



Vegetation Ecology and Dynamics of Land Cover Change of Abune Yosef Mountain Range, Lasta District, Amhara Regional State, Northern Ethiopia

Kflay Gebrehiwot Yaynemsä

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Kflay Gebrehiwot Yaynemsä

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By

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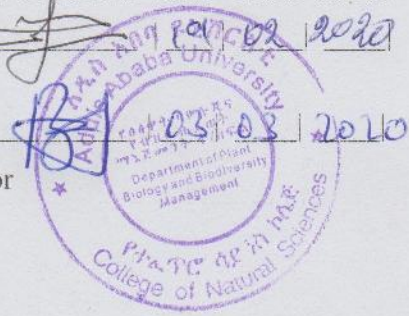
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Approved by Examining Board:

1. Prof.Zerihun Woldu (Advisor) Zerihun Woldu | 19 | 02 | 2020
2. Prof.Sebsebe Demissew (Advisor) Sebe Demissew | 19 | 02 | 2020
3. Dr.Ermias Teferi (Advisor) Ermias Teferi | 19 | 02 | 2020
4. Dr. Temesgen Desalegn (Advisor) Temesgen Desalegn | 19 | 02 | 2020
5. Dr. Tamrat Bekele (Internal Examiner) Tamrat Bekele | 25 | 02 | 2020
6. Prof.Albert P.Groojans (External Examiner) Albert P. Groojans | 03 | 03 | 2020

Dr. Bikila Warkineh

Chair of Department or Graduate Programme Coordinator



Abstract

Vegetation Ecology and Dynamics of Land Cover Change of Abune Yosef Mountain Range, Lasta District, Amhara Regional State, Northern Ethiopia

Kflay Gebrehiwot
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The understudied flora, Abune Yosef mountain range, is under pressure from land use changes. This research was conducted to study the vascular plant composition, plant communities, diversity, conservation status, species richness pattern along elevation gradient, and spatiotemporal land use and land cover change. A total of 85 nested sample plots measuring 20 X 20 m, 5 X 5 m and 1 X 1 m were established for trees, shrubs, and herbs respectively. Topographic, edaphic and disturbance variables were also collected from each plot. IUCN Red List and a combination of density of mature individuals, habitat specificity, and species local range was considered to assess global and local rarity respectively. Two Landsat satellite imageries from 1986 (Thematic Mapper, TM) and 2017 (Operational Land Imager, OLI) were used. Aerial photographs were used for ground referencing of the 1986 satellite image. Agglomerative hierarchical clustering and Shannon diversity index were employed to classify plant communities and quantify community diversity and evenness. Canonical correspondence analysis (CCA) was used to describe vegetation-environment-disturbance relationships. Descriptive statistics and rarity forms ratio were used for vascular plants conservation status analysis. To investigate land use land cover change (LULCC), supervised classification using Maximum Likelihood Classifier of two Landsat images from 1986 and 2017 was performed. Ground reference points and aerial photographs were used for accuracy assessment. One hundred ninety nine vascular plant species belonging to 64 families and 155 genera were recorded in five plant communities. The most species rich families were Asteraceae 42(21.1%), Poaceae 15(7.5%), Lamiaceae 12(6.03%) and Fabaceae 11(5.5%) respectively. Thirty two families were represented by a single species. The species richness followed a monotonically decreasing pattern towards higher elevation. Of the vascular plants assessed following IUCN Red List criteria, about 5% are threatened and the remaining are of least concern. Locally, only 17 species (8.54%) of the plants revealed common, and the remaining entertained six forms of rarity. The first axis explained 43.63% of the overall inertia and is correlated with Elevation, pH, slope aspect, total Nitrogen, soil organic Carbon & Clay. On the other hand, the second axis explained 32.06% of the total inertia and is correlated with bulk density, slope, logging, & available Phosphorus. The LULCC results demonstrated that the area of Afroalpine grassland has declined by -64.76% over the last 31 years, from 10, 500 ha to 3700 ha. Other

declines were seen in grazing land (-72.15%, 5,900 ha), open woodland from (-100%, 3,900 ha) and shrubland (-7.04%, 2,500 ha). On the other hand, agricultural land area has increased from 38,300 to 48,700 ha (+27.15%), barren land from 5,400 to 8,900 ha (+64.81%), rivers, riverbeds and gullies from 1,100 to 3,700 (+236.56%), plantation forests from 2,500 to 4,700 ha (+88%) and urban settlements from 300 to 500 ha (+66.66%). The present study revealed that topographic variables have a profound influence on species distribution. Exclusive to church forests, the vegetation cover showed a declining trend over the study period. The main drivers of LULCC were identified as increased human population pressure, and temperature and precipitation variability. Since the majority of the plants are rare in the mountain range, landscape level conservation approach by establishing corridors between the vegetation types to maintain ecological and evolutionary processes is recommended.

Keywords: Elevation gradient; Floristic composition; LULC; Multivariate analysis; Plant community; Plant Rarity; Remote sensing

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DEDICATION

This work is dedicated to:
My lovely late younger brother **Gebre Gebrehiwot**

My father **Gebrehiwot Yaynemsä**

My mother **Letay Belay**

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Acronyms

AA	Afroalpine Belt
AAG	Afroalpine Grassland
AGL	Agricultural Land
AHC	Agglomerative hierarchical clustering
avP	available phosphorus
BD	Bulk Density
BRL	Barren Land
CA	Correspondence Analysis
CCA	Canonical Correspondence Analysis
CHF	Church forests
CSA	Central Statistical Agency of Ethiopia
DAF	Dry evergreen Afromontane Forest
DBH	Diameter at Breast Height
DCA	Detrended Correspondence Analysis
DEM	Digital elevation model
DPSIR	Drivers, Pressure, State, Impact and Responses
EB	Ericaceous Belt
EFS	Ericaceous Forest/Shrubland
EMA	Ethiopian Mapping Agency
EOTC	Ethiopian Orthodox Tewahido Church
FEE	Flora of Ethiopia and Eritrea
GD	Gondar Floristic Region
GRL	Grazing Land
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conserving Nature and Natural Resources
IVI	Important Value Index
LULCC	Land use and land cover change
m a.s.l.	meters above sea level
MEFCC	Ministry of Environment, Forest and Climate Change
MRPP	Multi-Response Permutation Procedure
NMDS	NonMetric Dimensional Scaling
OLI	Landsat Operational Land Imager
OTV	ordinal transform values
PCA	Principal Component Analysis
PCoA	Principal Coordinate Analysis
pH	Soil pH
PLN	Plantations
RBG	Rivers, Riverbeds and Gullies
RDA	Redundancy Analysis
SBL	Shrubland
SOC	Soil Organic Carbon
TM	Landsat Thematic Mapper
TN	total Nitrogen
TU	Tigray Floristic Region
URS	Urban settlements
USGS	United States Geological Survey
WDL	Woodland
WU	Welo Floristic Region

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Topographically complex regions are the centers of speciation, species turnover, high taxonomic and ecological diversity (Steinbauer *et al.*, 2016; Badgley *et al.*, 2017). Ethiopia is topographically complex with elevations varying from about 125 meters below sea level to about 4533 meters above sea level (m a.s.l.). Hence, it is part of the Archipelago-like center of endemism (Afromontane), Archipelago-like center of extreme floristic impoverishment (Afroalpine) and Somalia-Masai regional center of endemism (White, 1983). Ethiopia is also represented in Afrotropical ecoregion by the Ethiopian highlands (Olson & Dinerstein, 2002). It also hosts two of the 36 biodiversity hotspots namely: the Eastern Afromontane and the Horn of Africa hotspots (Mittermeier *et al.*, 2004; Hoffman *et al.*, 2016) which are regarded as the major center of diversity and endemism for several plant species.

Vegetation is an unequivocally important component of the terrestrial environment. It is an important source of genetic resources for several domesticated and important wild plants. Although species richness and diversity varies across vegetation types depending on environmental factors, Ethiopia is known to be a center of plant diversity.

Anthropogenic influences altered the global pattern of biodiversity and ecosystem processes (Ellis, 2015), carbon dynamics and plant diversity (Sleeter *et al.*, 2018) which plays a major role in climate change. Land use changes such as agricultural expansion, habitat destruction, habitat fragmentation, drought, overexploitation, and others are causing the vegetation cover to nosedive at an alarming rate. Land use change intensity, particularly in tropical mountainous regions, has a significant impact on changing floristic composition, modifying plant community, and negatively affect ecosystem functions (Peters *et al.*, 2019).

Vegetation is highly affected by landscape connectivity. Landscape fragmentation affects vegetation in two peculiar ways namely habitat and connectivity loss which are associated with the area and plant dispersal (Taylor *et al.*, 1993; Fischer & Lindenmayer, 2007). These in return caused a decline in floristic diversity (Taylor *et al.*, 1993), increase in species extinction risk (MacArthur & Levins, 1967), and influence the taxonomic structure of plant communities (Uroy *et al.*, 2019). Furthermore, Rosche *et al.* (2018) reported that plant genetic erosion is a common phenomenon in fragmented landscapes. This could be due to the land use and land cover changes which leads to habitat fragmentation, increased forest/grassland/woodland patches and decrease plant population (Lindenmayer & Fischer, 2013).

In Ethiopia, exclusive to forest cover dynamics, there is a paucity of data in the dynamics of grasslands, woodlands, and shrublands. The forest cover of Ethiopia in the 1900s was about 40% (Bekalo & Bangay, 2002). This has drastically reduced to less than 3% (Badege Bishaw, 2001). Exclusive to Churches and some isolated protected areas, the forest cover in Ethiopia is much degraded and covered with scanty vegetation.

However, recent reports claim forest cover is increasing to 11.4% (FAO, 2015). This shows positive progress in the forest cover. However, this could be attributed to the change in forest definition which considers the tree cover of 20%, tree height of 2 m and above, and 0.5 hectare coverage (Ministry of Environment Forest and Climate Change, MEFCC, 2016) while the FAO definition of forest considers the thresholds of 10% canopy cover, a 0.5 ha area and a 5 m height. The main reason to change the national forest definition is to capture the *Terminalia-Combretum* dense woodlands found in Gambella and Benishangul Gumuz Regional States.

Data on the important woodland cover dynamics of Ethiopia is very limited. The FAO (2015) estimate of the woodland cover of Ethiopia showed a slight decrease (0.4%) from 1990-2015. However, studies at regional, district or watershed level showed contradicting result unlike their counterpart, forests. For example, an increase in woodland cover was reported in

some parts of Ethiopia (Lemlem Tadesse *et al.*, 2017). On the contrary, a decrease in woodland cover was reported in different parts of Ethiopia (Adenew Taffa *et al.*, 2015; Binyam Alemu *et al.*, 2015; Kefyalew Sahle *et al.*, 2016; Sisay Hailemariam *et al.*, 2016).

Similar contradictions are common in the grassland cover. While an increase in grassland coverage was reported in some parts of Ethiopia (Alemayehu Urgesa *et al.*, 2016; Lemlem Tadesse *et al.*, 2017), a decline in area coverage was also reported by several authors (Ermias Teferi *et al.*, 2013; Aramde Fetene *et al.*, 2014; Adenew Taffa *et al.*, 2015; Tsehaye Gebrelibanos & Mohammed Assen, 2015; Kefyalew Sahle *et al.*, 2016; Sisay Hailemariam *et al.*, 2016). Yohannes Kidane *et al.* (2012) reported an increase in Afroalpine grassland while a decrease in Afromontane grassland cover. Hence, local investigation of land cover change dynamics could have a crucial value in helping policy and decision makers develop effective management plan.

Ethiopia has 50% of all the Afrotropical lands above 2,000 m and 80% of all the lands above 3,000 m a.s.l. (Yalden & Largen, 1992). Abune Yosef mountain is part of the Eastern Afromontane biodiversity hotspot (Mittermeier *et al.*, 2004; Hoffman *et al.*, 2016), Key Biodiversity Areas, and terrestrial ecoregions. The mountain range comprises different vegetation types such as dry evergreen Afromontane forests and grasslands (DAF) particularly Church forests, Ericaceous forest (EB), and Afroalpine vegetation (AA). It harbors several wild animals, for example, *Canis simensis*, which is endangered and endemic (Saavedra *et al.*, 2009b). Characteristic plant species of Afroalpine and sub-Afroalpine vegetation such as *Lobelia rhynchopetalum*, *Erica arborea*, *Alchemilla abyssinca*, *Euryops pinifolius*, and *Festuca* species; and dry evergreen Afromontane forests such as *Juniperus procera* and *Olea europaea* subsp. *cuspidata* exist in Abune Yosef mountain range.

To develop conservation planning and prioritization and reduce biodiversity loss, empirical data on plant composition, vegetation-environment relation, and land cover changes plays a

crucial role in showing the gaps. Although most of them are restricted on dry and moist evergreen montane forests, several researches on similar aspects were conducted in different parts of Ethiopia on. Welo floristic region (WU) in general Abune Yosef mountain range, in particular, is understudied (Friis *et al.*, 2001). Despite the researches on the treeline dynamics and land use/land cover change in the Lib Amba mountains of the neighboring district (Jacob *et al.*, 2015a; b), research on vegetation ecology and land use/land cover change are lacking in Abune Yosef mountain range. Thus, the study fills the gap by combining floristic composition, plant diversity, vegetation-environment relations to land cover changes along the elevation gradient.

1.2. Problem justification and research questions

Mountains are characterized by harboring unique biodiversity though they cover only 13–25% of the terrestrial environment (Kapos *et al.*, 2000; Körner *et al.*, 2011). Tropical mountain regions have received only marginal attention in science and society, despite their ecological and economic importance (Bussmann, 2002). However, mountain ecosystems have recently received considerable interest based on the understanding that climate change might have serious irreversible impacts on physical and biological systems in these habitats (Loader *et al.*, 2009).

Ethiopian mountains make a major part of the East African Mountains. The Afroalpine region of Ethiopia, however, covers only 2% of the country which is largest in the Afrotropical area (Yalden, 1983). Grimshaw (2001) revealed that the fundamental ecology of Afromontane plants, particularly eastern Africa, as still poorly studied. However, extensive vegetation studies have been conducted in Ethiopia, most of them focusing on the dry and moist evergreen Afromontane forests. Despite their ecological and conservation implications, research on vegetation along elevational gradient including the Afroalpine ecosystem is very limited.

Elevational gradients of biodiversity have received renewed attention because predicted changes in climate (Desalegn Chala *et al.*, 2016; Yohannes Kidane *et al.*, 2019) are manifested first and most strongly at high latitudes and elevations, especially in tropical environments. The topographic, edaphic, and disturbance parameters vary at a profound leap along elevation gradients than the latitudinal gradients in a very short distance. Hence, research along elevational gradient is an enlightening field of study (Nogues-Bravo *et al.*, 2008). Consequently, research on vascular plant species richness pattern along elevation gradient plays a crucial role in developing conservation planning and prioritization in mountain regions.

About 12% of the world's population lives in mountains which results in moderate to high perturbation regimes (Martinelli, 2007). Previously, the best place for agricultural expansion and natural resource exploitation was the areas with medium altitude though it is recently reported middle stone-age foragers resided in high elevations of the glaciated Bale mountains, Ethiopia (Ossendorf *et al.*, 2019). However, due to the population pressure and global warming, these days, the high elevation areas are facing a lot of pressure from encroachment, overgrazing, and wood extraction. Consequences of these issues are reflected in the land cover change. Particularly, the climate sensitivity and presence of relict periglaciations of the highest mountains is affecting the sensitive treeline and land cover changes (Hendickx *et al.*, 2014). Abune Yosef mountain range, thus, would not escape from both anthropogenic and climate change impacts.

Thus, conducting detailed investigation on the vascular plant diversity/floristic composition, richness along elevation gradient, vegetation-environmental-disturbance variables relations, and spatio-temporal land use and land cover changes on the understudied floristic region (WU), particularly Abune Yosef mountain range, is expected. This will have a significant contribution to imply conservation planning and prioritization and set sound management plan of the study area.

Hence, the following research questions are raised:

- 1. Species richness** - species richness is an iconic measure of biodiversity used to identify biodiversity hotspots (Magurran & McGill, 2011). Hence, it plays a crucial role in conservation planning and prioritization. *What is the vascular plants species composition and diversity?*
- 2. Population structure** – population structure shows the status of a population, which is crucial for management purpose. *Does the population structure of the dominant tree species follow a regular pattern?*
- 3. Vegetation-environment-disturbance relationship** – vascular plant species richness, diversity, and distribution is determined by a couple of biotic and abiotic factors such as environmental (example: elevation, slope, and moisture), disturbance (example: grazing and logging) and competition. *Which environmental and disturbance factor(s) is (are) significantly influencing species distribution?*
- 4. Plant community** - plant communities are markers of an ecosystem (Mirkin & Naumova, 2015). Identification and description of plant communities are important to deal with conservation and environmental issues of the threatened communities. *What are the plant communities occurring in the study area?*
- 5. Species richness pattern along elevation gradient** - Successful conservation and management of plant diversity need an explicit exploration of the plant species richness pattern along environmental gradients and the factors which govern it in the area of interest. *Does vascular plant species richness along elevation gradient portray any particular pattern?*
- 6. Vascular plants conservation status** - Understanding the threats and extinction risks of a particular species is an important step in biodiversity conservation (Cosiaux *et al.*, 2018). *What is the extinction debt of the plants in Abune Yosef mountain range?*

7. Land cover change - Although National level LULCC products are available for Ethiopia, the overall accuracy is very poor, <50% for mountainous regions (Binyam Tesfaw *et al.*, 2018). In order to manage and conserve natural resources, empirical and quantitative research is inevitable to understand the spatiotemporal extent and drivers of land use and land cover change (LULCC) in a particular area. *What is the extent of spatiotemporal land cover change in the study area?*

1.3. Objectives

1.3.1. General objective

The general objective was to study the vegetation ecology and dynamics of land use and land cover change in Abune Yosef mountain range, Amhara Regional State, northern Ethiopia.

1.3.2. Specific objectives

The specific objectives of this research were to:

- ✎ Document the vascular plant composition and diversity
- ✎ Investigate the relationship of selected environmental and disturbance variables with species distribution
- ✎ Identify plant community types of the study area
- ✎ Investigate vascular plants species richness patterns along elevation gradient
- ✎ Determine the conservation status of the vascular plants
- ✎ Analyze spatiotemporal land use and land cover change

CHAPTER TWO

2. REVIEW OF RELATED LITERATURE

2.1. Vegetation types and vascular plants diversity

Probably the first vegetation classification of Ethiopia was done by Pichi-Sermolli (1957) as part of north eastern Africa (Ethiopia, Eritrea, Djibouti, and Somalia) as briefly discussed in Friis & Sebsebe Demissew (2001). He divided the vegetation types into twenty four. However, it was not explicit because it was based on previous geographical and botanical information. Furthermore, it was not representative at all (Friis *et al.*, 2010).

After two decades White (1983) classified the vegetation of Africa in general including the Ethiopian vegetation, center of endemism as a criteria. Out of the 80 vegetation types presented by White 13 are found in Ethiopia (Friis *et al.*, 2010). The vegetation classification of White (1983) is as important as the vegetation classification of Ethiopia by Friis (1992) and Friis *et al.* (2010). However, the location of White's vegetation map lacks precision (Friis *et al.*, 2010).

Friis (1992) classified the vegetation of Ethiopia into six viz. (1) Lowland dry peripheral semi-deciduous forest, (2) Transitional rainforest, (3) Broad-leaved Afromontane rainforest, (4) Undifferentiated Afromontane forest with either *Podocarpus falcatus* or both *Podocarpus falcatus* and *Juniperus procera*, (5) Dry single-dominant Afromontane forest with *Juniperus procera*, and (6) Transition between dry single dominant Afromontane forest and east African evergreen and semi-evergreen bushland and thicket.

Several authors (Sebsebe Demissew *et al.*, 1996, 2004; Zerihun Woldu, 1999; Friis & Sebsebe Demissew, 2001) classified Ethiopian vegetation/ecosystem into eight viz. (1) Afroalpine and Sub-Afroalpine, (2) Dry Evergreen Montane Forest and Grassland Complex, (3) Moist Evergreen Montane Forest, (4) *Acacia-Commiphora* Woodland, (5) *Combretum-Terminalia* Woodland, (6) Lowland Semi-evergreen Forest, (7) Desert and Semi-Desert

Scrubland and (8) Aquatic ecosystem; which was never included in the previous vegetation classification systems.

A much improved and better described Ethiopian vegetation classification system was proposed (Friis *et al.*, 2010). These authors classified Ethiopian vegetation into twelve potential natural vegetation (PNV) viz. (1) Desert and semi-desert scrubland (SSD); (2) *Acacia-Commiphora* woodland and bushland (ACB) which has two subtypes ((2a) *Acacia-Commiphora* woodland and bushland proper (ACB), (2b) *Acacia* wooded grassland of the rift valley (ACB/RV)); (3) Wooded grassland of the western Gambella Region (WGG); (4) *Combretum-Terminalia* woodland and grassland complex (CTW); (5) Dry evergreen Afromontane forest and grassland complex (DAF) which have four subtypes viz. (5a) Undifferentiated Afromontane forest (DAF/U), (5b) Dry single-dominant Afromontane forest of the Ethiopian highlands (DAF/SD), (5c) Afromontane woodland, wooded grassland and grassland (DAF/WG) and (5d) Transition between Afromontane vegetation and *Acacia-Commiphora* bushland on the eastern escarpment (DAF/TR); (6) Moist evergreen Afromontane forest (MAF); (7) Transitional Rainforest (TRF); (8) Ericaceous belt (EB); (9) Afroalpine belt (AA); (10) Riverine vegetation (RV); (11) Fresh water lakes, lake shores, marshes, swamps, and flood plains vegetation (FLV) and (12) Salt water lakes, lake shores, salt marshes and pan vegetation (SLV). This classification system is very informative and, probably, representative. Exclusive to vegetation types 8-12 it looks an extension of previous classification systems.

