	-0.155	0.086	-0.073	-0.120
CORE_MN	0.972	-0.056	-0.153	0.090	-0.072	-0.116
CORE_AM	0.968	-0.057	-0.163	0.092	-0.080	-0.128
DCORE_MN	0.965	-0.082	-0.172	0.100	-0.087	-0.109
DCORE_AM	0.960	-0.070	-0.174	0.102	-0.097	-0.141
CAI_AM	0.944	-0.062	0.046	0.047	0.090	0.291
CA	0.939	0.334	0.036	0.027	-0.030	0.005
PLAND	0.939	0.334	0.036	0.027	-0.030	0.005
CLUMPY	0.907	0.007	0.188	0.057	0.160	0.327
PARA_AM	-0.900	-0.082	-0.210	-0.059	-0.157	-0.324
PLADJ	0.900	0.082	0.210	0.059	0.157	0.324
AI	0.899	0.072	0.208	0.055	0.154	0.331
DCORE_CV	0.858	0.362	0.137	-0.057	0.005	0.173
PROX_CV	-0.777	-0.236	-0.393	0.202	-0.261	0.131
AREA_CV	0.775	0.553	0.085	0.064	0.138	0.174
PROX_AM	0.568	0.567	0.265	-0.234	0.264	0.313
PD	-0.136	0.948	0.162	0.122	-0.083	-0.057
NP	-0.136	0.948	0.162	0.122	-0.083	-0.057
TE	0.077	0.918	0.338	-0.003	-0.034	0.125
ED	0.077	0.918	0.338	-0.003	-0.034	0.125
CWED	0.079	0.898	0.305	0.110	-0.178	0.094
ENN_MN	-0.130	-0.822	-0.083	-0.134	-0.199	0.399
SHAPE_CV	0.083	0.815	0.408	0.033	0.342	0.079
IJI	0.130	0.796	0.028	0.107	-0.143	0.296
CORE_CV	0.430	0.773	-0.057	0.168	0.077	0.138
ENN_CV	0.082	-0.773	0.156	-0.124	0.308	0.245
CONNECT	0.051	-0.751	-0.201	-0.263	-0.298	0.403
FRAC_CV	-0.117	0.739	0.520	0.243	0.157	-0.241
FRAC_AM	0.489	0.714	0.265	0.056	0.349	0.141
SHAPE_MN	-0.095	0.709	0.651	0.154	0.103	-0.111
PAFRAC	-0.146	0.683	-0.377	0.326	0.184	-0.431
COHESION	0.443	0.676	0.083	0.286	0.362	0.177
FRAC_MN	-0.110	0.669	0.667	0.190	0.027	-0.196
SHAPE_AM	0.519	0.664	0.299	-0.065	0.273	0.249
ENN_AM	-0.315	-0.637	-0.154	-0.445	-0.436	0.256
PARA_CV	0.017	0.164	0.975	-0.062	0.007	0.112
PARA_MN	0.033	-0.343	-0.933	-0.030	0.020	0.028
CAI_CV	0.096	-0.299	-0.912	0.033	-0.112	0.161
CAI_MN	0.008	0.038	0.877	-0.117	0.092	0.425
TECI	0.246	0.596	-0.046	0.758	-0.048	-0.027
ECON_MN	0.289	0.576	0.016	0.757	-0.057	0.005
ECON_AM	0.232	0.613	-0.077	0.744	-0.044	-0.050
ECON_CV	-0.101	-0.059	0.074	-0.060	0.931	-0.015

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 12 iterations.

APPENDIX IV: PCA Results After Varimax Rotation (*Patch Metrics*).