Recently, Intermediate evergreen Afromontane forest (IAF) is proposed as a new vegetation type of Ethiopia (Abiyot Berhanu *et al.*, 2018). This new vegetation type shares some species from Dry evergreen Afromontane forest and moist evergreen Afromontane forest. Furthermore, their species distribution modeling revealed that Gojam (GJ) and Gondar (GD) floristic regions, with an elevation range between 1500-2800 m a.s.l., are the potential areas for this vegetation type. However, Tamrat Bekele (1994) early mentioned the transition zone between the moist

southwest highlands and the relatively dry Afromontane region of north needs due research attention.

Tropical ecosystems, especially montane forests are the most species-rich ecosystem on earth. This is due to the availability of optimal resources required for living organisms. However, they are severely exploited because of their equal importance for agriculture. The montane forests of East Africa particularly Ethiopia have exceptional species richness, high concentrations of endemic species however they are under great human land-use pressure (Mittermeier *et al.*, 2004).

Ethiopia possesses large assemblage of plants, the fifth largest floral diversity in tropical Africa (Maczulak, 2010) consisting more than 5,757 higher plants with about 10% endemism (Ensermu Kelbessa & Sebsebe Demissew, 2014). This covers 17% and 10% of endemic and near-endemic plant species, respectively, of the Horn of Africa (Friis *et al.*, 2005). Ethiopia is, thus, considered as a center of plant diversity (WCMC, 1992).

2.2. Plant Community Dynamics in Fragmented Landscapes

Although the ideas might be very closely related, ecologists define plant community in different ways. van der Maarel & Franklin (2013) defined plant community as “*a relatively uniform piece of vegetation in a uniform environment, with a recognizable floristic composition and structure that is relatively distinct from the surrounding vegetation.*” Even though ecologists agree that plant community is an association of plant species in an environment, there are two plant community structure models that deviate at certain issues. These are the community-unit and continuum concept.

The community-unit concept states plant community develops together as a single unit like an organism and is driven mainly by climate (Clements, 1916). The community-unit concept states that communities are highly structured, repeatable, and identifiable associations of species controlled by environmental gradients. This is often depicted graphically as a series of

non-overlapping groups of species response curves along an environmental gradient (Collins *et al.*, 1993).

On the other hand, the proponents of continuum concept of plant community as hypothesized by Gleason (1926) is described as “*Each species is distributed in its own way, according to its own genetic, physiological, and life-cycle characteristics and its way of relating to both physical environment and interactions with other species; hence no two species are alike in distribution.*” Continuum theory states that plant communities change gradually along complex environmental gradients, such that no distinct associations of species can be identified.

The debates about community theories are still persisting. Looijen & Andel (1999) explained three problems of ecological communities, viz. ambiguity in defining communities, the absence of clear boundary in communities, and heterogeneity in the composition of communities. Hence, these authors proposed a new definition of communities as “the particular set of individuals occurring in the intersection of the areas occupied by different populations of species.” Nevertheless, this definition could have a drawback because it could lead to an unstable excessive number of plant communities.

Perhaps, the pioneering research conducted in Ethiopia to test community continuum was in the 1960s by Beals (1969). The study was conducted in steep (Bati to Combolcha/*Kombolcha* from 800 to 2050 m a.s.l.) and gentle (Awash to Shashamanne from 1000 to 1900 m a.s.l.) altitudinal gradients of vegetation change. The result showed community discontinuities in the steep slope than the gentle slope. Most part of Ethiopia is turning to be anthropic landscape (White, 1983) with some remnant natural vegetation due to land use changes.

Severe habitat fragmentation is often the cause for habitat loss or conversion into other land use types. Temporal and spatial discontinuities in plant community structure or vegetation

pattern are common phenomenon in the Anthropocene era. Hence, the vegetation in northern Ethiopia in general Abune Yosef mountain range in particular would be rather considered either as metacommunity (Leibold *et al.*, 2004) or meta-ecosystem (Loreau *et al.*, 2003). Because most of the remnant natural vegetation is confined to a very small patches which exist in a highly fragmented landscape. These plant communities are connected by dispersal whereas the ecosystem by spatial flows of energy, materials and organisms across ecosystem boundaries.

2.3. Multivariate data analysis: Classification and Ordination

The statistical analysis of observations and more than one variables is termed as multivariate data analysis. Cluster analysis and ordination are some of the commonly used approaches in environmental science in general and vegetation ecology in particular. These approaches are discussed in the following subsections.

2.3.1. Cluster analysis

Cluster analysis is a classification approach in which things are grouped together on the bases of their similarity. The more similar they are the more probability to be in the same cluster. It can be used to discover structure in data without providing an explanation (Zerihun Woldu, 2017). The interpretation of the clusters depends on the knowledge of the author's pre-analysis data and study area. Moreover, it also depends on the distance methods used, grouping rules applied, and cluster analysis method. The outputs of the cluster analysis can be scatterplots, dendrograms, trees, lineage diagrams, and silhouette. There are two types of cluster analysis viz. non-hierarchical and hierarchical clustering. Both of them are discussed by giving more emphasis to hierarchical clustering.

2.3.1.1. Non-hierarchical clustering

Although non-hierarchical clustering is not commonly used like hierarchical classification in vegetation ecology, there are various non-hierarchical methods (Kent, 2012). Cluster based partitioning method is an example of non-hierarchical clustering. Non-hierarchical partitioning algorithms attempt to derive clusters from an undifferentiated set of vegetation plots directly

without a hierarchical dendrogram (Peet & Roberts, 2013) i.e. it produces a single partition without any hierarchy in the group (Borcard *et al.*, 2011). The number of clusters should be determined in advance, unlike hierarchical clustering.

2.3.1.2. Hierarchical clustering

In contrast to non-hierarchical clustering, the members of inferior-ranking clusters become members of larger, higher-ranking clusters. Most of the time, hierarchical methods produce non-overlapping clusters (Borcard *et al.*, 2011). The output of the hierarchical cluster analysis is a dendrogram which allows cutting at an arbitrary height to create a reasonable number of clusters. Hierarchical clustering is often based on resemblance matrix or dissimilarity. There are two types of hierarchical cluster analysis.

2.3.1.2.1. Divisive hierarchical clustering

Hierarchical divisive clustering begins with all plots in a single cluster, which is then divided into two subclusters recursively until the clusters get too small or too homogeneous to subdivide according to criteria established by the user (Peet & Roberts, 2013). Due to this reason, it is called a “top-down” approach. Divisive methods may be monothetic or polythetic. Monothetic methods use a single descriptor (the one that is considered the best for that level) at each step for partitioning, whereas polythetic methods use all descriptors; in most cases, the descriptors are combined into an association matrix (Borcard *et al.*, 2011). However, Legendre & Legendre (2012) claimed that polythetic divisive methods are not satisfactory.

2.3.1.2.2. Agglomerative hierarchical clustering

Agglomerative hierarchical clustering begins with the discontinuous collection of objects, which are successively grouped into larger and larger clusters until a single, all-encompassing cluster is obtained (Borcard *et al.*, 2011). In contrast to divisive hierarchical clustering, it is a “bottom-Up” approaches. It works by first finding the clusters of the most similar items and progressively adding less similar items until all items have been included into a single large cluster (Zerihun Woldu, 2017).

2.3.2. Diversity Indices

Species diversity could provide better information than simply list of species since it often considers the relative abundance of the species. Even though there is no single universally accepted diversity index, there have been several indices used to estimate species diversity and evenness. Some of the widely used diversity indices include Shannon-Weiner and Simpson diversity index.

2.3.2.1. Shannon diversity index

Shannon-Wiener index (H') or Shannon diversity index makes the assumption that individuals are randomly sampled from an 'infinitely large' population and also assumes that all the species from a community are included in the sample (Kent, 2012). However, the last assumption is not always easy to meet and presupposes that the ecologist knows exactly what the species composition of the community is.

The Shannon diversity index is calculated from the formula (Equation 1):

$$\text{Diversity } (H') = - \sum_{i=1}^s p_i \ln p_i = - \sum_{i=1}^s \left[\left(\frac{n_i}{n} \right) \ln \left(\frac{n_i}{n} \right) \right] \quad (1)$$

Where; s is the number of species, p_i is the proportion of individuals or the abundance of the i th species, and $\ln = \log$ base n ; n_i is the number of individuals belonging to i th of S species in the sample and n is the total number of individuals in the sample.

Any base of logarithms may be taken, with \log_2 and \log_{10} being the most popular choices. The choice of log base must be kept constant when comparing diversity between samples. Values of the index usually lie between 1.5 and 3.5, although in exceptional cases, the value can exceed 4.5.

According to Shannon equitability or evenness index (E), evenness is calculated as follows (equation 2):

$$E = \frac{H'}{H_{\max}} = \frac{- \sum_{i=1}^s p_i \ln p_i}{\ln S} \quad (2)$$

The higher the value of E the more even the species is in their distribution within the quadrat.

2.3.2.2. Simpson diversity index

Simpson derived an index based on the probability that any two individuals taken at random from an infinitely large community will belong to the same species (Simpson, 1949) expressed in the following formula (equation 3):

$$D = \sum_{i=1}^s p_i^2 \quad (3)$$

Where p_i is the proportion of the number of individuals or the abundance of the i th species. It is usually reported as $1-D$ ($1 - \sum p_i^2$) the complement or $1/D$ ($1/\sum p_i^2$) the reciprocal (Kent, 2012).

An evenness measure can also be obtained by dividing the reciprocal form of the index by the number of species in the sample (S) as in equation 4:

$$\text{Evenness} = \frac{(1/D)}{S} \text{ or } \frac{1-D}{S} \quad (4)$$

The reciprocal is, however, widely used. The result lies between 0 and 1 and is not influenced by species richness, unlike the other diversity indices.

Generally, the diversity indices with their respective formula are described in table 1.

Table 1. Species diversity indices

	Diversity index				
	Shanon	Simpson	Margalef	Reciprocal Berger Parker	Hill's diversity
Diversity	$H' = \sum_{i=1}^s p_i \ln p_i$	$D = \sum_{i=1}^s p_i^2$ OR $1-D$ or $1/D$	$D_M = \frac{(S-1)}{\ln(N)}$	$D = (N_{max})^{-1}$	$N_1 = exp(H')$ $N_2 = 1/\sum_{i=1}^s p_i^2$
Evenness	$E = \frac{H'}{\ln(s)}$	$E = \frac{(1-D)}{S}$ OR $E = \frac{(1/D)}{S}$			

Where: S = number of species; N = number of individuals; p_i = the proportion of individuals found in the i th species; N_{max} = number of individuals in the most abundance species.

2.3.3. Ordination

The encyclopedia of ecology (Syms, 2008) defined ordination as “*a set of analyses that collectively aim to summarize and present multivariate data, in which multiple dependent or response variables have been recorded, to display differences between samples graphically into fewer dimensions than the original data set*”. Shortly, it is a graphical representation of the similarity of sampling units and/or attributes in resemblance space (Wildi, 2013). It transforms the vector observations into a new set of vector observations. In contrast to cluster analysis that searches for discontinuities in the dataset, ordination extracts the main trends in the form of continuous axes (Zerihun Woldu, 2017). This provides much-focused information of the relative position of objects by reducing dimensions. There are two ordination types viz. indirect ordination or unconstrained (Principal Component Analysis (PCA), Correspondence Analysis (CA), NonMetric Dimensional Scaling (NMDS), and Detrended Correspondence Analysis (DCA)) and direct or constrained (Canonical Correspondence Analysis (CCA) and Redundancy Analysis (RDA)) ordination.

2.3.3.1. Indirect or Unconstrained ordination

Indirect ordinations are based on the analysis of sample units (floristic data) independently of any preconceived notions of controlling environmental/biotic factors or successional sequences (Kent, 2012). It positions sample units according to covariation and association among the species (McCune & Grace, 2002).

2.3.3.1.1. Principal component analysis (PCA)

PCA is an unconstrained ordination tool which assumes a linear relationship of sample units and environmental and/or biotic relationship. It creates new variables that consist of uncorrelated, linear combinations of the original variables by using Orthogonal Euclidian, independent of previously extracted axes, space (Wildi, 2013; Zerihun Woldu, 2017). The most interesting and strongest covariation among variables emerges in the first few axes (components), hence "principal components" (McCune & Grace, 2002). PCA works based on

two principles (McCune & Grace, 2002; Legendre & Legendre, 2012; Wildi, 2013; Zerihun Woldu, 2017) which make it a powerful tool in vegetation data analysis. First, it reduces many variables to a smaller number of new derived variables that adequately summarize the original information and can be used for further analysis. Secondly, reveal patterns in the data, especially among objects, that could not be found by analyzing each variable separately.

Ordinations using PCA may be subject to an effect known as an arch, in which a plot of samples in ordination space of axis 1 versus axis 2 displays a curvilinear pattern rather than a linear gradient along the axis (an ‘arch’), or in an extreme form a bending in which samples that are very dissimilar are closer to each other than should be expected (a ‘horseshoe’) (Syms, 2008). This effect (also known as the Guttman effect) is a result of the limitations of the different distance measures preserved by PCA when samples have been taken across long environmental gradients and the composition of the community undergoes large changes. The Euclidean distance preserved by PCA is insensitive to double-zeroes – so samples that share no species in common appear to be more similar to each other, thus generating an arch in the ordination.

2.3.3.1.2. Correspondence analysis (CA)

Correspondence Analysis, formerly called reciprocal averaging (RA), is an eigenvector technique which performs a simultaneous ordination of both site and species scores (McCune & Grace, 2002). It is an eigen-analysis of a Chi-square distance matrix i.e. the eigenvalue of the CA axis is equivalent to the correlation coefficient between species scores and sample scores (Greenacre & Primicerio, 2013; Zerihun Woldu, 2017). The rows are the first descriptors and the columns are the second descriptors. Correspondence analysis is often used in community composition analysis based on presence-absence or abundance data (Legendre & Legendre, 2012). Like PCA, CA also suffers from the arc or horseshoe effect. To avoid this it is advised to detrend CA.

2.3.3.1.3. Principal coordinate analysis (PCoA)

Although it is very similar to PCA in principle, PCoA also known as metric multidimensional scaling allows the user to choose any distance measure which makes it more preferable (Legendre & Legendre, 2012; Wildi, 2013). In PCOA, when the sample units are ordinated, the eigenvalues and eigenvectors are derived species-similarity matrix is used to derive the coordinates of the sample units and vice versa (Wildi, 2013).

2.3.3.1.4. Nonmetric multidimensional scaling (NMDS)

NMDS is applied if the aim is to plot dissimilar objects far apart in the ordination space and similar objects close to one another due to the preservation of ordering relationships among objects (Legendre & Legendre, 2012). It can also use missing distance measures. The more missing distances there are, the easier the computations as long as there are enough measures left to position each object with respect to a few of the others (Legendre & Legendre, 2012). Consequently, this method is a widely used ordination tool. Interestingly, NMDS like PCoA is not limited to particular distance measures. Furthermore, it doesn't have any specified assumption. McCune & Grace (2002) claimed that specifying the minimal stress and slow computation with large data sets are the disadvantages of NMDS, otherwise, it should be the choice for ecological research.

2.3.3.1.5. Detrended Correspondence Analysis (DCA)

DCA is developed as a solution to the Arc or Horseshoe effect in CA. It is an eigenvector ordination technique based on correspondence analysis and ordines species and sample units simultaneously (McCune & Grace, 2002). Furthermore, it avoids the tendency to compress the axes ends relative to the middle which happens in CA.

2.3.3.2. Direct or Constrained ordination

In constrained ordination, sample units are ordinated on the bases of measurements of environmental factors in those sample units (McCune & Grace, 2002). It is applicable to

investigate patterns along environmental gradients. Constrained ordinations are directly influenced by a set of explanatory variables and the resulting axes are constrained by environmental factors since the matrix with environmental factors directly enter the ordination algorithm (Zerihun Woldu, 2017). The idea of constrained ordination is to search for a few weighted sums of environmental variables that fit the data of all species best, i.e. that give the maximum total regression sum of squares (Ter Braak & Prentice, 2004).

2.3.3.2.1. Redundancy Analysis (RDA)

RDA like PCA shows the Euclidean distance between sites in the ordination graphs and assumes linear relationships. In contrast to PCA, in RDA the ordination is constrained by the environmental variables, shown in the environmental matrix (Kindt & Coe, 2005). It is a method which combines regression and PCA (Borcard *et al.*, 2011).

2.3.3.2.2. Canonical Correspondence Analysis (CCA)

CCA finds a linear combination of variables in each of the two sets that the maximum mutual correlation. In CCA, since species are assumed to have unimodal response surfaces with respect to linear combinations of the environmental variables, the species are logically represented by points (corresponding to their approximate optima in the two-dimensional environmental subspace), and the environmental variables by arrows indicating their direction and rate of change through the subspace (Ter Braak & Prentice, 2004).

The choice of ordination approach/s depends on the input structure and the assumed relationships of variables. PCA and RDA are recommended for short environmental gradients whereas DCA and CCA for long environmental gradients (Austin, 2013; Paliy & Shankar, 2016). Furthermore, if the goal is identifying gradients of variation in a set of measured variables and if the length of the first axis in DCA is greater than 4, ordination techniques such as CCA that assume unimodal relationships should be advocated (Paliy & Shankar, 2016; Zelený, 2018).

2.4. Mountain Biodiversity

Mountains are characterized by their steepness and ruggedness which also entertains elevational differences (Körner, 2004). The steepness, in particular, causes the forces of gravity to shape them and create habitat types and disturbances typical for mountains and which make exposure a driving factor of life (Körner *et al.*, 2011). Consequently, mountains are the major hotspots of biodiversity than would be expected by area (Mutke & Barthlott, 2005). Furthermore, mountains play a crucial role in sustainable development because they are not only sources of fresh water for people, industries, irrigation for downstream areas but also food security, poverty alleviation, and, ultimately, political stability is critically linked to mountain resources, and hence to the development taking place in mountain areas (Mountain Agenda, 2002).

Besides all the ecological and social importance, however, mountains are facing anthropogenic pressures. Kohler *et al.* (2010) claimed that mountains, which host half of the global biodiversity hotspots, are threatened by climate change and anthropogenic pressures. Thus, there should be a balance in land use, conservation practices and developmental activities around mountain areas.

2.5. Vascular plant species richness patterns along elevation gradient

The relationship between plant species richness pattern and environmental variables remains a central issue of ecologists (Hegazy *et al.*, 2007). Dramatic variation in environmental drivers (e.g., solar insolation, temperature, precipitation) occurs over a relatively short elevational gradient, such that ecological mechanisms, rather than biogeographic or historic mechanisms, likely mold biotic responses (Willig & Presley, 2019). Plant species diversity and their distribution can be influenced by different environmental variables, to mention some among the others, soil, elevation, slope, aspect, and moisture.

There is no rigid pattern of species richness pattern along elevation gradient. However, several studies argued that species distribution along elevation gradient resulted in either (i) hump-shaped (Acharya *et al.*, 2011; Ren *et al.*, 2012); (ii) a monotonic decline in species richness with increasing elevation (Mallen-cooper & Pickering, 2008; Sharma *et al.*, 2009; Trigas *et al.*, 2013); (iii) a monotonic increase of species richness with increasing elevation (Baruch, 1984); (iv) the lowest species richness at intermediate elevation (Peet, 1978); and (v) no obvious relationship between species richness and elevation (Wilson & Sykes, 1988; Lovett, 1999). These trends have been discussed in relation to different environmental variables (Grytnes, 2003; Körner, 2004; Rahbek, 2005). Nevertheless, Rahbek (2005) emphasized that the hump-shaped and monotonic decline is more recognizable.

Vascular plant species richness pattern along elevation gradient does not necessarily reflect a similar pattern for endemic vascular plant species richness. Usually, high altitude areas host higher endemic plants than their respective lower altitude areas due to their spatial heterogeneity and extreme microclimates such as moisture and temperature. High endemic plants at high elevation is attributed to isolation of mountain zones and high species richness at a lower elevation is attributed to evolution and dispersal (Vetaas & Grytnes, 2002; Steinbauer *et al.*, 2016). High endemic plants at a higher elevation (Steinbauer *et al.*, 2016) and mid-elevation (Wang *et al.*, 2007; Trigas *et al.*, 2013; Manish *et al.*, 2017) were reported in different continents.

2.6. The interplay: Vegetation, Land Use, and Human Impact

Biological diversity is becoming threatened at an alarming rate due to land use change and development pressures. Declining of biodiversity in general and plant diversity, in particular, could be detrimental to all living organisms in the terrestrial environment. Considering the several threats to biological diversity, the lion's share goes to human beings. Biodiversity extinction rate is estimated to be 1,000-10,000 times the geological background rate (Pimm *et*

al., 1995). This definitely creates a major disruption in biogeochemical cycles on earth in which it's 30 to 50% of the land surface is transformed by human action (Leuschner, 2005). Out of the 7,000 plant species assessed following IUCN Red List Criteria, Brummitt *et al.* (2015) showed that 20% are threatened due to anthropogenic threats.

Anthropogenic impact on vegetation dynamics includes such as overgrazing (livestock), fire (wild or domestic), deforestation, climate change, the introduction of invasive alien species, forest clearance for agricultural expansion, and a variety of land use activities. Nevertheless, deforestation is the major potent cause of vegetation cover change. Air pollution and Nitrogen deposition which significantly influences the atmospheric composition to become different from any that its ancestors would have experienced is also a major threat to plants (Corlett, 2016).

The impact of human beings on vegetation, as a result, is reflected on ecosystem functioning and network structure of interacting species (Morris, 2010). The loss of one species could have a profound impact on other species, especially on co-existing species. This may cause secondary extinction (Koh *et al.*, 2004) though some species may benefit occasionally. Furthermore, “*if a species is lost from an ecosystem it is not just the species itself that is lost, but its interactions, and the ecological functions that result from these interactions, for example, seed dispersal*” (Morris, 2010).

2.6.1. Deforestation

Globally, deforestation has been causing a significant area loss of vegetation cover and land transformation since 1850 (James, 2013). Although there are reports which argue the forest cover of Ethiopia in the last 18th Century was around above 40%, this was not supported by systematic survey data (McCann, 1997). This usually leads to the ill-advised generalization about the origins and forecast of deforestation. However, deforestation *sensu lato* is an indicator of environmental history and a harbinger of bleak future (McCann, 1997).

Consequently, Nyssen *et al.* (2004) recommended the issue of deforestation needs urgent action at all levels.

2.6.2. Overgrazing

Livestock grazing in deforested land, grassland and/or rangeland could lead to loss of vegetation cover. Although it is widely believed by the scientific community that light grazing could increase plant productivity and diversity, heavy grazing could have a detrimental impact on vegetation cover. This could be due to the excessive trampling of animals which cause soil removal by wind, soil deterioration and erosion, soil compaction, increased bulk density, decrease soil organic carbon, reduced photosynthesis and loss of plants, and it may facilitate shrub encroachment in grasslands (Nyssen *et al.*, 2004; Goudie, 2013). These results in decreased water infiltration, increased erosion, and decreased biomass. Nevertheless, the effect of grazing varies along elevation gradient (Speed *et al.*, 2013).

2.6.3. Agricultural expansion

Agriculture is the main stay of Ethiopia. The ox-plow in its current form as a dominant tool appears in rock painting dating as far back as 500 AD (McCann, 2017). Considering being 2nd populous country in Africa, the need for agricultural and grazing land expansion is persisting. Due to degradation, however, there is no enough space left and productivity is decreased (Nyssen *et al.*, 2004). The absence of land use policy aggravates via deforestation and agricultural encroachment. Hurni (1988) reported 50 ton per hectare per year soil loss due to agriculture which is 25 fold higher than soil formation rate in Ethiopia.

2.6.4. Climate change

Man-induced climate change is causing a tremendous impact on vegetation. Although climate-driven increase in global terrestrial net primary production in tropical ecosystems was reported (Nemani *et al.*, 2003), range shift, phenology shift, phenotypic plasticity evolution and extinction due to climate change were also reported (Thomas *et al.*, 2004; Walther, 2010). This

might cause pollinator- phenology mismatches in particular and disruption of trophic structure at large.

2.6.5. Drought

Tracing the historical drought events happened in Ethiopia, it is a frequently recurring phenomenon that affect the environment and food security. More than 30 drought events were recorded since 1970 covering either the whole nation or in part. After 1970 drought visits the country at least at 10 years interval in which northern Ethiopia is the most exposed (Tagel Gebrehiwot *et al.*, 2011). In recent years, however, the frequency and spatial coverage is increasing.

Although the impact of drought varies based on the magnitude, frequency, and duration, the disaster of drought is not confined to social and economic crises. Rather, biological diversity is greatly affected vis-à-vis ecosystem productivity. Research from northern Ethiopia reported drought as the major driver of LULCC in general and loss of vegetation cover in particular (Direess Tsegaye *et al.*, 2010).

2.7. Plant conservation status

Plants play a crucial role in the ecosystem. They are at the center of ecosystem stability, services and functions. Economic and cultural values are also the presents of plants to the people. Food, fiber, forage, oxygen, medicinal, water purification, prevention of soil erosion, carbon sequestration, religious and aesthetics are some of the economic and ecological values of plants. However, plants are facing major threats in the era of Anthropocene.

Out of the 310, 343 described plant (including green and red algae, and mosses) species, 24, 230 (8% of the described plant species) have been evaluated by the International Union for Conservation of Nature (IUCN). The threatened plants species increased from 5328 in 1996/98 to 12, 505 in 2017 (IUCN, 2017). This two-decade data shows plants are at an ultimate threat. Considering, the number of species assessed and the remaining unassessed and undescribed

species, the global coverage of floristics, this IUCN work is the tip of the iceberg. Furthermore, regional, national and local evaluation are very limited.

According to the world conservation union report, IUCN 1997, IUCN (1998) 163 (2.5%) of the vascular plants in Ethiopia were threatened. IUCN Red List of endemic trees & shrubs of Ethiopia and Eritrea assessed 135 endemic plants (31 trees and 104 shrubs) and revealed that 116 of them are threatened (Vivero *et al.*, 2005). However, assessment of endemic flowering taxa assessed 596 taxa covering 550 species which are 9.7% of the estimated plants in FEE (Vivero *et al.*, 2006) and found 77.4% of them are threatened.

2.7.1. Rarity

Understanding the rarity of a species plays a crucial role in developing conservation priority by reasonably allocating the limited budget for conservation (Sisk *et al.*, 1994). The term “*rarity is frequently used as a synonym for low abundance or small range, and as the converse of common or widespread, without any attempt to place hard limits on where rarity ends and commonness begins*” (Gaston, 1994). Rarity is often determined by species geographical distribution, population, and habitat specificity (Rabinowitz, 1981; Gaston, 1994; Flather & Sieg, 2007). Rarity studies can be performed both at local spatial scales, regional, and biogeographical scales (Gaston, 1994).

Although the spatial scale should be taken into account, rare species have a great extinction risk than common species (Matthies *et al.*, 2004). However, if the spatial scale is very small this argument may have a flaw. Certainly, a species could be regarded as rare on a local scale, yet common at a regional or global scale (Flather & Sieg, 2007). Moreover, rarity forms don't consider the underlying causes of rarity (Jesus, 1998) which makes inferring about the differences between common and rare species undue. In this case, it might be complemented by the resource demanding IUCN Red List assessment.

The causes of rarity and threats of extinction reported globally are almost similar. The major

causes include habitat conversion, habitat destruction, habitat fragmentation, overexploitation, invasive alien species, overgrazing, over-harvesting, fire either wild or man-induced and climate change are some of the major threats to plants (Brummitt *et al.*, 2015). Habitat loss and degradation, alien species, intrinsic factors and exploitation are the major threats which caused 91%, 15%, 9%, 8% threats respectively of the plants assessed (Hilton-taylor, 2000).

Land transformation, per se habitat loss and fragmentation (Sisk *et al.*, 1994; Wilcove *et al.*, 1998; Honnay *et al.*, 2005; Flather & Sieg, 2007; Brummitt *et al.*, 2015), direct exploitation of a species (Pärtel *et al.* (2005), exotic and invasive species (Wilcove *et al.*, 1998), intrinsic characteristics of a species and habitat specificity (Flather and Sieg, 2007) are some of the leading causes of rarity either locally, regionally, or globally.

Loss of plants could lead to the loss of ecosystem multifunctioning (Fanin *et al.*, 2017) such as provisioning ecosystem services (food, water, timber, medicine fiber, soil, fodder), cultural services (aesthetic, spiritual, recreation), and regulating services (water purification, preventing soil erosion, climate).

2.8. Land use and land cover change (LULCC)

Land use and land cover change is a very complex process which is highly influenced by biophysical, socio-economical and economic factors (Arsanjani, 2012) such as long-term natural changes in climate conditions; geomorphological and ecological processes; human-induced alterations of vegetation cover and landscapes; interannual climate variability; and human-induced greenhouse effect (Lambin & Strahler, 1994). Land cover refers to “*the physical and biological cover over the surface of the land, including water, vegetation, bare soil, and/or artificial structures*” (Molders, 2012; Ellis, 2013). Whereas, Land use involves “*both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation—the purpose for which the land is used*” (TurnerII *et al.*, 1995).

Land use and land cover change is a global research agenda (Lambin *et al.*, 2006) because

it causes loss of biodiversity, increase pollution, increase climate variability (Mahmood *et al.*, 2010; Arsanjani, 2012) and affects the moisture and temperature states (Molders, 2012). Thus, it has a potentially strong influence on ecosystem services and functions (Wang *et al.*, 2015). The multiple impacts of LULCC include loss of provisional services i.e., lack of food, feed, fiber, and timber; increased disease risks; atmospheric chemistry, climate change, and life support functions; loss of agrobiodiversity and biodiversity; degradation of soil quality; and alteration to freshwater hydrology, agricultural water use, and coastal zones (Chhabra *et al.*, 2006).

Of particular importance are anthropogenic influences such as agricultural expansion, deforestation, and urbanization, as these are major contributors to CO₂ emissions. According to the IPCC (IPCC, 2007), about one-third of the anthropogenic CO₂ emissions since 1750 has come from land use changes. Houghton *et al.* (2012) estimated the net flux of carbon from LULCC from anthropogenic carbon emissions to be 12.5 percent from 1990 to 2010. However, Arneth *et al.* (2017) claimed that the estimations of CO₂ emissions from LULCC are underestimated and, perhaps, are larger than widely assumed. Furthermore, Bennett *et al.* (2005) predicted LULCC to be a major driver of changes in the provision of ecosystem services up to 2050.

In Ethiopia, land degradation associated with LULCC is responsible for the annual loss of about \$4.3 billion (Samuel Gebreselassie *et al.*, 2016). Ethiopia is the 12th and 2nd populous country in the world and Africa respectively with a population of over 107.5 million people and this population is increasing at a rate of 2.46% year⁻¹ (Worldometers, 2018).

More than 80% of the population of Ethiopia relies on rain-fed agriculture for subsistence. Consequently, LULCC is occurring at an alarming rate. Research in some parts of Ethiopia has revealed that the major drivers of LULCC are population growth and settlement; agricultural expansion; deforestation and land clearing; and fire (Yohannes Kidane *et al.*, 2012; Alemayehu

Urgesa *et al.*, 2016). Reconstruction of pre-agricultural expansion vegetation cover of Ethiopia by Binyam Tesfaw *et al.* (2015) showed that more than one-third of today's farmlands were previously covered mainly by broadleaved evergreen and deciduous forest.

Agricultural land expansion in the Ethiopian highlands has been increasing since 1860 at the expense of forests, shrublands, and grasslands (Hiywot Menker & Rashid, 2014). Agriculture plays a significant role in alleviating poverty, but the absence of a ratified policy on land use planning in Ethiopia is contributing to rapid land cover changes without a full understanding of the social, economic, and ecological impacts.

2.8.1. Image Processing and Classification

Land use and land cover change detection could be affected by image registration, differing atmospheric conditions, sensor differences, and different viewing conditions (Chen *et al.*, 2012). Thus, image preprocessing is crucial to avoid bias arising from noise and instrument artifacts.

Among the various steps of data preprocessing for change detection, multi-temporal image geometric correction (Toutin, 2004) and radiometric correction (Chander *et al.*, 2009) are the most important. Tools and techniques are needed to detect, describe, and predict these changes to facilitate sustainable management of natural resources (Chen *et al.*, 2012). After the image preprocessing information is extracted by different approaches such as unsupervised and supervised classification. These approaches are discussed in the next sub-sections.

2.8.1.1. Unsupervised classification

The theory behind unsupervised classification is, similar pixel values are organized into groups without interpretive guidance from the analyst (Adams & Gillespie, 2006). These groups are the bases for the different land uses classes. It is, therefore, at the hands of the investigator to identify and name the different LULC classes. Unsupervised classification could be helpful if the investigator is not familiar with the study area. However, care must be taken since the

unsupervised classification may create some undesired clusters (Hansen, 2012).

2.8.1.2. Supervised classification

Unlike unsupervised classification, in supervised classification interpretive guidance from the analyst is mandatory. The analyst selects a group of contiguous pixels from part of an image known as a training area that defines the digital number values in each channel for a class (Adams & Gillespie, 2006). Thus, supervised classification works on the bases of the ground reference data.

2.8.2. Accuracy Assessment

If we want to apply our output into management practices, the map should be as accurate as possible. Thus, an approach which assesses the accuracy of the map generated should be applied in both unsupervised and supervised classification. An accuracy level of 85% was introduced by Anderson *et al.* (1976) and it is now widely accepted and used as a standard in map accuracy assessment. However, an accuracy of 85% could be more than enough in some cases but may not be satisfactory in other cases (Congalton & Green, 2009). Thus, the accuracy level cutoff should be set based on the objective of the researcher.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study area description

Abune Yosef mountain range is located in North Wollo Zone, Amhara Regional State which is part of a high basaltic plateau situated west of the main Ethiopian Rift (Coltorti *et al.*, 2007). The area ranges from 11°50'00" to 12°15'00" latitude and 38°30'00" to 39°25'00" longitude (Figure 1). Its elevation reaches up to 4284 meters above sea level (m a.s.l.) at the mountain peak. The ridge of Abune Yosef mountain range continues northwards to the Tigray Plateau and westwards to the Simien Mountains. This mountain is the source of rivers that provide water for the downstream population which include several Districts and it is the origin of the Tekeze river.

The name abune Yosef comes after the Saint Abune Yosef who established and lived in Abune Yosef church at the top of the mountain. There is a folk told by the community and religious groups, the priests and Monks. Here is the folk.

Once up on a time a poor man in the Abune Yosef Mountain lost his mother. However, he wasn't lucky enough to attend his mother's burial ceremony. He would have lost his cereals due to the herds of *Theropithecus gelada* (Gelada Baboon) which could left his family bare of food if he had left the farmland for the burial ceremony. Hence, he was forced to stay in his farmland keeping the *Theropithecus gelada* (Gelada Baboon) from destroying his cereals.

Saint Abune Yosef saw the poor man crying in his farmland. St. Abune Yosef then asked "young man why are you crying"? The poor man replied "I have lost my mother, but I am couldn't to attend my mom's burial ceremony". The St. Abune Yosef asked why? The poor man replied "If I leave my farmland *Theropithecus gelada* (Gelada Baboon) herds will destroy my cereals as a result I can't feed my family." I don't deserve to be migrated.

Then St. Abune Yosef ordered the poor man to go and attend his mother's burial ceremony. He then forbid the *Theropithecus gelada* (Gelada Baboon) not to feed on the cereals and the people not to collect remnants of the cereals. The leftovers of the cereals are for the *Theropithecus gelada* (Gelada Baboon) species.

Even though the time when is not known, the *Theropithecus gelada* (Gelada Baboon) don't feed on the cereals and the people don't collect the cereal remnants starting from the forbid of St. Abune Yosef. Both the *Theropithecus gelada* (Gelada Baboon) and the people are keeping their promises.

The mountain range hosts 43 mammals of which 7 species are endemic (22% of the known endemic mammals in Ethiopia and Eritrea) (Saavedra *et al.*, 2009b). The endemic mammals in the study area include Ethiopian wolf (*Canis simensis*), Gelada baboon (*Theropithecus gelada*), Bailey's shrew (*Crocidura baileyi*), Long-eared bat (*Plecotus balensis*), Gray-tailed narrow-headed rat (*Stenocephalemys griseicauda*), Unstriped grass rat (*Arvicanthis abyssinicus*), and Dega rat (*Desmomys harringtoni*).

It also has 221 bird species of which 6 species are endemic (35% of the endemic bird species reported from Ethiopia and Eritrea) (Saavedra *et al.*, 2009a). The endemic bird species reported from this massif includes Yellow-fronted parrot (*Poicephalus flavifrons*), Ankober serin (*Serinus ankoberensis*), Erlanger's lark (*Calandrella erlangeri*), Abyssinian longclaw (*Macronyx flavicollis*), Black-headed siskin (*Serinus nigriceps*) and Abyssinian catbird (*Paroplasma galinieri*).

3.2. Demographics

Ethiopia has conducted a population census in 1984, 1994, and 2007. It is not possible to get the census data of Lasta district of 1984 because the National population census was done at zonal level. Even though the National population census of 1994 was done at district level, the study area was merged with other kebeles under Bugina district. As a result, the only population

data which is part of the current administrative boundary is Lalibela town with a population of 8, 484 (CSA, 1994) which almost doubled to 17, 367 in 2007 (CSA, 2007). The total population of Lasta district is about 117, 777 of which 58, 451 are men and 59, 326 women. Only 17, 367 or 14.75% are urban inhabitants (CSA, 2007).

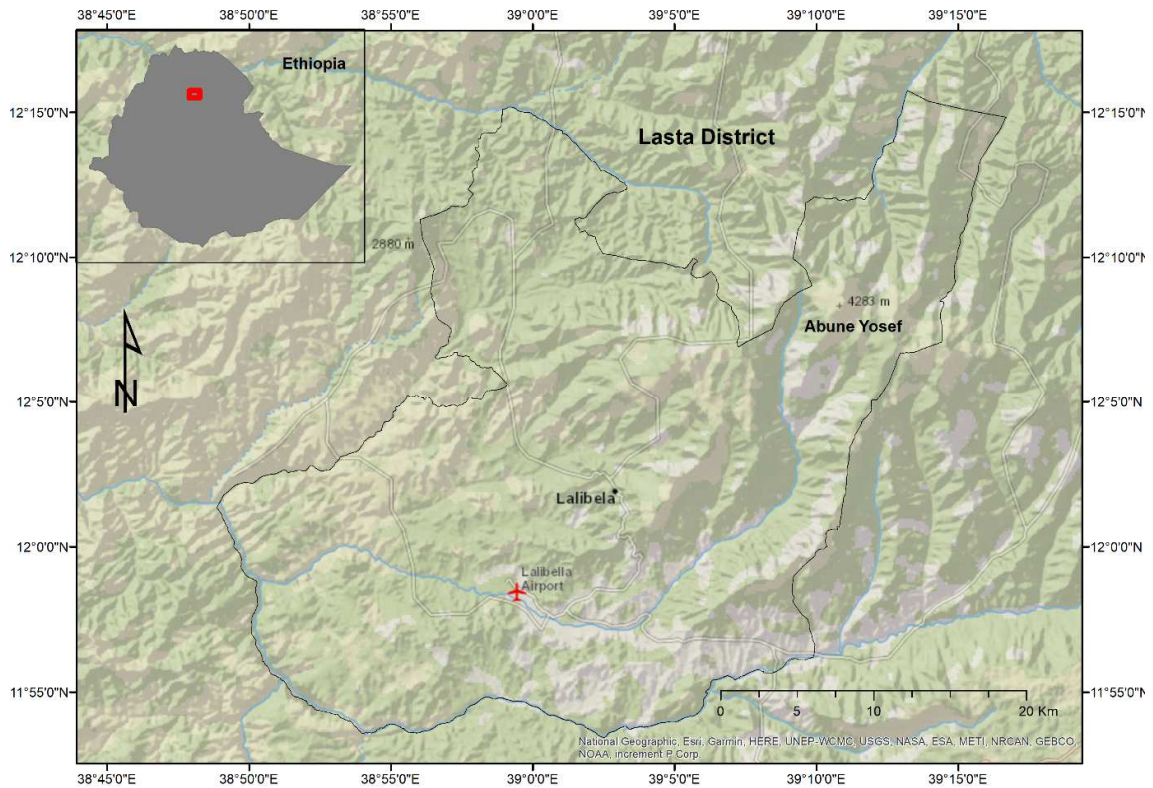


Figure 1. Map of the study area. The inset map shows Ethiopia and Lasta district.

3.3. Climate

The rainfall data of 1993-2014 was obtained from Ethiopian National Meteorological Agency (ENMA) (ENMA, 2017) Lalibela station, 2500 m a.s.l. The weather data from the gauge stations provide little information about the Afroalpine belt because it is installed at 2500 m a.s.l. Thus, the temperature data is collected from grid and satellite data from ENMA at an elevation of 4284 m a.s.l. The mean annual temperature of the study area is 19.5 °C . This corresponds to the monthly minimum and maximum temperature of 7.9 °C and 24.7 °C respectively. The climate diagram showed that the study area receives a bimodal mean annual rainfall of about 790 mm/year in which highest rainfall is received during summer

(June to September) and small rain is received during spring (March and April) (Figure 2).

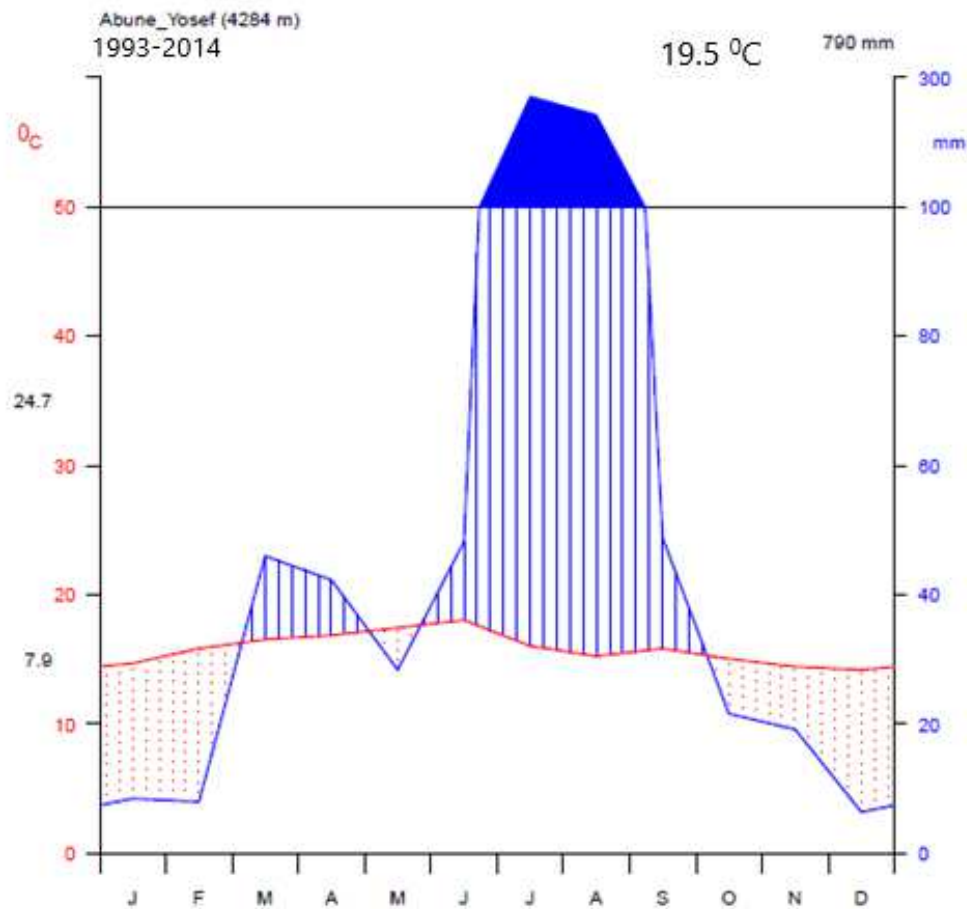


Figure 2. Climate diagram of Abune Yosef mountain range (ENMA, 2017)

3.4. Geology and Soils

The high plateaus of Ethiopia formed 45 million years ago from tertiary uplift followed by volcanism and form basalt layers (Rosqvist, 1990; Hendickx *et al.*, 2014). The Enduring volcanic activity resulted in the building up of high mountain of northern Ethiopia which includes a few of the highest peaks such as Abune Yosef mountain (Billi, 2015).