	Component						
	1	2	3	4	5	6	7
CIRCLE	0.969	0.065	0.073	0.078	0.066	0.014	-0.041
CIRCLE_CSD	0.969	0.065	0.073	0.078	0.066	0.014	-0.041
CIRCLE_LSD	0.969	0.065	0.073	0.078	0.066	0.014	-0.041
SHAPE_LPS	0.932	0.063	0.174	-0.13	0.081	0.01	-0.022
SHAPE_CPS	0.932	0.063	0.174	-0.13	0.081	0.01	-0.022
FRAC_CPS	0.929	0.041	0.057	0.299	0.057	0.02	-0.053
FRAC_LPS	0.929	0.041	0.057	0.299	0.057	0.02	-0.053
CIRCLE_LPS	0.927	0.039	0.027	0.293	0.05	0.019	-0.056
CIRCLE_CPS	0.927	0.039	0.027	0.293	0.05	0.019	-0.056
GYRATE_LPS	0.927	0.052	0.138	0.09	0.083	0.014	-0.029
GYRATE_CPS	0.927	0.052	0.138	0.09	0.083	0.014	-0.029
FRAC	0.917	0.174	0.281	-0.077	0.117	0.016	-0.006
FRAC_CSD	0.917	0.174	0.281	-0.077	0.117	0.016	-0.006
FRAC_LSD	0.917	0.174	0.281	-0.077	0.117	0.016	-0.006
PERIM_CPS	0.912	0.041	0.074	0.366	0.068	0.02	-0.05
PERIM_LPS	0.912	0.041	0.074	0.366	0.068	0.02	-0.05
AREA_CPS	0.886	0.041	0.084	0.431	0.076	0.02	-0.047
AREA_LPS	0.886	0.041	0.084	0.431	0.076	0.02	-0.047
CONTIG_CPS	0.838	0.037	0.077	0.517	0.07	0.021	-0.049
CONTIG_LPS	0.838	0.037	0.077	0.517	0.07	0.021	-0.049
CONTIG_LSD	0.711	0.098	0.318	0.59	0.11	0.025	-0.023
CONTIG_CSD	0.711	0.098	0.318	0.59	0.11	0.025	-0.023
CONTIG	0.711	0.098	0.318	0.59	0.11	0.025	-0.023
AREA_LSD	0.002	0.991	0.054	0.042	-0.007	0.011	-0.012
AREA_CSD	0.002	0.991	0.054	0.042	-0.007	0.011	-0.012
AREA	0.002	0.991	0.054	0.042	-0.007	0.011	-0.012
PERIM_LSD	0.033	0.984	0.066	0.03	0.012	0.007	0.001
PERIM_CSD	0.033	0.984	0.066	0.03	0.012	0.007	0.001
PERIM	0.033	0.984	0.066	0.03	0.012	0.007	0.001
NCORE	0.003	0.961	0.102	0.027	0.012	0.006	0.004
NCORE_CSD	0.003	0.961	0.102	0.027	0.012	0.006	0.004
NCORE_LSD	0.003	0.961	0.102	0.027	0.012	0.006	0.004
CORE_CSD	-0.028	0.913	0.04	0.051	-0.036	0.016	-0.033
CORE_LSD	-0.028	0.913	0.04	0.051	-0.036	0.016	-0.033
CORE	-0.028	0.913	0.04	0.051	-0.036	0.016	-0.033
GYRATE_CSD	0.318	0.846	0.35	0.031	0.084	0.02	0.018
GYRATE_LSD	0.318	0.846	0.35	0.031	0.084	0.02	0.018
GYRATE	0.318	0.846	0.35	0.031	0.084	0.02	0.018