These mountains consist of a high basaltic plateau situated west of the main Ethiopian Rift (Coltorti *et al.*, 2007). These basaltic plateau are aged to the late Oligocene to early Miocene also known as Oligo-Miocene (Zanettin *et al.*, 1974). Abune Yosef mountain is geologically

characterized as Miocene volcanic rift tiled lava flows with sedimentary sequences (Abbate *et al.*, 2015).

The typical soils found at lower elevations in the basalt-dominated highlands are reddish Skeletic Cambisols and black Pellic Vertisols (Descheemaeker *et al.*, 2006; Van De Wauw *et al.*, 2008); whereas, Andosols form the prevalent soil types in the Afroalpine zone with a lower limit at 3400–3600 m a.s.l. (Hurni & Messerli, 1981; Hurni, 1989; Wesche *et al.*, 2000).

Soil research in Afroalpine and sub-Afroalpine and vegetation in Ethiopia are very scanty; except the study in the Bale Mountains (Miehe & Miehe, 1994; Menassie Gashaw & Masresha Fetene, 1996). The soils of Afroalpine belts are comparatively porous with low water-holding capacity but offering good drainage. The soil conditions in the lower part of the Afroalpine belt are different, where the closed vegetation has facilitated accumulation and retention of more fine-textured material.

The soil types of the study area are dominantly andosols. Vertisols and Ferralsols were also observed at lower elevations in the agricultural lands and bare lands. However, the harmonized world soil database version 1.2 recognized only two soil types viz. the dominant mountain soil type Leptosols and Cambisols (FAO, 2012) (Figure 3A). The soil texture triangle showed that the dominant particle size distribution is loam (Figure 3B).

3.5. Vegetation

The District consists of four potential natural vegetation types (Friis *et al.*, 2010; van Breugel *et al.*, 2015) (Figures 4A & B and Plate 1-3). These are Dry evergreen Afromontane forest and grassland complex (DAF), Ericacious Belt (EB), Afroalpine Belt (AA), and *Combretum-Terminalia* woodland and wooded grassland (CTW). Due to its unaccessibility and conversion into other land uses, particularly agricultural and shrubland, the CTW is excluded from vegetation-environment relationship study.

The lower and middle elevation are prone to anthropogenic disturbances and most of it is converted into agricultural land and settlements. The DAF is one of the overexploited ecosystems in Ethiopia and is known for its declined forest cover and shallow soil depth (Zerihun Woldu, 1999). The main reason is the prevailing climatic factors are favorable for agricultural practices and the livelihood of the people.

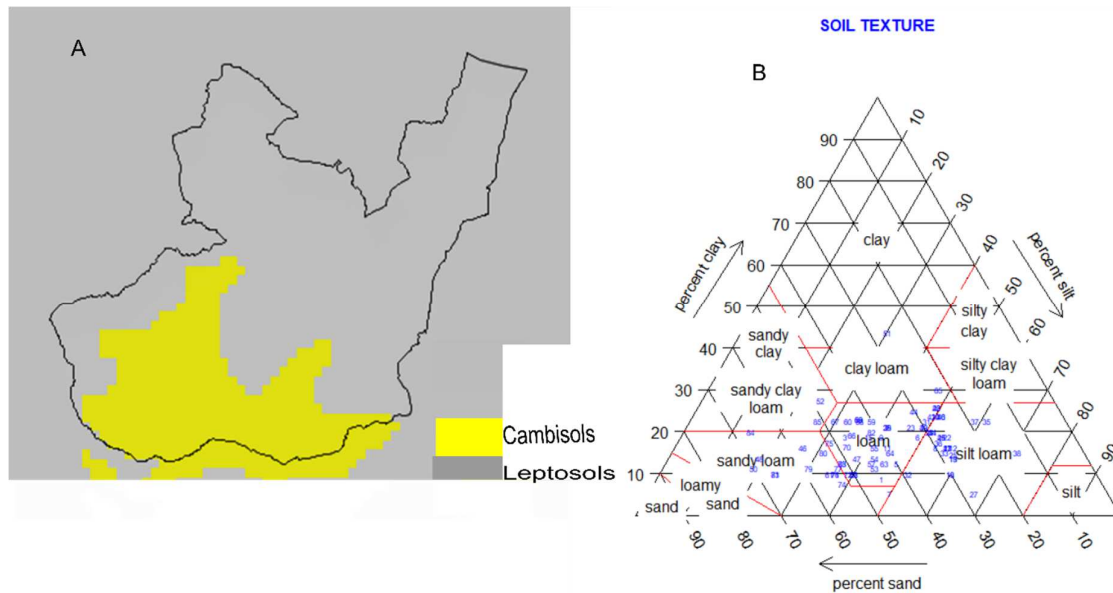


Figure 3A & B. Dominant soil types (FAO, 2012) (A) and Soil texture triangle (B) in the study area

The lower elevational belt which is moderately warm zone and highly disturbed vegetation type is found at elevations between 1,581 and 2,500 m a.s.l., is Afromontane woodland, wooded grassland and grassland (DAF/WG). Very scattered *Acacia* species such as *Acacia abyssinica*, *Acacia etbaica*, *Acacia tortilis*; *Croton macrostachyus*, *Cordia africana*, *Euclea racemosa*, *Otostegia integrifolia*, *Dodonaea angustifolia* and species such as *Hyparrhenia* spp. are commonly found in this vegetation type. *Euclea racemosa*, *Otostegia integrifolia*, and *Dodonaea angustifolia* are some of the species indicating environmental degradation.

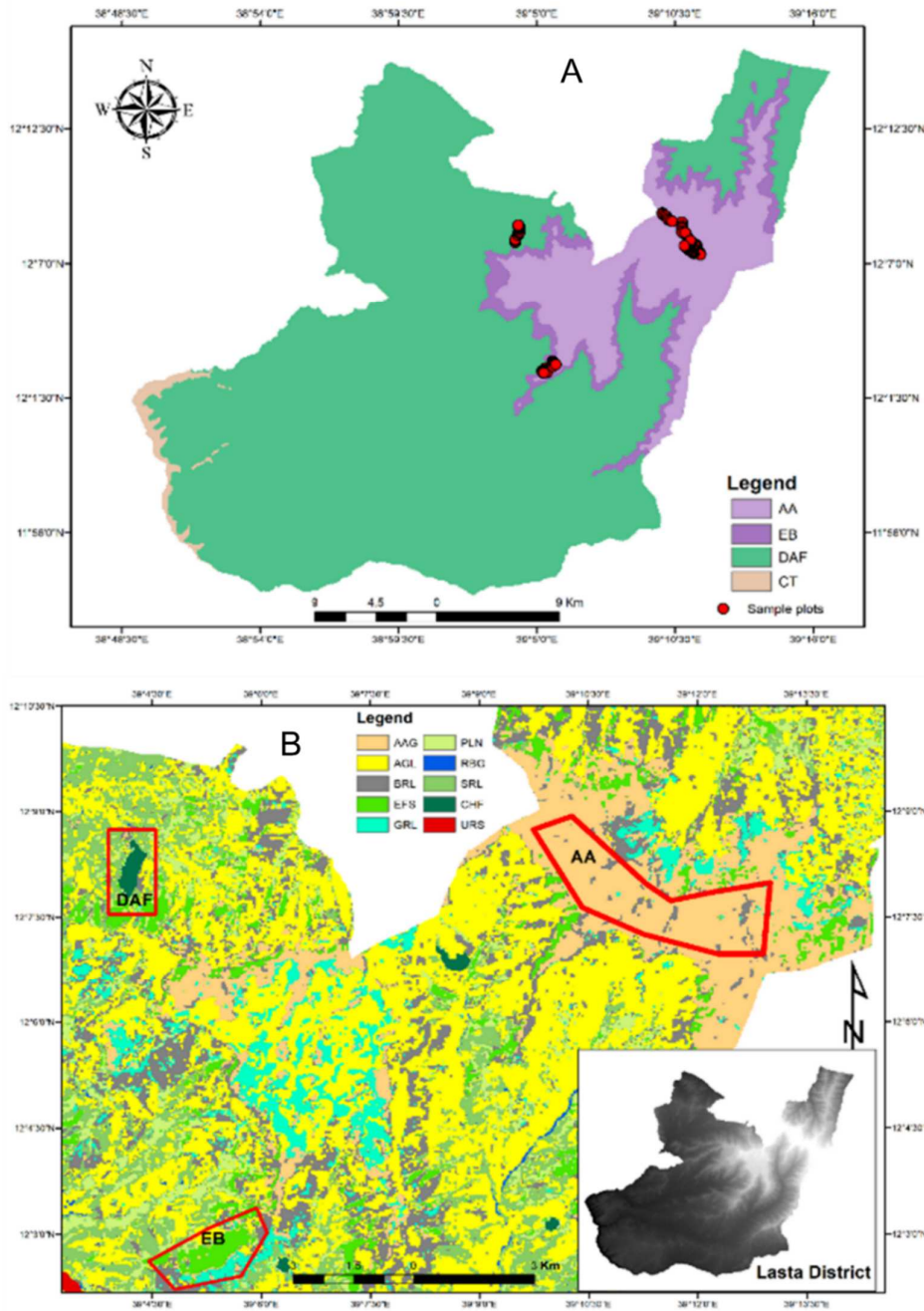


Figure 4A & B. (A) Potential natural vegetation types of Abune Yosef mountain range according to the potential natural vegetation types of Ethiopia (van Breugel *et al.*, 2015). The red dots are the sample plots for the ecological study: AA = Afroalpine vegetation, EB = Ericaceous belt, DAF = Dry evergreen Afromontane forest and grassland complex and evergreen or semi-evergreen bushland and thicket at lower margins, and CTW = Dry Combretum wooded grassland. (B) Vegetation types where ecological data were sought from: AA = Afroalpine grassland, EB = Ericaceous forest, DAF = Dry evergreen Afromontane forest and grassland complex. The legend shows the LULC classes of the study area (AAG = Afroalpine grassland, AGL = Agricultural land, BRL = Baren land, EFS = Ericaceous forest/shrub, GRL = Grazing land, PLN = Plantation forest, RBG = River, river beds and gullies, SRL = Shrubland, CHF = Church forest, and URS = Urban settlements)

Dry single-dominant Afromontane forest of the Ethiopian highlands (DAF/SD) found at elevation between 2500-3000 m a.s.l. Dry single-dominant Afromontane forest of the Ethiopian highlands (DAF/SD) vegetation type is represented by characteristic species such as *Juniperus procera*, *Olea europaea* subsp. *cuspidata*, *Acokanthera schimperi* (dominant species), *Carissa spinarum*, *Calpurnia aurea*, *Clausena anisata*, *Clutia abyssinica*, *Discopodium penninervium*, *Euclea racemosa* subsp. *schimperi*, *Grewia ferruginea*, *Maesa lanceolata*, *Myrica salicifolia*, *Psydrax schimperianum*, *Teclea nobilis*, *Rhus natalensis*, *Hagenia abyssinica*, *Hypericum revolutum* and *Urera hypselodendron* (Friis *et al.*, 2010).

However, a considerable characteristic species such as *Acokanthera schimperi*, *Clausena anisata*, *Euclea racemosa* subsp. *schimperi*, *Grewia ferruginea*, *Myrica salicifolia*, *Psydrax schimperianum*, *Teclea nobilis*, *Hagenia abyssinica*, and *Hypericum revolutum* are missing from the present study. Furthermore, *Myrica salicifolia*, *Hagenia abyssinica* and *Hypericum revolutum* were still found in the Ericaceous forest.



Plate 1A-C. Dry evergreen Afromontane forest and grassland complex vegetation type. (A & B) shows the herbaceous layer (ex. *Delphinium dasycaulon*) and the tree layer (*Juniperus procera*) and (C) shows one of the DAF characteristic woody climber i.e., *Urera hypselodendron*

Eventhough both the lower and upper limits of the Ericaceous belt may vary within a small range, the ideal range of EB is between 3000 and 3200 m a.s.l. (Friis *et al.*, 2010). Despite the elevation range differences, several authors used different terminology such as “Ericaceous belt” (Hedberg, 1964; Friis *et al.*, 2010), “Ericaceous bushland” (White, 1983) or “Ericaceous scrub” (Tewolde B. G. Egziabher, 1988; Sebsebe Demissew *et al.*, 1999). In the present study, this vegetation type is found in a very small remnant natural vegetation within a very steep slope. Hence it is disturbed and fragmented landscape which makes using the term “Ericaceous belt” difficult. Thus, in this dissertation, the term Ericaceous forest is used.

The characteristic species of this vegetation type includes *Erica arborea*, *Hypericum revolutum*, *Myrsine melanophloeos*, *Alchemilla haumannii*, *Geranium arabicum*, *Anthemis tigreensis*, *Erigeron afroalpinum*, *Haplocarpha rueppellii*, *Helichrysum citrispinum*, *Helichrysum splendidum*, *Helichrysum gofense*, *Helichrysum formosissimum*, *Senecio schultzii*, *Romulea fischeri*, *Satureja biflora*, *Thymus schimperi*, *Trifolium acaule*, *Trifolium burchellianum*, *Aloe steudneri*, *Kniphofia foliosa* and *Primula verticillata* (Friis *et al.*, 2010). Nevertheless, considerable characteristic species of the EB were found to be a characteristic species of the Afroalpine vegetation at elevation above 3700 m a.s.l. in the present study. These are *Anthemis tigreensis*, *Haplocarpha rueppellii*, *Helichrysum citrispinum*, *Senecio schultzii*, *Kniphofia foliosa* and *Primula verticillata*.

On the contrary, this vegetation type shared several characteristic species with DAF/SD. Some of the shared species comprise *Juniperus procera*, *Olea europaea* subsp. *cuspidata*, *Clusia lanceolata*, *Discopodium penninervium*, *Maesa lanceolata*, *Rhus natalensis*, *Hagenia abyssinica*, and *Hypericum revolutum*.

The elevation above 3,500 m, which is considered potentially Afroalpine belt, is much converted into agricultural land. In the Abune Yosef mountain range, the Afroalpine ecosystem has been reduced over the last decades and it currently remains above 3700 m a.s.l. Agricultural practices are not uncommon at an elevation of near 3800 m a.s.l. Currently, the Afroalpine ecosystem covers only 3700 ha.

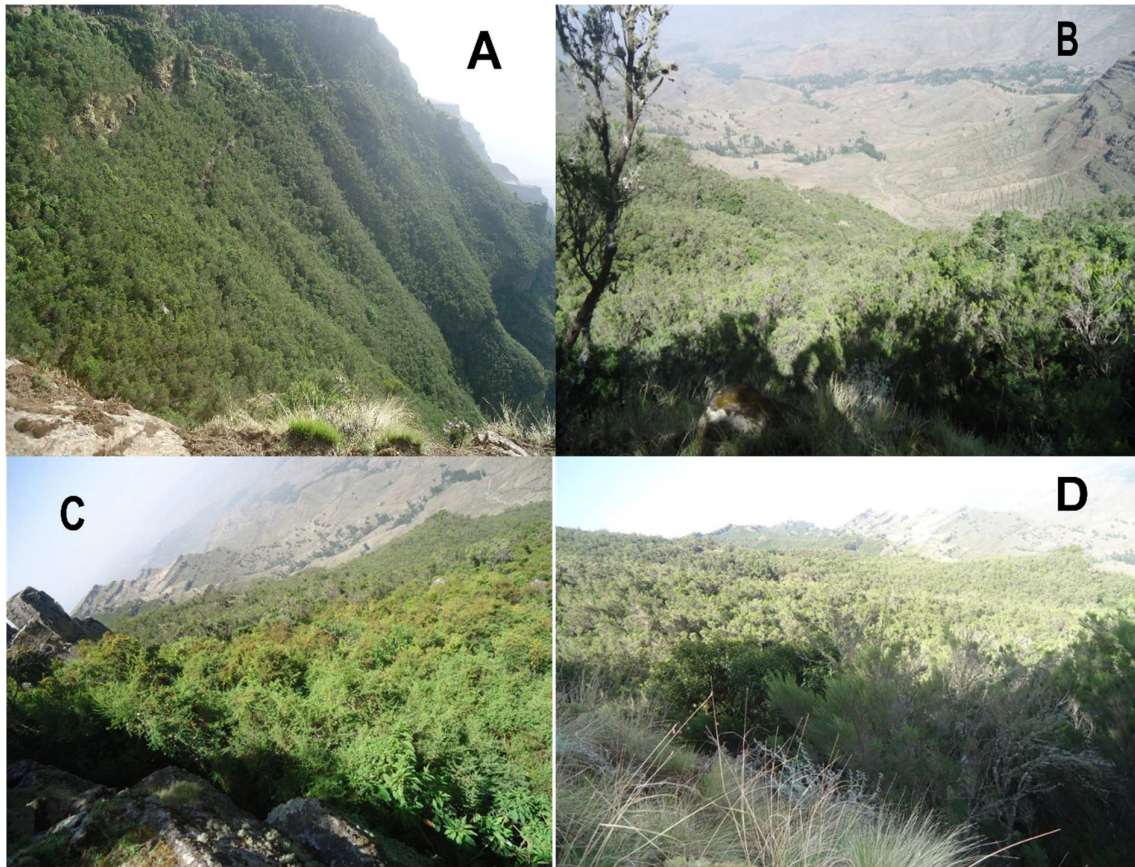


Plate 2A-D: The Ericaceous forest in the EB. (A) Shows the steep slope, (B) & (C) partly shows the *Erica* dominated forest and adjacent agricultural land, and (D) shows *Festuca* species at the forest margin.

The Afroalpine belt is characterized by its large numbers of geographically vicarious taxa and high endemic plant species (Hedberg, 1969). The Afroalpine belt host plant species with life forms often different from the other vegetation types (Hedberg, 1964). These life forms are giant rosette plants, tussock grasses (and sedges), acaulescent rosette plants, cushion plants, and sclerophyllous shrubs (and dwarf-shrubs). Although Friis *et al.* (2010) reported that the lower belt is dominated by small trees and shrubs, the Afroalpine vegetation in the present

study which is dominantly above 3700 m a.s.l. is above tree line. However, some tree species such as *Juniperus procera* and *Hagenia anyssinica* were observed around Abune Yosef monastery and homesteads at an elevation about 3700 m a.s.l.

The characteristic species of this vegetation type are mostly herbs such as the giant *Lobelia rhynchopetalum*, *Carex monostachya*, and *Festuca* spp. The conspicuous and endemic giant *L. rhynchopetalum* was not previously reported from Welo floristic region (WU). However, it is very common in the Afroalpine belt.

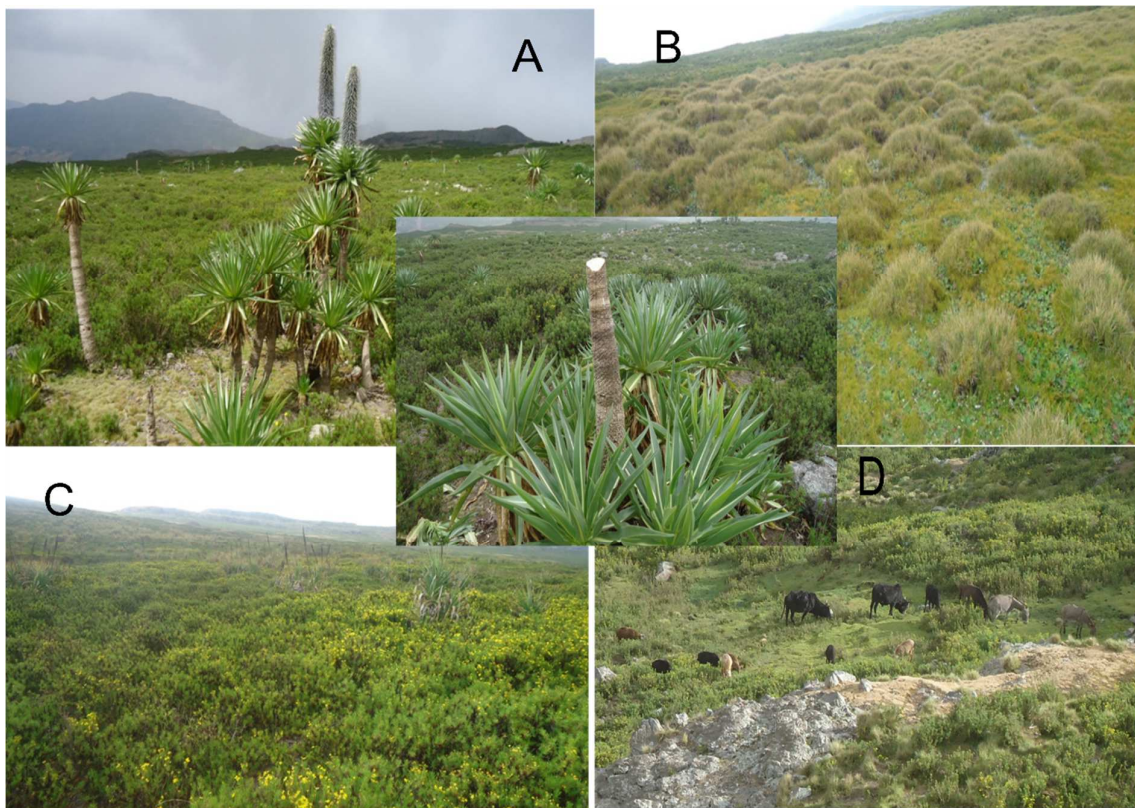


Plate 3A-D: Afroalpine Belt Vegetation type. (A) Shows the giant Lobelia (*Lobelia rhynchopetalum*), (B) shows the herbaceous plant *Carex monostachya*, (C) shows the dominant shrub/subshrub (*Euryops pinifolius*) of the AA, and (D) shows the livestock grazing at the plateau of the mountain and stump of *Lobelia rhynchopetalum*.

3.6. Data collection methods

3.6.1. Vegetation data collection

A reconnaissance survey was made in March 2016 to select appropriate sites. A combination of preferential and systematic sampling method was employed to collect vascular plants and

environmental data. The preferential method was chosen to select the remnant natural or semi-natural vegetation distributed in the fragmented landscape due to two reasons. The vegetation types that appear were typical to the researcher and these were the only one readily available (Orloci and Kenkel, 1987). The systematic sampling was, however, to establish the sample plots in each vegetation types. Hence, the analysis was performed based on the data extracted from the systematic sampling. Sample plots of 20 m X 20 m, 5 m X 5 m and 1 m X 1 m for trees, shrubs, and herbs respectively were established (Mueller-Dombois & Ellenberg, 1974) at 100 m interval in different vegetation types namely DAF/SD, EB, and AA (Table 2). Sample plots for the herbs were collected from five replicates i.e., four at each corner and one at the center. Vascular plants in all sample plots were recorded. Vascular plants in the surrounding but absent in the sample plots were recorded for the floristic list.

Vegetation data required for plant community structure (frequency, density, and dominance) were recorded. Diameter at Breast Height (DBH) at 1.3 m was measured using diameter tape for all tree species. Basal area was calculated from DBH. On the other hand, Importance Value Index (IVI) was computed from the summation of relative frequency, relative density, and relative dominance. Species cover abundance in each sample plot was estimated visually in the field and later transformed according to van der Maarel (1979) ordinal transform values (OTV).

Plant specimen identification was performed both *in situ* and in the national herbarium following flora of Ethiopia and Eritrea (FEE) (volume 1-8). For some species regional floras such as Flora of Tropical East Africa were consulted. All plant specimens are deposited in the National Herbarium (ETH).

3.6.2. Environmental and Anthropogenic disturbance data collection

Environmental variables data, which could have either a direct or an indirect impact on vegetation, were collected. These are; elevation, slope, aspect, soil texture, bulk density, soil pH, Organic Carbon (SOC), total Nitrogen (TN), and available phosphorus (avP).

- a. Elevation and Aspect: Elevation and aspect of each sample plot were recorded using hand-held Garmin GPS72H and Suunto compass respectively. Aspect was given a code according to Zerihun Woldu *et al.* (1989) N = 0; E = 2; S = 4; W = 2.5; and Tamrat Bekele (1994) NE = 1; SE = 3; SW = 3.3 and NW = 1.3. The latitude and longitude plus UTM coordinate were also recorded.
- b. Slope: the slope was measured by using Clinometer.
- c. Soil samples were taken from five subplots of the sample plots laid for vegetation sampling at a depth of 0-30 cm. Soil samples from subplots were mixed to form soil composite and only one sample was taken for analysis.
- d. In order to determine the anthropogenic disturbances, the following parameters were considered. These are tree/shrub logging and grazing. The parameters were codified conventionally as tree/shrub logging (0 = no logged shrub/tree, $1 \leq 2$, $2 \leq 4$, and $3 \geq 5$). Visual observation of the ground, domestic animals' dung, and footprints were considered for estimating the livestock grazing intensity. Local people were also consulted to identify if the dungs and some footprints are either from livestock or wild animals so as assign the ordinal scale. Thus, the level of livestock grazing was given a conventional range as a slight modification of Kebrom Tekle *et al.* (1997); and Zerihun Woldu & Backéus (1991) i.e., 1 = slight grazing intensity, 2 = moderate grazing intensity, 3 = heavy grazing intensity.

Table 2. Vegetation types characteristics from where data were sought

Characteristics of vegetation types		DAF/SD	EB	AA
Plots sampled		15 (17.65%)	25 (29.41%)	45 (52.94%)
Area (ha) sampled		0.6	1	0.1
Elevation (m a.s.l.)	Range	2571-2973	3014-3285	3834-4168
	Mean	2740.6±131.5	3189.7±71.2	3993.2±95.7
Slope range (°)		3-20	2-35	5-24
Disturbance level		Medium	Medium	High
Management type		Church forest	*Privately managed	Community-based conservation

*It is only protected privately with no guidelines set on the management and utilization

3.6.3. Plants conservation status

The global conservation status of plants in the study area was assessed based on the IUCN Red List of threatened species (Viswanathan 1986; IUCN, 1997; Oldfield *et al.* 1998; Vivero *et al.* 2005).

The application of IUCN Red List criteria for local conservation status assessment could not be managed due to time, available data, geography, expertise, and budget constraints. Consequently, an alternative method, point-scoring method, which incorporates total density of mature individuals, species range and habitat specificity (Table 3) was employed to assess the local conservation status or rarity of plants in Abune Yosef mountain range. This is a slight modification of the seven forms of rarity (Rabinowitz, 1981) to suit the landscape of the study area. The lower the score the higher priority for conservation i.e., scarce density of mature individuals, restricted habitat specificity and species local range.

Total density of mature individuals: it is the number of individuals known to be capable of reproduction. Species with more than 100 mature individuals is abundant whereas those with less than 100 individuals are said to be scarce.

Species local range (realized range): it is the elevation range where the species is currently found in the mountain range. A species is considered widely distributed if it is at least found along an elevation of greater than 500 m. On the contrary, narrow distribution is related to a realized range of a species of less than 500 m.

Habitat specificity: habitat specificity mainly refers to the particular vegetation type where the species is currently found. If a species is found in only one vegetation type, its habitat specificity is restricted. On the other hand, widespread habitat specificity is related to the distribution of a species in more than two vegetation type.

Table 3. Rabinowitz’s rarity forms (RF = rarity form)

Specie local range	Wide		Restricted	
	Widespread	Restricted	Widespread	Restricted
Habitat specificity	Widespread	Restricted	Widespread	Restricted
Abundant population	Common	RF2	RF4	RF6
Scarce population	RF1	RF3	RF5	RF7

RF1: It is characterized by a low density of mature individuals, wide species realized range, and widespread habitat specificity.

RF2: This rarity type is described by a wide species realized range, restricted habitat specificity, and abundant mature individuals.

RF3: The third rarity type of rarity form is explained as a low (scarce) density of matured individuals, wide species local range, and restricted habitat specificity.

RF4: The fourth Rabinowitz’s rarity form is explained as widespread habitat specificity, abundant density of matured individuals, and restricted species local range.

RF5: The fifth Rabinowitz’s rarity form is explained as widespread habitat specificity, scarce density of matured individuals, and restricted species local range.

RF6: The sixth rarity form is explained as restricted habitat specificity, abundant density of matured individuals, and restricted species local range.

RF7: This rarity form is explained as restricted habitat specificity, scarce density of matured individuals, and restricted species local range.

3.6.4. Land use and Land cover change

Eventhough the ecological study encompasses three vegetation types, the LULCC study covers the whole district. However, emphasis was given to the vegetation types in which the ecological study was performed. Geo-processed satellite images were obtained from United States Geological Survey (USGS) Earth Explorer homepage (<http://earthexplorer.usgs.gov/>). Whereas, aerial photographs were collected from EMA.

3.6.4.1. Data acquisition

Two Landsat satellite imageries from 1986 (Thematic Mapper, TM) and 2017 (Operational Land Imager, OLI) were downloaded from the United States Geological Survey (USGS) Earth Explorer (<https://earthexplorer.usgs.gov/>). Aerial photographs were obtained from Ethiopian Mapping Agency (EMA) and used for ground referencing of the 1986 satellite image. Detailed information about the satellite imageries used is shown in Table 4.

Table 4. Information about earth observation data used in this study

Path & Row	Date of acquisition	Earth observation data	Image resolution/scale
Path 169, Row 052	1986-01-28	Thematic Mapper, TM	30m
	2017-02-02	Operational Land Imager, OLI	30m
	1982	Aerial Photograph	1:50,000

3.6.4.2. Image preprocessing, image classification, change detection and accuracy assessment

The overall analysis of image pre-processing, classification, change detection and accuracy assessment was performed based on the designed conceptual framework demonstrated in Figure 5.

3.6.4.2.1. Image pre-processing

The digital numbers of the satellite imageries of 1986 were converted to radiance (equation 5) and then to reflectance (equation 6) and the radiance of the satellite image of 2017 was converted to reflectance (equation 7 & 8) before processing classification.

$$L_{\lambda} = \left(\frac{L_{MAX\lambda} - L_{MIN\lambda}}{Q_{CALMAX} - Q_{CALMIN}} \right) * (Q_{CAL} - Q_{CALMIN}) + L_{MIN\lambda} \quad (5)$$

Where L = Spectral radiance, L_{MAX} =Highest radiance, L_{MIN} = Lowest radiance, Q_{CALMAX} = Calibrated maximum cell values, Q_{CALMIN} = Calibrated minimum cell values, Q_{CAL} = Digital number

$$\rho_{\lambda} = \frac{\pi * L_{\lambda} * d^2}{ESUN_{\lambda} * \cos\theta_s} \quad (6)$$

Where ρ_{λ} =Reflectance, L_{λ} =Spectral radiance, d = Distance from the earth to the sun, $ESUN_{\lambda}$ = Mean solar exoatmospheric irradiance, θ_s = Solar zenith angle=90-sun elevation

$$R_i' = M_i Q_{cal} + A_{\rho} \quad (7)$$

Where R_i' = Reflectance without correction for solar angle, M_L = Band-specific multiplicative rescaling factor from the metadata, Q_{cal} = Quantized and calibrated standard product pixel

values (DN), $A\rho$ = Band-specific additive rescaling factor from the metadata

$$R_l = \frac{R_l'}{\cos(\text{solar zenith angle})} \quad (8)$$

Where R_l = Reflectance, R_l' = Reflectance without correction, Solar Zenith angle = 90 - Solar Elevation angle

The aerial photographs were scanned with a photographic scanner at 300 dots per inch (dpi) and saved in Tif format. The autosync tool in ERDAS IMAGINE 2015 was used for georeferencing and orthorectification of the aerial photographs. An orthorectified aerial photographs mosaic covering the study area were created. Because the orthorectification was performed in synchrony with the digital elevation model (DEM), it improved the accuracy of the aerial imagery and terrain distortions.

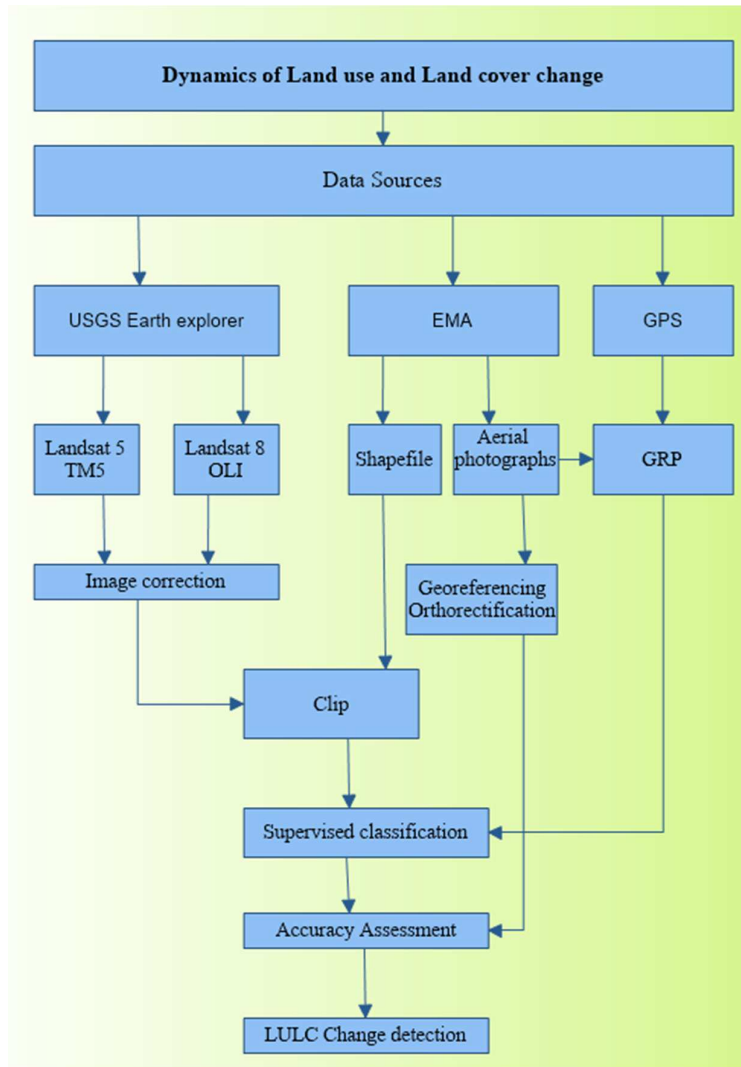


Figure 5. A conceptual framework for LULCC Analysis

3.6.4.2.2. Image classification and change detection

A supervised classification approach using a maximum likelihood algorithm was employed to classify the images based on the ground reference points collected. Supervised classification allowed us to categorize the landscape according to ground reference points of land use land and cover classes that are of high interest in the region for the ecosystem services and functions provided (Table 5). Ground reference points were collected from field survey using GPS with ± 5 m accuracy. These were supplemented with few ground reference points taken from Google Earth because the lowlands were largely inaccessible. Even though Congalton (1991) recommended at least 50 ground reference points for each class, the present study used 30-50 ground reference points by considering the cover of each LULC classes. Image classification was conducted using the Image Analysis toolbar in ArcGIS 10.5.

Table 5. Description of land use and land cover classes

No.	Land use and land cover type	Description	Code
1	Afroalpine Grassland	<i>Lobelia rhynchopetalum</i> , <i>Euryops pinifolius</i> , <i>Alchemilla</i> species, and <i>Festuca</i> species are the dominant species. It is found above 3500 m.a.s.l.	AAG
2	Ericaceous Forest/Shrubland	<i>Erica arborea</i> , <i>Hypericum quartinianum</i> , <i>Myrica salicifolia</i> , <i>Rosa abyssinica</i> etc. are some of the dominant species in this land cover type. It is found between 3000 and 3300 m a.s.l.	EFS
3	Church Forest*	Some characteristic species of dry evergreen Afromontane forests are found in this area such as <i>Juniperus procera</i> , <i>Allophylus abyssinica</i> , and <i>Olea europaea</i> subsp. <i>cuspidata</i> . It is found surrounding the Ethiopian Orthodox churches.	CHF
4	Plantation forest	<i>Eucalyptus</i> and <i>Cupressus</i> plantations which cover above 0.5 ha	PLN
5	Shrubland	<i>Euclea racemosa</i> , <i>Dodonaea angustifolia</i> , <i>Senna singueana</i> , and <i>Otostegia integrifolia</i> are the dominant species. Plants less than two meters high, with crown cover less than 10%.	SBL
6	Agricultural land	Arable or fallow land of annual crops	AGL
7	Grazing Land	Grasslands which primarily serves as grazing land for livestock	GRL
8	Urban settlements	Urban areas including towns, industries, and other institutions	URS
9	Barren Land	Areas dominated by exposed soils or bedrocks	BRL
10	Rivers, riverbeds & gullies	Rivers are either annual, biannual or perennial. Riverbeds are bare of water when the river is dry. However, gullies are areas created by erosion which are often bare of water.	RBG
11	Open Woodland	Land covered by herbaceous vegetation with scattered trees where the canopy cover is less than 3%	WDL

* “Land spanning at least 0.5 ha covered by trees and bamboo, attaining a height of at least 2 m and a canopy cover of at least 20% or trees with the potential to reach these thresholds in situ in due course” (MEFCC, 2016).

3.6.4.2.3. Accuracy assessment

An accuracy assessment was conducted before analyzing the change (Congalton & Green, 2009). A confusion matrix for 2017 image using ground reference data was created. The reference data for the 1986 image was collected from 56 aerial photographs obtained from the Ethiopian Mapping Agency. Fifty six photograph scenes were brought from EMA; georeferenced and orthorectified using 30 m DEM. Stratified random sampling was applied to generate random points and assess classification accuracy. Stratified random sampling affords the option to increase the sample size in classes that occupy a small proportion of an area to reduce the standard errors of the class-specific accuracy estimates for these rare classes (Olofsson *et al.*, 2014).

3.6.4.2.4. Driving forces, Pressures, State, Impact and Response (DPSIR) Framework

A semi-quantitative DPSIR framework (Smeets & Weterings, 1999) was used to address the causes of LULCC as demonstrated in the scheme (Figure 6). This framework was designed to assess the relationship between driving forces such as population and climate change and pressures such as agricultural expansion and unsustainable resource utilization. These interrelationships cause transformations in land use and land cover, which affects ecosystem goods and services; and human wellbeing. A robust application of this framework connects the driving forces and pressures with policy measures to address them. Climate data (precipitation and temperature) spanning 22 years (1993 – 2014) were retrieved from the Ethiopian National Metrological Agency. Furthermore, population data were obtained from central statistical agency of Ethiopia.

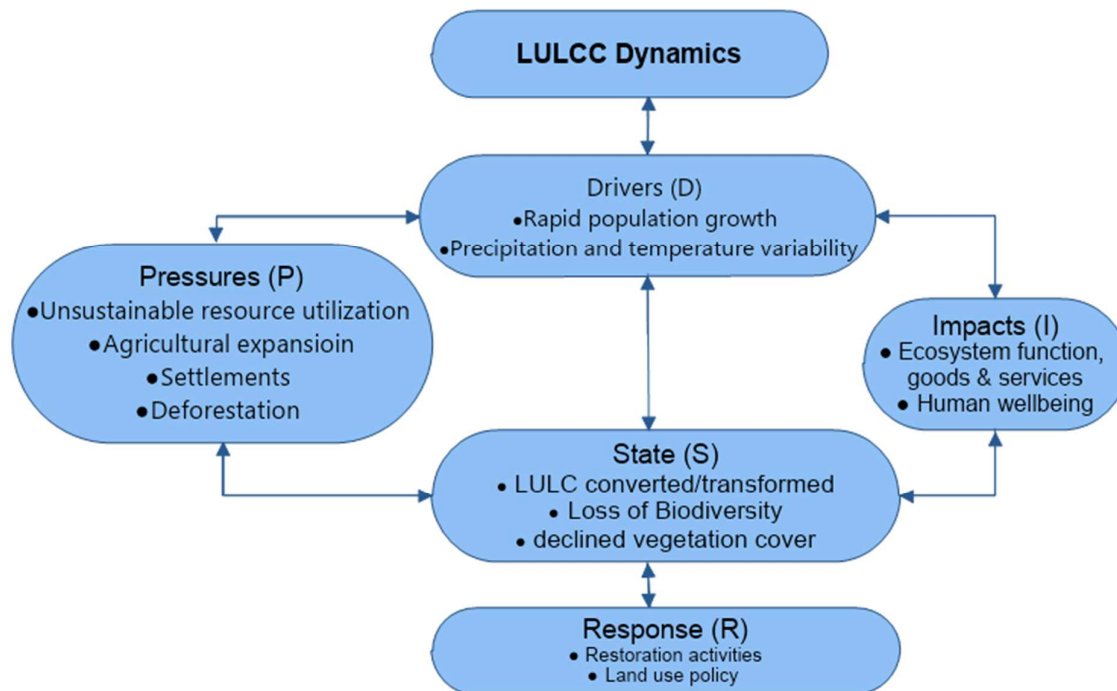


Figure 6. DPSIR Framework modified from Smeets and Weterings (1999)

3.7. Data analysis

3.7.1. Plant community structure

Structural parameters (relative frequency, relative density, dominance, basal area, and IVI) were computed following the formula described by Kent (2012). The basal area and population structure were analyzed only for tree species with DBH \geq 2.5 cm. A bar graph of DBH classes was generated.

3.7.2. Plant community classification

Plant community classification was achieved through cluster analysis using agglomerative hierarchical clustering (AHC) using Ward's minimum variance clustering methods (Borcard *et al.*, 2018). Association of species and sample plots was described by indicator species (Cáceres & Legendre, 2009). Plant community clusters or groups were tested by using Multi-Response Permutation Procedure (MRPP). The distance matrix used for classification and MRPP is the same. Plant community names were assigned based on synoptic cover-abundance value. The analysis was done using R version 3.5 (R Core Team, 2018). The R packages used for the

analysis are *Vegan*, *ecodist*, *cluster*, *ggplot2*, *labdsv*, *dendextend*, *Scales*, *lattice*, *latticeExtra*, *BiodiversityR*, *grid*, and *indicspecies* (Zerihun Woldu, 2017; R Core Team, 2018).

3.7.2.1. Vascular plants species richness and diversity

To estimate vascular community diversity and evenness, Shannon-Wiener index of diversity and evenness was computed. Species richness estimation and rarefaction were computed by using *vegan* package and function *estimateR*. The relationship between elevation and species richness, Chao1, ACE, and growth forms was better determined by running linear models (LMs).

3.7.2.2. Vascular plant species turnover (β -Diversity)

Vascular species turnover (β – diversity) along the elevation gradient were determined following Wilson and Shmida (1984) which is quantified as (equation 9):

$$\beta_T = \frac{b + c}{2a + b + c} \quad (9)$$

where β_T is Wilson and Shmida's beta diversity/turnover, a is the total number of species that occur in both sites, b represents species occurring exclusively in the second site, and c those found only in the focal site. This diversity index is chosen because it is not influenced by alpha diversity and sample size.

Comparison of floristic composition of the three vegetation types was computed following Sørensen's coefficient of similarity (Sørensen, 1948) (equation 10). It is calculated as:

$$S = \frac{2a}{2a+b+c} \quad (10)$$

Where a = the species found both in site b and c, b = the species found in site b, and c = the species found in site c. The closer Sørensen's coefficient of similarity to 1 the more similar the sites are. This similarity coefficient was selected because it gives weight to species that exist in both sites. Outliers, seven species that present in all vegetation types are removed from the analysis.

The plant diversity, endemic richness and vascular plant species richness of the vegetation

types were compared using one-way analysis of variance (ANOVA) and Tukey's honestly significant difference [HSD] test.

3.7.3. Soil analysis

Soil samples were oven dried at 105 °C for up to 24-48 hours. The samples were sieved to remove the coarse soil particles, and the <2 mm fraction was analyzed for physical and chemical properties. The following soil physical and chemical properties were analyzed.

- a. Soil texture: The soil particle was determined following the Bouyoucos hydrometer method.
- b. Bulk density: the bulk density was measured following bulk density measurement of forest soils by Maynard & Curran (2008).
- c. Soil pH: Standard measurement of soil pH in water 1:25 (w/v) method was followed.
- d. Soil Organic Carbon (SOC): to determine soil organic Carbon the Walkley & Black (1934) procedure was followed.
- e. Total Nitrogen (TN): it was determined by Micro-Kjeldahl digestion method.
- f. Available phosphorus (avP): to determine available phosphorus Bray II method was used.