	Component						
	1	2	3	4	5	6	7
SHAPE	0.484	0.722	0.377	-0.071	0.111	0.016	0.027
SHAPE_CSD	0.484	0.722	0.377	-0.071	0.111	0.016	0.027
CAI_LPS	0.186	0.113	0.953	0.104	0.057	0.013	-0.004
CAI_CPS	0.186	0.113	0.953	0.104	0.057	0.013	-0.004
CORE_CPS	0.186	0.115	0.953	0.103	0.058	0.013	-0.003
CORE_LPS	0.186	0.115	0.953	0.103	0.058	0.013	-0.003
NCORE_LPS	0.187	0.116	0.952	0.102	0.058	0.013	-0.003
NCORE_CPS	0.187	0.116	0.952	0.102	0.058	0.013	-0.003
CAI	0.111	0.285	0.858	0.138	0.003	0.044	-0.034
CAI_CSD	0.111	0.285	0.858	0.138	0.003	0.044	-0.034
CAI_LSD	0.111	0.285	0.858	0.138	0.003	0.044	-0.034
PARA_LPS	-0.513	-0.053	-0.213	-0.804	-0.102	-0.02	0.019
PARA_CPS	-0.513	-0.053	-0.213	-0.804	-0.102	-0.02	0.019
PARA	-0.57	-0.081	-0.265	-0.753	-0.107	-0.024	0.022
PARA_LSD	-0.57	-0.081	-0.265	-0.753	-0.107	-0.024	0.022
PARA_CSD	-0.57	-0.081	-0.265	-0.753	-0.107	-0.024	0.022
ENN_CPS	-0.202	-0.025	-0.064	-0.113	-0.843	-0.027	0.293
ENN_LPS	-0.202	-0.025	-0.064	-0.113	-0.843	-0.027	0.293
PROX_LPS	0.209	0.035	0.093	0.091	0.82	0.267	-0.204
PROX_CPS	0.209	0.035	0.093	0.091	0.82	0.267	-0.204
PROX	0.036	0.034	0.046	0.022	0.141	0.985	-0.016
PROX_LSD	0.036	0.034	0.046	0.022	0.141	0.985	-0.016
PROX_CSD	0.036	0.034	0.046	0.022	0.141	0.985	-0.016
ENN_CSD	-0.104	-0.009	-0.023	-0.025	-0.302	-0.019	0.944
ENN_LSD	-0.104	-0.009	-0.023	-0.025	-0.302	-0.019	0.944
ENN	-0.104	-0.009	-0.023	-0.025	-0.302	-0.019	0.944

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a Rotation converged in 6 iterations.

APPENDIX V: Contingency Matrix

	Reference Data															Reference	Classified	Number	Producers	Users	
Classified Data	UN	AGST	CLSD	BURN	EF	ESH	GL	GLA	HEL	HELGL	MF	PAS	SHL	WL	WT	Totals	Totals	Correct	Accuracy	Accuracy	Kappa
-----	----	----	----	----	-----	-----	-----	----	----	-----	-----	----	----	-----	-----	-----	-----	-----	-----	----	----
UN	7	0	0	0	0	0	1	0	0	0	0	0	0	0	0	7	8	7	---	---	0.8699
AGST	0	34	0	0	0	2	0	0	0	0	0	1	3	2	0	34	42	34	100.00%	80.95%	0.7652
CLSD	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	100.00%	100.00%	1
BURN	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	2	2	100.00%	100.00%	1
EF	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	5	5	5	100.00%	100.00%	1
ESH	0	0	0	0	0	19	0	0	0	0	0	0	1	1	0	23	21	19	82.61%	90.48%	0.8908
GL	0	0	0	0	0	0	3	0	0	0	0	0	0	2	0	4	5	3	75.00%	60.00%	0.5909
GLA	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	3	3	3	100.00%	100.00%	1
HEL	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	4	4	4	100.00%	100.00%	1
HELGL	0	0	0	0	0	0	0	0	0	7	0	1	0	0	0	9	8	7	77.78%	87.50%	0.8684
MF	0	0	0	0	0	0	0	0	0	0	37	0	0	0	0	37	37	37	100.00%	100.00%	1
PAS	0	0	0	0	0	0	0	0	0	1	0	22	1	1	1	24	26	22	91.67%	84.62%	0.8225
SHL	0	0	0	0	0	2	0	0	0	1	0	0	9	0	0	14	12	9	64.29%	75.00%	0.7289
WL	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	10	4	4	40.00%	100.00%	1
WT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	1	50.00%	100.00%	1
																180	180	159			
Column Total	7	34	2	2	5	23	4	3	4	9	37	24	14	10	2	180	180	159			
Overall Classification Accuracy = 88.33%																					
-----End of Accuracy Totals -----																					
KAPPA (K^) STATISTICS																					
Overall Kappa Statistics = 0.8654																					
-----End of Kappa Statistics-----																					

Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all sources of materials for the thesis have been duly acknowledged.

GETU ABDISSA

This thesis has been submitted for examination with my approval as an advisor.

Mohammed Umer (Ph. D.)

Addis Ababa, Ethiopia

May 2010