3.7.4. Multivariate numerical analysis

3.7.4.1. Data analysis: Statistics and Ordination

Descriptive statistics such as minimum, maximum, mean, and standard deviation were computed for all environmental variables except for the nominal and ordinal variables (slope aspect, grazing and logging). Furthermore, pair-wise Pearson's correlation coefficient of the environmental variables were also computed.

3.7.4.2. Canonical Correspondence Analysis

If the length of the first axis, which is considered to be the measure of heterogeneity, is longer than 4 in DCA, it is assumed that the data set is heterogeneous and is suitable for unimodal richness pattern (Zelený, 2018). Furthermore, Zerihun Woldu (2017) claimed the unimodal

model is appropriate for high species turnover and is closer to the reality of ecological data along a long gradient.

3.7.5. Plant conservation status

Habitat specificity, density of mature individuals, and species local range were computed for each species. Descriptive statistics were used to analyze the rarity forms (local rarity) and global conservation status of the vascular plants.

3.7.6. Land use and Land cover change

The common post-classification comparison change detection approach was used to compare maps of the different years sources and provides detailed “from-to” change class (Ermias Teferi *et al.*, 2013). It is explained in the extent of change on hectare (ha) basis, percent and rate of change. The percent and rate of LULCC were computed for each LULC classes based on equation 11 and 12.

$$PoC = \frac{A2 - A1}{A1} \times 100 \quad (11)$$

$$RoC = \frac{A2 - A1}{A1} \times \frac{1}{(T2 - T1)} \times 100 \quad (12)$$

Where RoC = rate of change, PoC = percentage of change of a particular LULC class, A1 = area of the previous land use and land cover class, A2 = area of the recent land use and land cover class and T2 = current year, and T1 = previous year.

CHAPTER FOUR

4. RESULTS

4.1. Taxonomic composition

One hundred ninety nine vascular plant species belonging to 64 families and 155 genera were recorded in Abune Yosef mountain range (Appendix I). The most species rich families Asteraceae 42 (21.1%), Poaceae 15 (7.5%), Lamiaceae 12 (6.03%) and Fabaceae 11 (5.5%) comprise about 41% of the species recorded. On the other hand, thirty-two families were represented by a single species. Of these 21 percent are endemic. This consists of 7.7% of the 544 endemic vascular plants of the FEE. Thirteen species, with 2 endemic species, distributed in 11 families were also recorded outside the plots established (Appendix I).

The growth form showed trees, shrubs, herbs, and lianas comprise 17 (8.54%), 32 (16.08%), 146 (73.37%) and 4 (2.01%) respectively. Although very few species have a wide distribution, most of the species have a very restricted distribution along the elevation gradient.

4.2. New records to the floristic region

Welo floristic region (WU) is one of the 16 floristic regions in the flora of Ethiopia and Eritrea. About 93 (44%) of the vascular plant species are new records to WU (Appendix I). These are distributed in 32 families and 89 genera. Furthermore, 22 endemic vascular plant species were also documented as new records to this floristic region. *Lobelia rhynchopetalum*, *Arisaema polydactylum*, *Bartsia decurva*, *Carex monostachya*, *Cotula abyssinica*, *Festuca macrophylla*, *Haplocarpha rueppellii*, *Helichrysum citrispinum*, *Impatiens rothii*, *Primula verticillata*, and *Oreophyton falcatum* are some of the new records to WU floristic region.

4.3. New record to the flora of Ethiopia and Eritrea

A new species, *Papaver* aff. *decaisnei* Hochst. ex Steud (Papaveraceae) (Figure 7) is recorded from the Afroalpine Belt. The lectotype of this plant is found in Naturalis Biodiversity Centre, formerly Leiden University (L). The lectotype revealed the specimen was collected from Tigray

(TU), Sinai. However, there is no place known to be Sinai in Tigray. Furthermore, there is no geographic coordinates in the lectotype. Globally, it is distributed in Egypt, Gulf States, Pakistan, Iran, Palestine, Saudi Arabia, Russian Federation, Jordan, and Sinai.



Figure 7. *Papaver aff. decaisnei*

4.4. Plant community structure

4.4.1. Frequency

The most frequent species in the study area were found to be *Erica arborea* and *Euryops pinifolius* consisting a relative frequency of 96 and 89% respectively. Few species (8%) including *Becium grandiflorum*, *Achyranthes aspera*, *Clutia lanceolata*, *Juniperus procera* and *Rosa abyssinica* have a relative frequency of > 50%. However, the majority (92%) of the species such as *Artemisia schimperi*, *Carduus macracanthus*, *Rhamnus staddo*, *Oreophyton falcatum*, and *Herniaria abyssinica* have a relative frequency of $\leq 50\%$. The DAF and EB were accompanied by species with relatively higher frequency than the Afroalpine grassland.

4.4.2. Density

The total density of trees and shrub species with DBH \geq 2.5 cm was found to be 761.76 stem ha⁻¹. *Erica arborea* and *Juniperus procera* accounted for about 20.84% and 14.62 % of the total density in the study area. Several species such as *Maytenus arbutifolia*, *Maesa lanceolata*, *Rhus retinorrhoea*, *Dombeya torrida*, *Rhamnus staddo*, *Ficus vasta*, and *Ficus sycomorus* accounted for less than one percent of the total density in the study area.

4.4.3. Importance Value Index (IVI)

The highest and lowest IVI of the tree species was found to be 126.64 for *Erica arborea* and 4.46 for *Rhus natalensis* respectively. About 58.8% of the tree species have IVI above 20 while the remaining 41.2% have IVI of less than 20 (Table 6).

Table 6. IVI of the tree species (RF=Relative frequency, RD=Relative Density, RDO=Relative Dominance, and IVI= Importance Value Index)

S. No.	Species	RF	RD	RDO	IVI
1	<i>Allophylus abyssinicus</i>	13	1.27	0.13	14.4
2	<i>Bersama abyssinica</i>	7	0.21	0.12	7.33
3	<i>Discopodium penninervium</i>	25	4.23	0.09	29.32
4	<i>Dombeya torrida</i>	7	0.21	0.30	7.51
5	<i>Erica arborea</i>	96	30.44	0.20	126.64
6	<i>Ficus sycomorus</i>	7	0.21	0.65	7.86
7	<i>Ficus vasta</i>	7	0.21	0.01	7.22
8	<i>Hagenia abyssinica</i>	8	1.06	0.38	9.44
9	<i>Hypericum quartinianum</i>	16	5.29	0.16	21.45
10	<i>Juniperus procera</i>	56	21.35	0.43	77.78
11	<i>Hypericum revolutum</i>	63	3.59	3.78	70.37
12	<i>Myrica salicifolia</i>	36	3.59	0.71	40.3
13	<i>Nuxia congesta</i>	20	2.96	0.13	23.09
14	<i>Olea europaea</i> subsp. <i>cuspidata</i>	28	0.21	0.84	29.05
15	<i>Rhus natalensis</i>	4	0.42	0.04	4.46
16	<i>Rhus retinorrhoea</i>	5	18.39	0.02	23.41
17	<i>Vernonia rueppellii</i>	52	6.34	0.20	58.54

4.4.4. Diameter at Breast Height and Basal Area

The study area is dominated by small or medium DBH size trees (Figure 8). The first DBH class, 2.5-10 cm, consists of about 50% of the total DBH sizes followed by the second DBH size class, 10.5-18.5 cm, which accounted for about 18% of the DBH size classes. The DBH size class above 50 cm comprised only about 12%. This is also dominated by few tree species such as *J. procera*, *H. revolutum*, *H. quartinianum*, and *M. salicifolia*.

The basal area of tree species with DBH > 2.5 cm was found to be 18.54 m² ha⁻¹. The basal area is entirely attributed to the DAF and EB since the plants with DBH ≥ 2.5 cm were entirely recorded from these vegetation types. *Juniperus procera*, *Erica arborea*, *Hypericum revolutum*, *Hypericum quartinianum*, *Vernonia rueppellii*, and *Discopodium penninervium* contributed the most to the basal area of the present study.

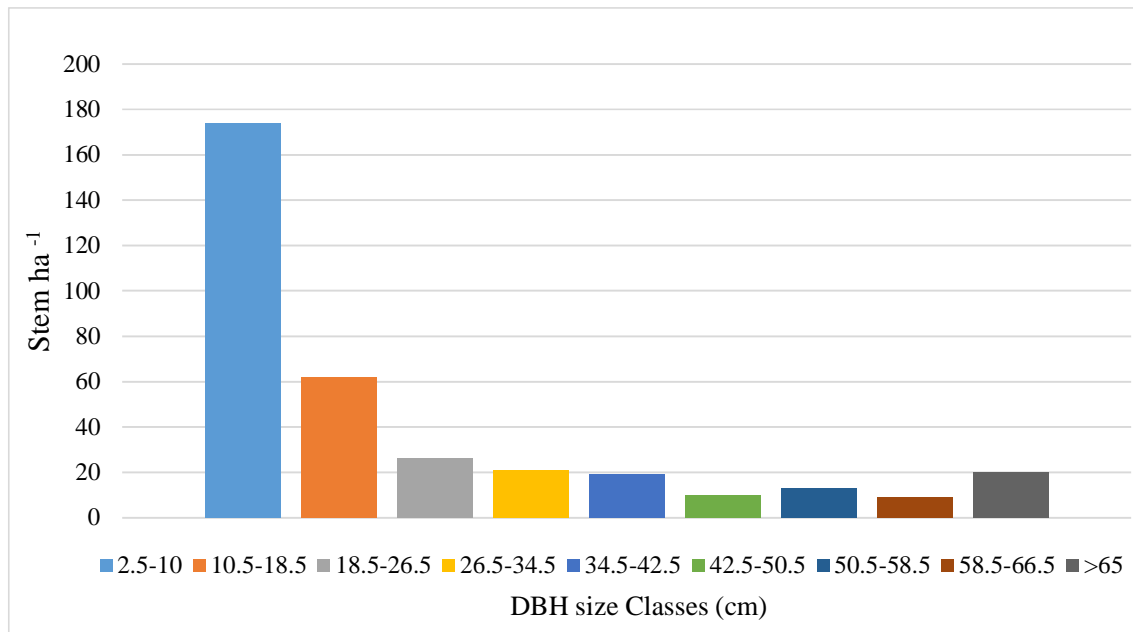


Figure 8. DBH size Classes distribution (cm)

4.4.5. Population structure of some selected tree species

The population structure of the selected tree species revealed either a reverse J-shape or J-shape pattern. *Erica arborea*, *O. europaea* subsp. *cuspidata*, *N. congesta*, and *H. revolutum* followed a reverse J-shaped population structure. On the contrary *J. procera* followed J-shaped

population structure (Figure 9). Plant species such as *M. salcifolia* showed an episodic recruitment with relatively high individuals in the lower DBH size classes than the higher DBH size classes. However, some DBH size classes both in the lower and higher are episodic/missing.

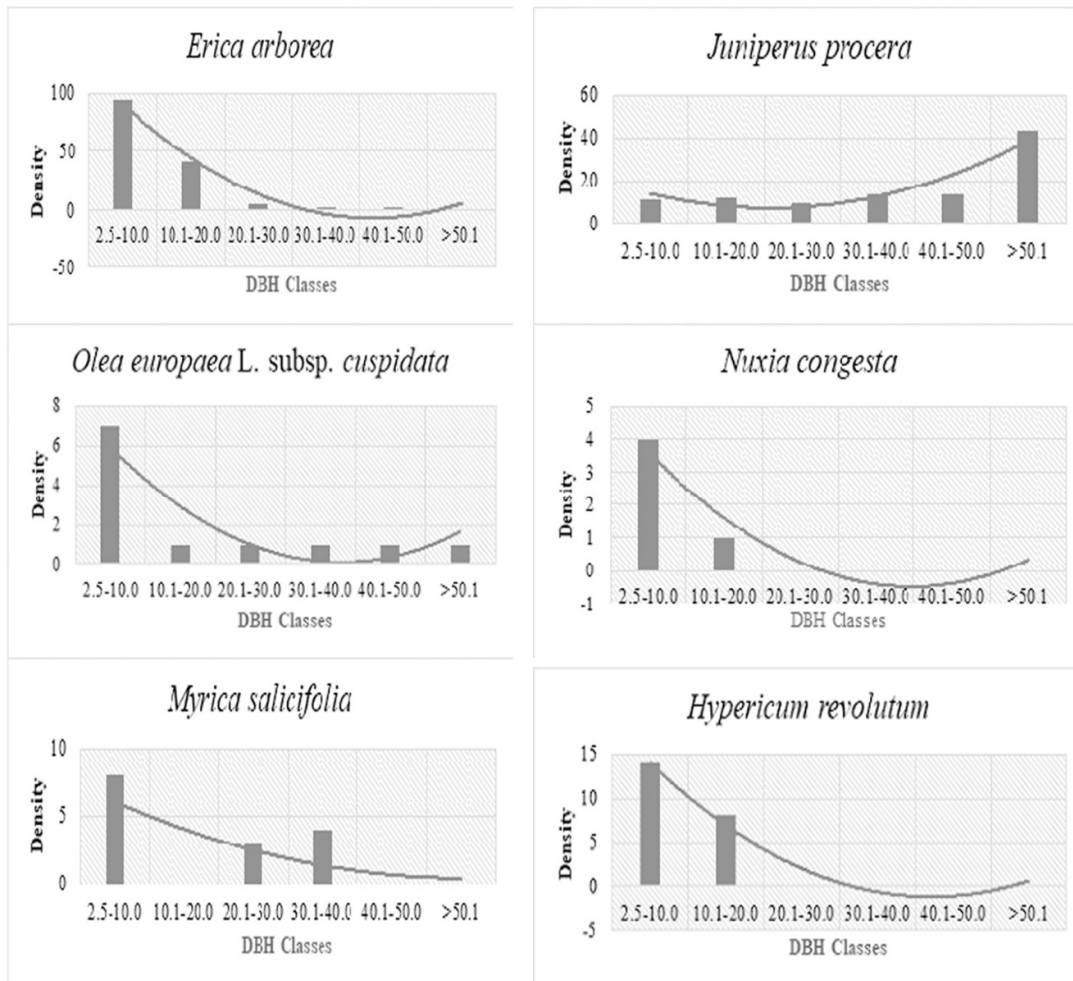


Figure 9. Population structure of tree species with high IVI

4.5. Plant community classification

Five plant communities were identified from the agglomerative hierarchical cluster analysis (Figure 10a). The MRPP test indicates a significant difference in the floristic compositions among the five plant communities ($R = 0.862$, $P < 0.001$). The homogeneity within groups (chance-corrected within-group agreement, A) is 0.397 (Figure 10b). The synoptic table and P-

value of indicator species of the plant community is shown in Table 7. The descriptive statistics of topographic and soil variables of the communities and the corresponding richness, diversity, and evenness is shown in Table 8. Each community type is described below.

1. *Euryops pinifolius* - *Kniphofia foliosa* community

This community is found in the Afroalpine vegetation that entertains relatively extreme weather condition. The elevation range of this community is between 3834-4168 m a.s.l. The slope in this community is relatively flat. Exclusive to livestock grazing, other anthropogenic disturbances are limited in this community type. This community is represented by *E. pinifolius* (shrub) and *K. foliosa*, *Cardamine hirsuta*, *Artemisia abyssinica*, *Festuca macrophylla*, and *Senecio farinaceus* (herbs).

2. *Lobelia rhynchopetalum* - *Festuca simensis* community

Community 2 is found at an elevation range of 3904-4164 m a.s.l. Like *Euryops pinifolius* - *Kniphofia foliosa* community, it is found in the Afroalpine vegetation type, which includes the top of the mountain range. A thicket of *E. pinifolius* dominates the shrub layer whereas the herbaceous layer is dominated by *F. simensis*, *Epilobium stereophyllum*, *Haplocarpha rueppellii*, *Festuca abyssinica*, and *Senecio schultzii*. However, the cover-abundance of *E. pinifolius* is not as dense as in community 1.

3. *Becium grandiflorum* - *Olea europaea* L. subsp. *cuspidata* community

Unlike community 1 and 2, community 3 has a wider range, which is found in three-vegetation type viz. EB, DAF, and AA between 2629-4006 m a.s.l. though most of the plots are from the AA. Community 3 comprises 12 plots and 60 species. This community entertained tree, shrub and herb growth forms. While the shrub layer is dominated by *B. grandiflorum* and *Rumex nervosus*, the tree layer is dominated by *Hypericum quartinianum* and *Olea europaea* L. subsp. *cuspidata*. The herbaceous layer is covered by *Hypoestes forskalii*.

4. *Erica arborea* - *Vernonia rueppellii* community

This community is found at the mid-elevation along the gradient between 3014-3275 m a.s.l.

It is found in the EB which has a very steep slope. Relatively this community comprises numerous plots and species with 23 and 68 respectively. *Hypericum revolutum* and *Rosa abyssinica* are some of the commonly found woody species in this community. A very common fern *Dryopteris schimperiana*, is also found in this community.

Table 7. Synoptic table and P-value of indicator species

	C 1	C 2	C 3	C 4	C 5	P-value
<i>Euryops pinifolius</i>	7.24	6.92	6.67	0	0	0.001
<i>Kniphofia foliosa</i>	5.82	5	5.5	0	0	0.001
<i>Cardamine hirsuta</i>	4.33	3	5.5	0	0	0.006
<i>Artemisia abyssinica</i>	4	0	0	0	0	0.738
<i>Senecio farinaceus</i>	4	1	0	0	0	0.774
<i>Ranunculus multifidus</i>	4	1	5.33	0	0	0.014
<i>Festuca macrophylla</i>	4	0	4.5	3	0	0.032
<i>Lobelia rhynchopetalum</i>	4.62	6.77	6.33	0	0	0.001
<i>Festuca simensis</i>	2.5	5	4.67	0	4	0.17
<i>Epilobium stereophyllum</i>	1	4	0	0	0	0.493
<i>Haplocarpha rueppellii</i>	3.43	4	2.75	0	0	0.095
<i>Festuca abyssinica</i>	4.14	4	5	0	0	0.102
<i>Senecio schultzei</i>	3	3.14	5	0	0	0.045
<i>Hypericum quartianum</i>	0	0	9	3.75	0	0.355
<i>Becium grandiflorum</i>	0	0	7	4.42	0	0.001
<i>Rumex nervosus</i>	0	0	6	0	6	0.83
<i>Hypoestes forskalii</i>	0	0	6	0	2.67	0.003
<i>Olea europaea</i> L. subsp. <i>cuspidata</i>	0	0	6	1	4	0.001
<i>Erica arborea</i>	0	0	0	6.29	0	0.001
<i>Vernonia rueppellii</i>	0	0	0	5.43	0	0.001
<i>Myrica salicifolia</i>	0	0	0	5.22	0	0.001
<i>Nuxia congesta</i>	0	0	0	5.2	0	0.01
<i>Hypericum revolutum</i>	0	0	0	5.08	0	0.001
<i>Hagenia abyssinica</i>	0	0	0	5	0	0.211
<i>Juniperus procera</i>	0	0	0	4.08	7.14	0.001
<i>Osyris quadripartita</i>	0	0	0	1.33	6	0.036
<i>Calpurnia aurea</i>	0	0	0	0	5.2	0.001
<i>Buddleja polystachya</i>	0	0	0	4.5	5	0.477
<i>Allophylus abyssinicus</i>	0	0	1	5	5	0.373
<i>Thalictrum schimperianum</i>	0	0	0	0	5	0.483
<i>Asplenium aethiopicum</i>	0	0	0	0	5	0.073
<i>Hypoestes triflora</i>	0	0	0	0	4.6	0.001

5. *Juniperus procera* – *Osyris quadripartita* – *Calpurnia aurea* community

This community is found in the Ethiopian Orthodox Tewahido Church in a DAF/SD vegetation type where the *J. procera* is the dominant tree. It is found between 2571-2953 m a.s.l. It consists of 13 plots and 100 species. *O. europaea* and *Clutia lanceolata* are some of the dominant woody species next to *J. Procera*, *Allophylus abyssinicus*, *Buddleja polystachya*, *Calpurnia aurea* and *Osyris quadripartita*. *Achyranthes aspera*, *Thalictrum schimperianum*, and *Hypoestes triflora* are some of the common herbaceous plants in this community.

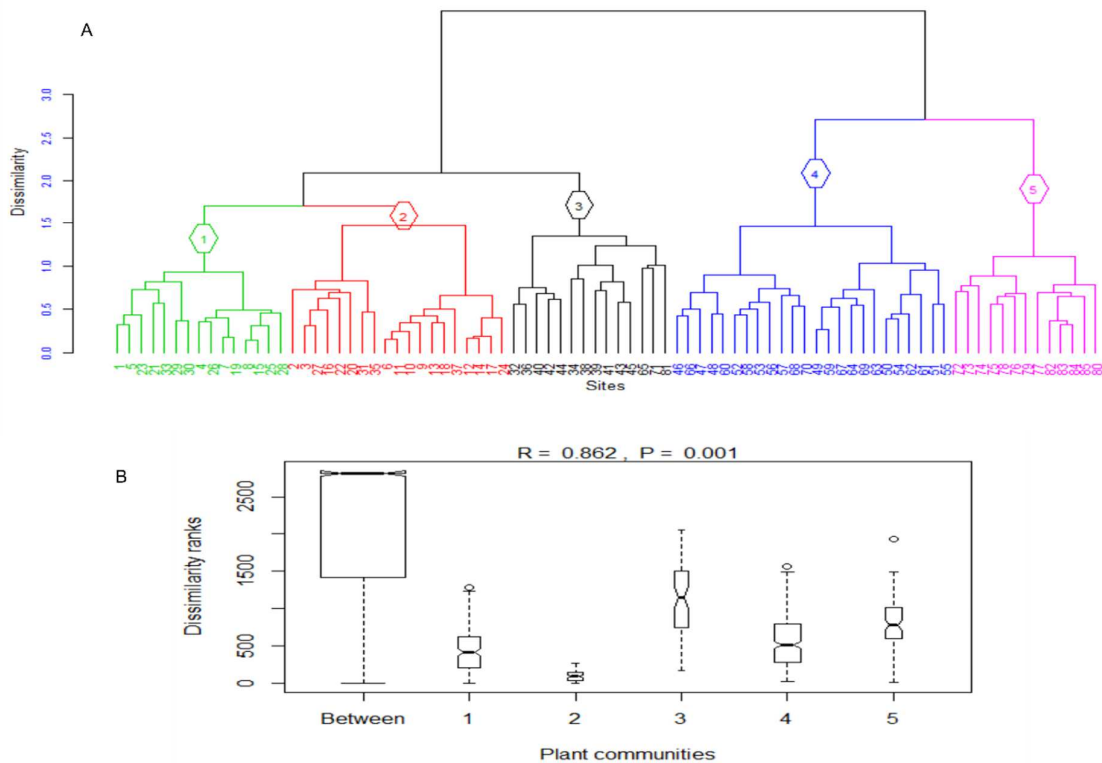


Figure 10. (a) Plant communities dendrogram and (b) MRPP test indicates a significant difference in the floristic compositions among the five plant communities

4.5.1. Vascular plants species richness and diversity

Following the Shannon diversity analysis, the richness, diversity, and evenness of each community accompanied by descriptive statistics of topographic and soil variables were revealed (Table 8). As a result, community 5 and 2 have the highest and lowest diversity with 3.90 and 2.43 respectively. This also corresponds to the higher and lowest evenness with 85

and 66% Shannon evenness respectively. Furthermore, the minimum and maximum Shannon diversity for each plot range from about 0.5 to 3.2 respectively (Figure 11). Consequently, individual plot diversity was found highest in the EB and DAF while the lowest was found in the Afroalpine grassland.

As depicted in Figure 11, the Shannon diversity along elevation gradient linearly declined towards higher elevation.

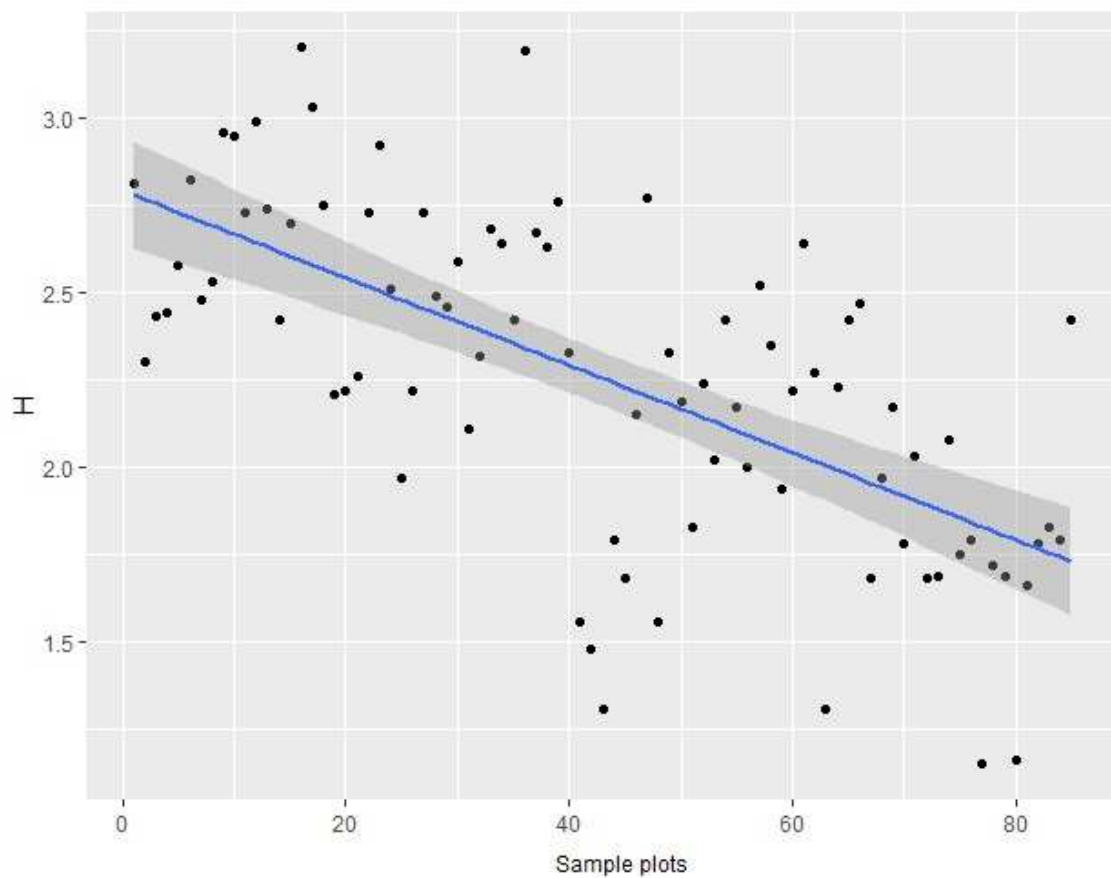


Figure 11. Shannon diversity along elevation gradient

Table 8. Descriptive statistics of topographic and soil variables of the communities (BD = Bulk density, N = total Nitrogen, SOC =soil organic Carbon, avP = available Phosphorus, S = species richness, H' = Shannon diversity, E = Shannon evenness)

Community	Statistic	Topographic variables		Soil variables								Diversity		
		Elevation	Slope	BD	pH	N	SOC	avP	Clay	Silt	Sand	S	H'	E
1	Minimum	3834	5	0.49	5.29	0.52	6.08	3.6	5.25	33.75	16.25	58	3.05	0.75
	Maximum	4168	19	1.06	6.03	0.87	11.83	33.86	25.75	67.25	47.5			
	Mean	3986.33	12.24	0.76	5.68	0.69	8.45	8.61	17.36	51.05	31.6			
	Std. Dev	81.88	4.13	0.15	0.25	0.1	1.51	6.94	5.82	7.69	8.14			
2	Minimum	3904	3	0.58	5.23	0.4	4.68	5.491	5.25	41.25	26.25	39	2.43	0.66
	Maximum	4164	20	0.91	6.03	0.87	9.2	32.97	23.75	67.25	40			
	Mean	4075.5	11	0.77	5.67	0.66	7.45	10.09	16.06	53.57	30.37			
	Std. Dev	94.6	5.29	0.11	0.27	0.15	1.37	7.55	5.59	7.6	4.85			
3	Minimum	2629	2	0.7	5.3	0.46	2.67	7.8	10	23.75	13.75	60	3.74	0.91
	Maximum	4006	13	1.32	6.93	0.79	14.88	33.94	30	71.25	66.25			
	Mean	3799.33	9.17	0.86	5.63	0.68	9.48	13.76	20.27	49.63	30.1			
	Std. Dev	418.03	3.1	0.17	0.44	0.12	3.44	7.63	5.39	10.95	12.64			
4	Minimum	3056	8	0.49	5.7	0.27	3.59	3.84	10	18.75	26.25	70	3.51	0.83
	Maximum	3275	35	1.06	6.58	1.05	11.22	91.53	43.75	48.75	70			
	Mean	3193.22	22.87	0.77	6.1	0.6	7.47	9.39	18.02	36.03	45.95			
	Std. Dev	60.9	7.46	0.14	0.21	0.19	1.87	18.09	7.71	7.87	9.42			
5	Minimum	2571	5	0.66	6.32	0.12	3.9	7.958	7.5	13.75	41.25	100	3.9	0.85
	Maximum	2953	19	1.53	7.22	0.8	16.2	123.385	22.5	38.75	66.25			
	Mean	2731.69	11.31	1.23	6.87	0.42	6.73	28.9	13.85	32.12	54.04			
	Std. Dev	120.59	4.44	0.3	0.28	0.21	3.07	35.47	4.72	7.35	6.62			

4.5.2. Vascular plants turnover (β -Diversity)

The lowest and highest Wilson and Shmida's β –diversity revealed 0.27 and 1.0 respectively. The mean β –diversity was found to be 0.86. Although complete replacement of species composition ($\beta = 1$) was documented in all of the vegetation types, it was pronounced between the Afroalpine grassland and DAF/SD. The ternary plot (Figure 12) showed that there is high species turnover along the elevation gradient.

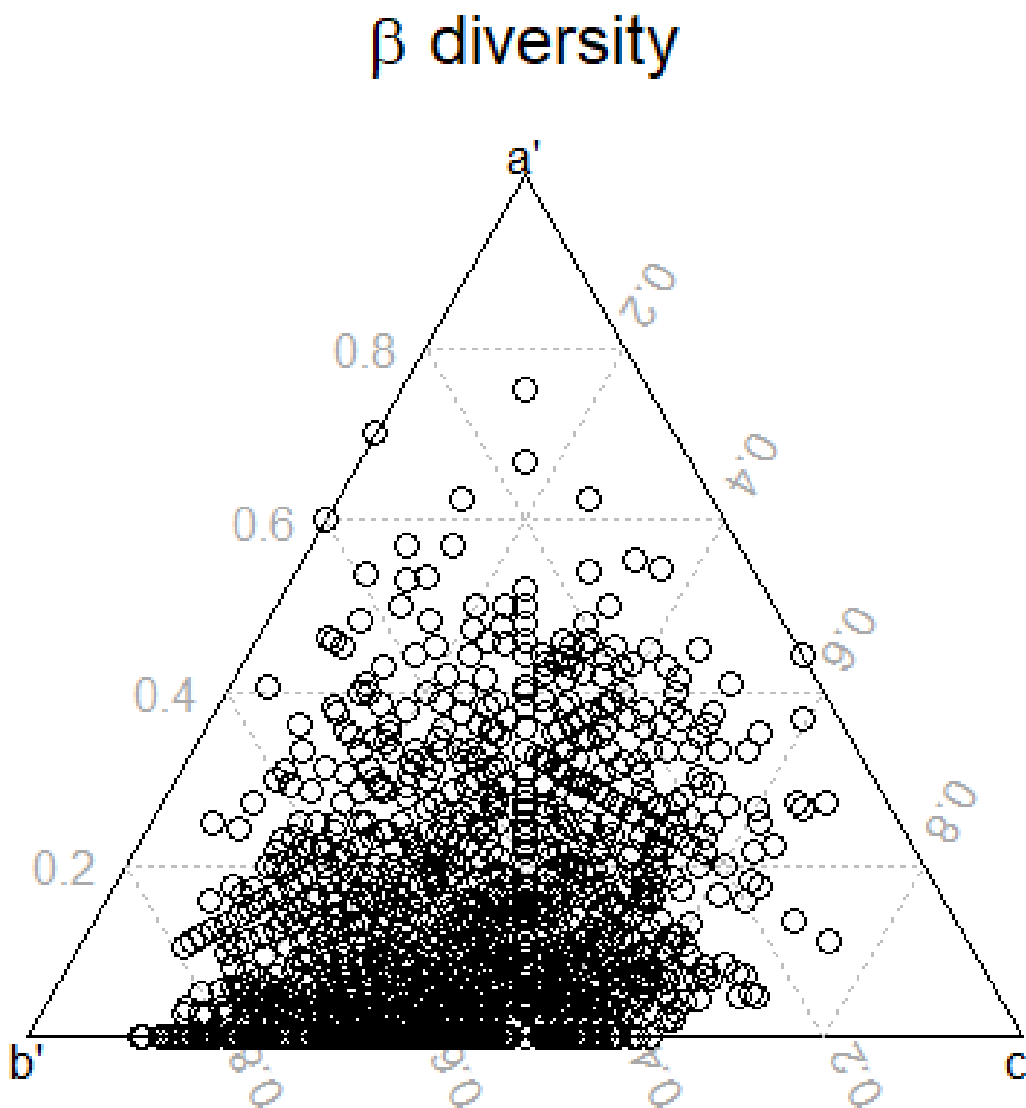


Figure 12. Species turnover (β -diversity) in Abune Yosef mountain range (a' = continuity (shared species), b' = species gains, c' = species losses)

The degree of shading in the ternary plot represents the value of a given beta diversity measure (darker shading for larger values for dissimilarity measures, lighter shading for similarity measures), relative to the values of a , b' and c' (each of which increase in the direction of the appropriate letter at the corners of the plot). The magnitude of a , the degree of species continuity between the two quadrats increases from the base of the plot towards its apex, and for a given value of a' the lateral position of a point reflects the relative contribution of species gains (b') and losses (c') (Koleff *et al.*, 2003).

4.6. Multivariate numerical analysis

4.6.1. Correlation analysis of the variables

A strong positive correlation was revealed between elevation and silt; bulk density and pH, sand and pH; and SOC and TN. On the other hand, a strong negative correlation was revealed between elevation and pH; and elevation and sand. A very negligible correlation was found between avP and slope; avp and TN; TN and clay (Table 9).

Table 9. Correlation analysis of variables: BD, Bulk Density; pH, soil pH; TN, soil total Nitrogen; SOC, soil organic carbon; AvP, soil avail phosphorus and *significance at the 0.05 level (2-tailed); **significance at the 0.01 level (2-tailed)

Variables	Elevation	Slope	Aspect	BD	pH	TN	SOC	AvP	Clay	Silt	Sand
Elevation	1										
Slope	-.310**	1									
Aspect	.421**	-.245*	1								
BD	-.352**	-.289**	-.055	1							
pH	-.808**	.254*	-.363**	.426**	1						
N	.404**	-.245*	.126	-.271*	-.505**	1					
SOC	.309**	-.221*	.195	-.239*	-.357**	.533**	1				
avP	-.323**	-.075	-.120	.423**	.240*	.005	-.031	1			
Clay	.185	-.005	.374**	-.056	-.251*	-.029	-.140	-.029	1		
Silt	.773**	-.452**	.231*	-.196	-.651**	.331**	.376**	-.167	-.019	1	
Sand	-.775**	.396**	-.380**	.203	.684**	-.265*	-.284**	.171	-.452**	-.876**	1
Grazing	-.062	-.016	.003	.046	-.036	.159	.127	-.014	.008	.039	-.027

4.6.1.1. Detrended correspondence analysis (DCA)

The length of the first DCA axis is **8.3526**. In addition to the length of the DCA axis, the study area also entertained high species turnover as stated in section 4.52. Since the length of the first axis is greater than 4, a constrained ordination method, CCA which assumes unimodal distribution of species was retained.

4.6.1.2. Canonical correspondence analysis (CCA)

The constrained (CCA) ordination explained 26% of the variance. The first two CCA axes explained 21 of the variance for significant variables (Table 10).

Community 1-3 are highly associated with elevation, SOC, slope aspect, BD, and slope (Figure 13). These communities are particularly found in the Afroalpine vegetation type. Community 4, on the other hand, is significantly associated with slope and logging. This community is dominantly the Ericaceous forest. Community 5 is strongly influenced by bulk density avP, and pH. This community represents the *Juniperus* church forest. The CCA biplot is presented in Figure 13.

Table 10. Canonical Corresponding Analysis (CCA1-6) and its corresponding constrained and unconstrained axes

Axis	CCA			CCA axes for significant variables		
	Eigenvalue	Proportion Explained	Cumulative Proportion	Eigenvalue	Proportion Explained	Cumulative Proportion
CCA1	0.88647	0.078510	0.07851	0.88601	0.07847	0.07847
CCA2	0.62761	0.055590	0.13410	0.60801	0.05385	0.13232
CCA3	0.28900	0.025600	0.15970	0.2879	0.0255	0.1578
CCA4	0.25922	0.022960	0.18265	0.24736	0.02191	0.17973
CCA5	0.23286	0.020620	0.20328	0.21387	0.01894	0.19867
CCA6	0.18970	0.016800	0.22010	0.16442	0.01456	0.21323
Total CCA axes	2.48	0.22		2.41	0.21	

4.6.1.3. Forward selection analysis and Permutation tests for environmental factors

Forward and backward stepwise selection of environmental variables revealed ten out of thirteen variables are significant though elevation, pH, BD, and slope are the strongest variables

($p \leq 0.001$) in influencing species composition and distribution (Table 11).

Table 11. Forward selection, a permutation test and correlation of environmental variables with the two first axes

Variables	CCA1	CCA2	Chi Square	F	Pr(>F)
Elevation	-0.99	0.119	0.8787	7.7430	0.001 ***
Slope	0.37	0.673	0.4181	3.6843	0.001 ***
Aspect	-0.58	-0.266	0.1723	1.5180	0.020 *
BD	0.40	-0.724	0.2850	2.5112	0.001 ***
pH	0.83	-0.390	0.2627	2.3146	0.001 ***
TN	-0.49	0.235	0.1665	1.4676	0.021 *
SOC	-0.37	0.064	0.2017	1.7777	0.004 **
avP	0.26	-0.292	0.2096	1.8470	0.020 *
Clay	-0.27	0.184	0.1515	1.3348	0.058 .
Logging	0.37	0.676	0.1700	1.4980	0.017 *
Significance level: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.'					

The variance explained after running forward selection and ANOVA doesn't show significant variation with the variance explained by all the variables (Table 11). The first axis explained 43.63% of the total inertia (variance). Elevation, pH, slope aspect, TN, SOC, and clay explained 34.14, 28.62, 20.0, 16.9, 12.76 and 9.31 percent of the constrained variance respectively. Elevation, slope aspect, TN, SOC, and clay were negatively correlated to the first axis while pH was positively correlated. On the other hand, the second axis explained 32.06% of the total inertia (variance). Bulk density, slope, logging, and AvP explained about 24.97, 23.21, 23.31, and 10.07 percent of the variance. Bulk density and avP were negatively correlated to the second axis while slope and logging were positively correlated to this axis.

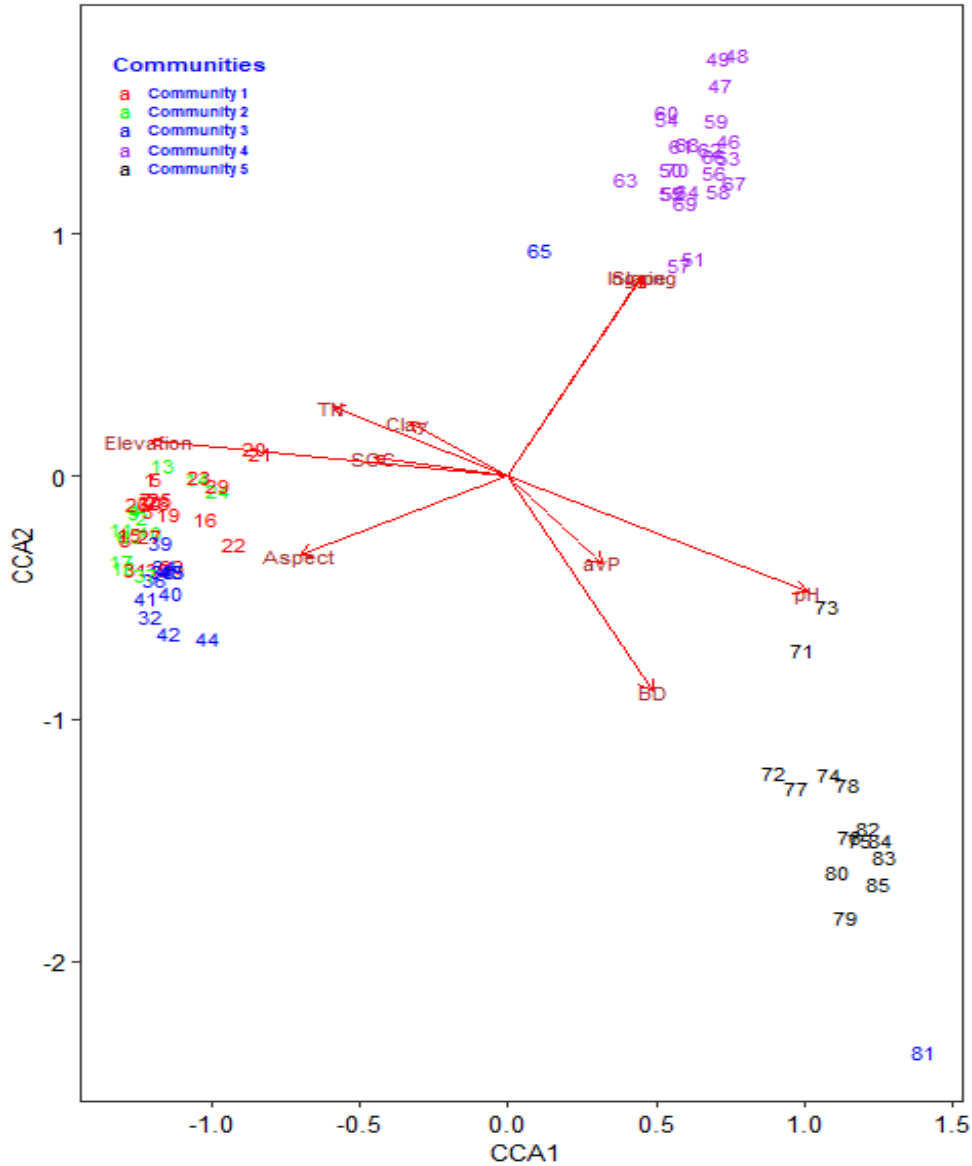


Figure 13. CCA biplot

4.7. Elevation gradient vascular plant species richness pattern and comparison between the vegetation types

Only seven species (3.5%) have wide elevational range i.e., that are found in all the vegetation types in the current study. These are *Alchemilla pedata*, *Arabis alpina*, *Geranium arabicum*, *Phagnalon abyssinicum*, *Satureja imbricata*, *Scabiosa columbaria*, and *Thymus schimperi*. On the contrary, about 74.37% are found in one of the three vegetation types. Furthermore, about 22.13% are found in two vegetation types.

The pattern of observed species richness, Shannon diversity and Shannon evenness along the elevation gradient followed a monotonic decline towards higher elevation ($R^2 = 0.50$, $P < 0.05$, $R^2 = 0.47$, $P < 0.05$, $R^2 = 0.06$, $P < 0.05$ respectively) (Figures 14A, D, & E). Similarly, the non-parametric species richness viz. Chao1 and ACE showed a monotonic decline ($R^2 = 0.38$, $P < 0.05$, $R^2 = 0.39$, $P < 0.05$) towards higher elevation with a peak at about 3000 m a.s.l. (Figures 14B & C).

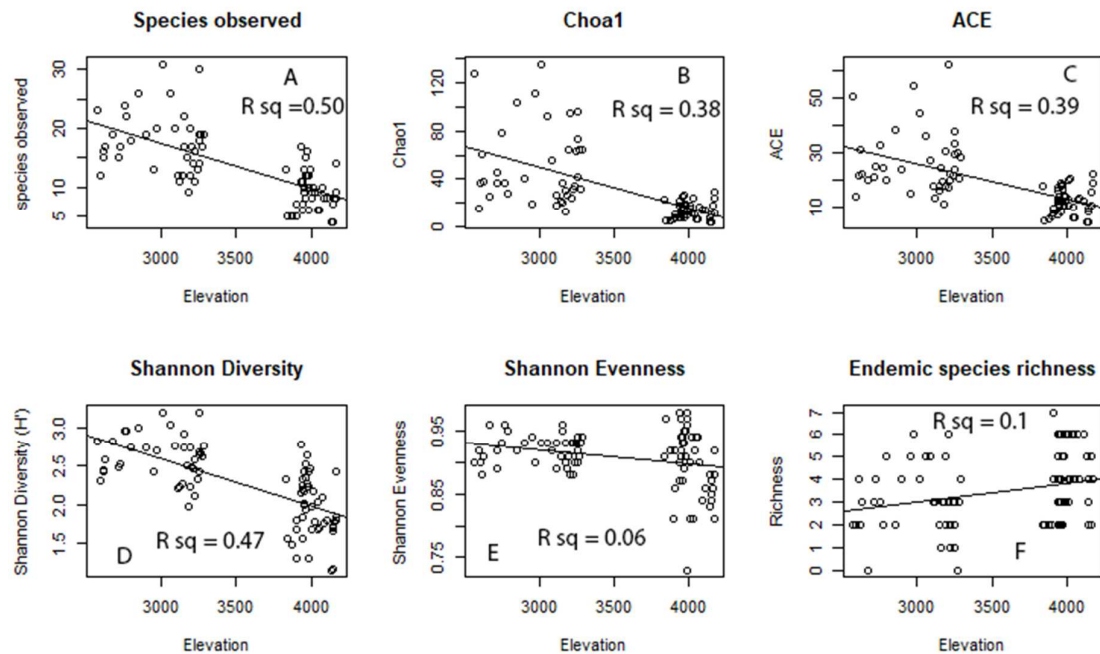


Figure 14. Elevation pattern of vascular plants (A) Species richness observed, (B) Chao1, (C) ACE, (D) Shannon diversity, (E) Shannon evenness, and (F) Endemic species richness

Average species richness was 18.46 ($SE = 1.05$) in DAF, 17.36 ($SE = 1.10$) in EB, and 9.15 ($SE = 0.46$) in AA. Vascular plants species richness was lower in the AA than the DAF and EB ($P = 0.01$) (Figure 15). Similarly, vascular plant species diversity was lower in AA than the DAF and EB ($P < 0.05$). On the contrary, the endemic vascular plants richness was significantly higher in the AA than the DAF and EB ($P < 0.01$). The average endemic richness of DAF, EB and AA was 3.13 ($SE = 0.4$), 2.84 ($SE = 0.28$) and 3.9 ($SE = 0.21$) respectively (Figure 15). Elevation showed a significant impact on the richness, diversity, and endemism of the vascular plants ($P < 0.05$).

The species shared between Dry evergreen Afromontane forest and Ericaceous forest, Ericaceous forest and Afroalpine grassland, Dry evergreen Afromontane forest and Afroalpine grassland are 26, 8 and 4 respectively. The Sørensen's coefficient of similarity revealed that the highest similarity is recorded between the Dry evergreen Afromontane forest and Ericaceous forest (32%) followed by Ericaceous forest and Afroalpine grassland (16%). Only 6% similarity is recorded between the Dry evergreen Afromontane forest and Afroalpine grassland (Table 12).

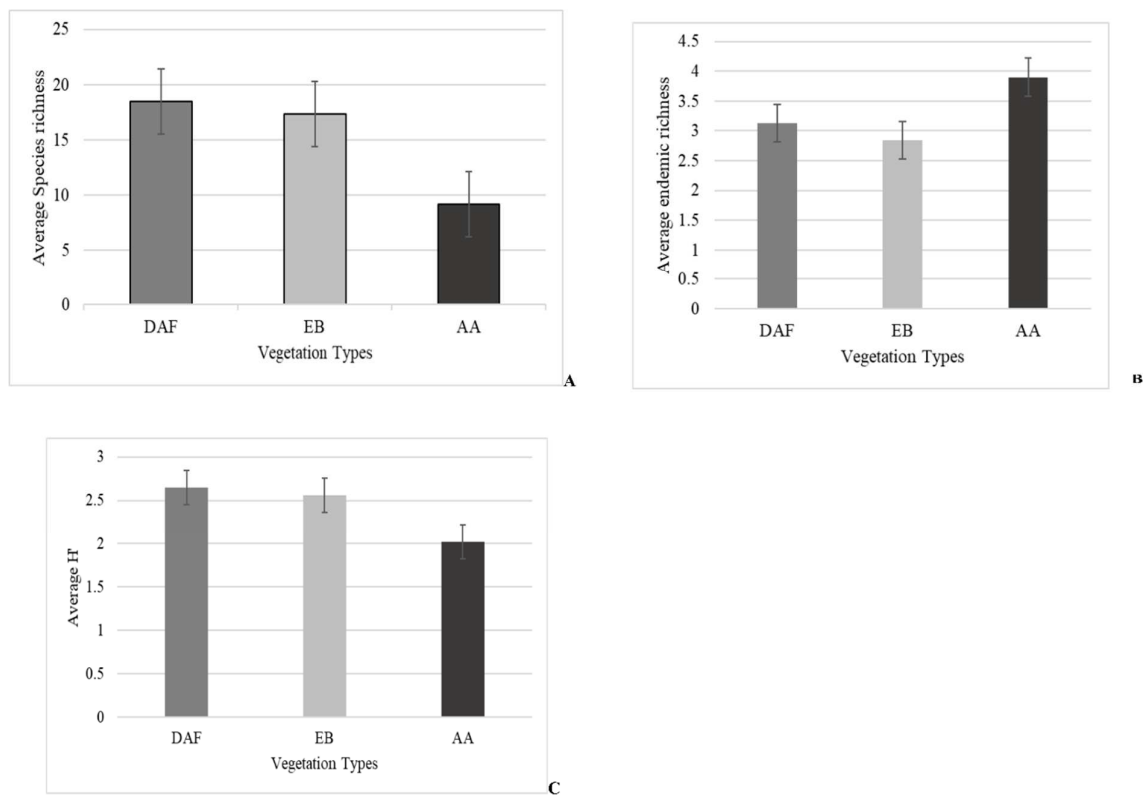


Figure 15. Comparison of vegetation types: Average (a) species richness, (b) endemic species richness, and (c) Shannon diversity index in the vegetation types (ANOVA and Tukey's HSD; $P < 0.05$).

Table 12. Number of shared species and Sørensen's similarity between vegetation types

Vegetation types	Number of shared species			Sørensen's similarity		
	AA	EB	DAF	AA	EB	DAF
AA	50	8	4	1	0.16	0.06
EB		31	26		1	0.32
DAF			73			1

4.7.1. Pattern of vascular plants endemism along elevation gradient

Vascular plant species endemism pattern along elevation gradient may or may not correspond to vascular plant species richness pattern. The endemic vascular plants distribution showed a linearly increasing pattern towards higher elevation (Figure 14F). Higher endemic plant species richness was recorded at about 3000 and 4000 m a.s.l. Interestingly, *Tagetes minuta*, *Chenopodium murale*, and *Galinsoga quadriradiata* are the only exotic species recorded along the gradient.

4.7.2. Growth forms pattern along elevation gradient

The growth forms showed different patterns along the elevational gradient (Figure 16). Trees species richness unlike the overall pattern of vascular plants species richness along the elevation gradient followed a slight hump-shaped pattern. It followed a monotonic increase up to a certain elevation, however, it followed a monotonic decline towards the higher elevation in which no single tree species was recorded above 3800 m a.s.l. which is above the treeline in the mountain range. Maximum tree species richness was found at about 3100 m a.s.l.

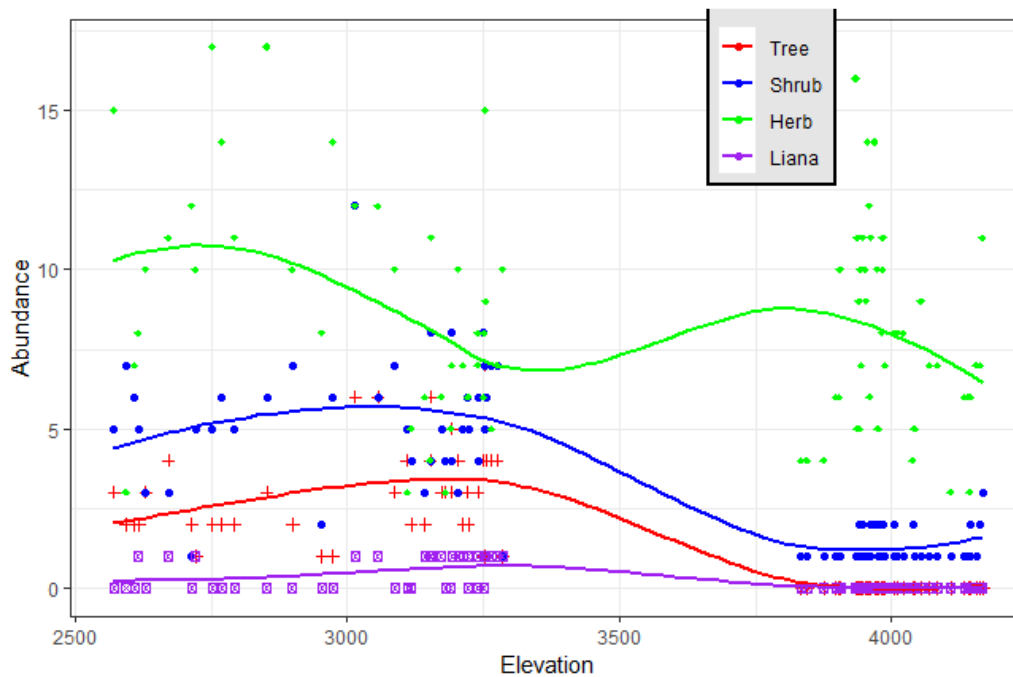


Figure 16. Growth forms pattern along elevation gradient

Shrubs also followed an almost similar trend with trees except the shrubs are distributed in all vegetation types although *E. pinifolius* was the dominant shrub found in the Afroalpine grassland. Maximum shrub species richness is recorded at an elevation of about 3100 m a.s.l. like the tree species richness. Herb plant species richness followed a different pattern from all other growth forms. Low herbaceous species richness was observed at medium elevations. The herbaceous plant species richness showed an inverted hump-shaped pattern. Both the lower and higher elevations entertained higher herbaceous species richness. However, the r squared value is only 7.9%. The lianas followed the same pattern to trees, with a monotonic increase up to a mid-elevation and monotonic decline towards higher elevation.

4.8. Plant conservation status

The majority, 77%, of the vascular plants from the study area are unassessed following the IUCN Red List criteria. However, the remaining 23% were assessed in different years by different researchers both nationally and globally. Of these, about 5% are threatened and the remaining are least concern (Table 13). Herbs (72.73%) were the most threatened growth forms followed by shrubs (27.27%). Out of the 42 endemic plants reported only 6 (14%) were assessed and 4 (9%) are threatened. *Verbascum arbusculum* is the only species with CR status. Three species viz. *Euryops pinifolius*, *Pentarrhinum abyssinicum* and *Plantago lanceolata* are VU. On the other hand, the endemic shrubs *Becium grandiflorum* and *Inula confertiflora* are NT. IUCN 1997 (IUCN, 1998) documented *Asplenium aethiopicum*, *Kalanchoe schimperiana*, *Rhynchosia stipulosa*, *Scabiosa columbaria* and *Felicia dentata* as possibly threatened plants.

4.8.1. Vascular Plants Local Rarity

Only 17 species (8.54%) of the vascular plants in Abune Yosef mountain range were found common. The remaining species entertained almost all types of rarity (Table 14, Appendix II). Exclusive to rarity form 2, all rarity forms were found in the study area. Of the 199 species analyzed for rarity, most of the species (55.78%) showed restricted species local range,

restricted habitat specificity, and scarce density of matured individuals (rarity form 7). This was followed by rarity form 6 (18.9%) which is characterized by restricted local species range, restricted habitat specificity, and abundant population of mature individuals. Nevertheless, rarity form 3 were also represented by only one species namely *Plectranthus garckeanus*. Of the species analyzed, 33 (16.58%) were found to have a wide realized range (eurytopic species) and the remaining 166 (83.42%) showed a narrow realized range (stenotopic species). Some of the species with wide distribution include *Alchemilla pedata*, *Allophylus abyssinicus*, *Arabis alpina*, *Bartsia decurva*, *Hebenstretia angolensis*, *Inula confertiflora*, and *Juniperus procera*. On the other hand, species such as *Anchusa affinis*, *Bersama abyssinica*, *Dombeya torrida*, *Erica arborea*, *Helichrysum citrispinum* and *Senecio schultzii* were found to have narrow distribution.

Table 13. IUCN status of vascular plants in Abune Yosef mountain range (CR = Critically Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, I** and R** = possibly threatened, NA = Not assessed)

IUCN status	Tree	Shrub	Liana	Herb	Frequency	Percent
CR	0	0	0	1	1	0.5
EN	0	0	0	0	0	0.0
VU	0	1	0	2	3	1.5
NT	0	2	0	0	2	1.0
LC	13	5	1	16	35	17.6
R**	0	0	0	4	4	2.0
I**	0	0	0	1	1	0.5
NA	4	24	3	122	153	76.9
Total					199	100

Regarding to the habitat specificity, only 51 (25.63%) of the species were found widespread (euryoecious species) i.e., occurred in more than one vegetation types. Species in this category include *Cineraria sebalzii*, *Clematis simensis*, *Discopodium penninervium*, *Galium simense*, and *Nepeta azurea*. On the contrary, 148 (74.37%) of the species were found only in one vegetation type which indicates they have locally restricted habitat specificity (stenoecious species). *Anthemis tigrensensis*, *Anthospermum herbaceum*, *Bersama abyssinica*, *Delphinium*

dasycaulon, and *Helichrysum citrispinum* were some of the species with restricted habitat specificity.

In terms of density of matured individuals, 58 (29.15%) were found locally abundant while the remaining 141 (70.85%) were found locally scarce. *Erica arborea*, *Euryops pinifolius*, *Juniperus procera*, *Osyris quadripartita*, *Rosa abyssinica*, *Achyranthes aspera*, and *Lobelia rhynchopetalum* are some of the locally abundant plants. *Arisaema polydactylum*, *Bersama abyssinica*, *Hagenia abyssinica*, *Hypericum revolutum*, *Myrica salicifolia*, *Pelargonium glechomoides*, and *Rhus natalensis* were some of the species with a locally scarce density of mature individuals.

Table 14. Percentage of Rabinowitz’s rarity forms of vascular plants in Abune Yosef mountain range

Specie local range	Wide		Restricted	
	Widespread	Restricted	Wide spread	Restricted
Abundant population	8.54 Common <i>Alchemilla pedata</i>	RF2	3.02 RF4 <i>Nepeta azurea</i>	18.9 RF6 <i>Lobelia rhynchopetalum</i>
Scarce population	7.54 RF1 <i>Allophylus abyssinicus</i>	0.5 RF3 <i>Plectranthus garckeanus</i>	6.53 RF5 <i>Mikaniopsis clematoides</i>	55.78 RF7 <i>Felicia dentata</i>

4.8.2. Local Rarity and IUCN Red List Status Comparisons

The comparison between local rarity and IUCN Red List status (Table 15) revealed that four species that are locally rare (Rarty form 3, 6 and 7) are threatened. Furthermore, five species are possibly threatened.

Table 15. Local rarity forms and IUCN Red List status comparisons

Rarity Forms	IUCN Red List status							
	CR	EN	VU	NT	LC	R**	I**	NA
Rarityforms (Number of species detected)								
Common (17)	0	0	0	1	2	1	0	13
Form1 (15)	0	0	0	0	5	0	0	10
Form3 (1)	0	0	1	0	0	0	0	0
Form4 (6)	0	0	0	0	1	0	0	5
Form5 (13)	0	0	0	0	0	2	0	11
Form6 (36)	0	0	1	1	4	1	0	29
Form7 (111)	1	0	1	0	23	0	1	85

4.8.3. Causes of rarity

Plants could be rare for several reasons. However, the reasons for the rarity of a particular species in a particular locality could emanate from either anthropogenic disturbances, stochastic events, or intrinsic behavior of the species.

In the present study, rarity is mainly attributed to anthropogenic disturbance, land use and land cover change. Land transformation, particularly, agricultural encroachment was found to be the main driver for habitat loss and fragmentation. The Afroalpine grassland shrunk to 3700 ha in 2017 from 10500 ha in three decades. It is converted rather into agricultural land and barren land. Grazing is also a common phenomenon in all vegetation types which might have a detrimental effect on rarity. In addition to grazing, exploitation of wood resources was observed in the DAF and EB which might cause local rarity of the species.

4.9. Land use and Land cover change

4.9.1. Accuracy assessment

The confusion/error matrix computation (Tables 16 & 17) revealed an overall accuracy of 86% and 88% with a Kappa coefficient of 82% and 84% for the 1986 and 2017 respectively.

Table 16. Confusion of matrix 1986

Class	AAG	AGL	BRL	EFS	GRL	PLN	RBG	SBL	CHF	URS	WDL	Total	User's Accuracy
AAG	45	2	0	1	0	0	0	0	0	0	0	48	0.94
AGL	4	165	0	0	2	0	2	4	0	0	0	177	0.93
BRL	1	2	19	0	2	0	0	0	0	0	0	24	0.79
EFS	0	1	0	12	2	0	0	0	0	0	0	15	0.80
GRL	1	0	0	0	33	0	0	2	0	0	0	36	0.92
PLN	2	3	1	0	0	5	0	0	0	0	0	11	0.45
RBG	0	2	1	0	0	0	6	1	0	0	0	10	0.60
SBL	3	20	2	0	1	1	0	136	0	0	1	164	0.83
CHF	0	0	0	0	0	0	0	0	10	0	0	10	1.00
URS	0	3	0	0	0	0	0	1	0	6	0	10	0.60
WDL	0	0	1	0	1	0	0	1	0	0	15	18	0.83
Total	56	198	24	13	41	6	8	145	10	6	16	523	0.00
Producer's Accuracy	0.80	0.83	0.79	0.92	0.80	0.83	0.75	0.94	1.00	1.00	0.94	0.00	0.86
Overall accuracy = 86%, Kappa = 82%													

Table 17. Confusion of matrix 2017

Class	AAG	AGL	BRL	EFS	GRL	PLN	RBG	SBL	CHF	URS	Total	User's Accuracy	
AAG	15	0	0	2	0	0	0	0	0	0	17	0.88	
AGL	0	205	2	0	2	1	3	2	0	0	215	0.95	
BRL	0	0	45	1	0	0	0	1	0	0	47	0.96	
EFS	1	0	0	12	0	1	0	1	0	0	15	0.80	
GRL	0	0	0	0	11	0	0	0	0	0	11	1.00	
PLN	0	5	2	0	0	17	0	1	0	0	25	0.68	
RBG	0	1	4	0	0	0	16	0	0	0	21	0.76	
SBL	0	19	5	0	2	0	3	115	1	0	145	0.79	
CHF	0	0	0	0	0	1	0	0	9	0	10	0.90	
URS	0	0	1	0	0	0	0	0	0	9	10	0.90	
Total	16	230	59	15	15	20	22	120	10	9	516	0.00	
Producer's Accuracy	0.94	0.89	0.76	0.80	0.73	0.85	0.73	0.96	0.90	1.00		0.88	
Overall accuracy = 88%, Kappa = 84%													

4.9.2. LULCC Dynamics

The study revealed that there was a vivid change in LULC (Table 18, Figures 17A & B). Only the church forest class experienced no change over the study time period. Agricultural land, barren land, urban settlements, plantation forests, and rivers, riverbeds and gullies showed an increasing trend. On the contrary, shrubland, open woodland, grazing land, and Afroalpine grassland showed a decreasing trend. Ericaceous forest/shrubland showed only modest change. The LULCC trajectories are depicted in Table 19.

Afroalpine grassland cover decreased from 10,500 ha (9.61% of the land cover in the study area) in 1986 to 3700 ha (3.43% of the whole land cover in the study area) in 2017. It was converted into agricultural land and grazing land. Shrubland cover in 1986 was 35,500 ha (32.63% of the land area) but it decreased to 33,000 ha (30.36%) in 2017. The open woodland which covered 3,900 ha in 1986 was completely converted into shrubland and agricultural land.

Table 18. LULC area extent for 1986 and 2017 (see Table 2 for the LULC classes Acronyms)

LULC Class	1986		2017		Change (ha)	Percent of change	Rate of change
	Proportion (%)	Area (ha)	Proportion (%)	Area (ha)			
AAG	9.61	10500	3.43	3700	-6800	-64.76	-2.09
AGL	35.19	38300	44.71	48700	10400	+27.15	0.88
BRL	4.94	5400	8.22	8900	3500	+64.81	2.09
EFS	2.99	3300	2.96	3200	-100	-3.03	-0.10
GRL	7.30	7900	2.02	2200	-5700	-72.15	-2.33
PLN	2.26	2500	4.30	4700	2200	+88.00	2.84
RBG	1.03	1100	3.42	3700	2600	+236.36	7.62
SBL	32.63	35500	30.36	33000	-2500	-7.04	-0.23
CHF	0.15	200	0.15	200	0	0.00	0.00
URS	0.27	300	0.44	500	200	+66.67	2.15
WDL	3.61	3900	0.00	0.00	-3900	-100.00	-3.23

The agricultural land and urban settlements, unlike the Afroalpine grassland and shrubland, showed increased cover. The result showed that the cover of agricultural land and urban settlements increased from 38,300 and 200 ha to 48,700 and 500 ha respectively. In the 1986

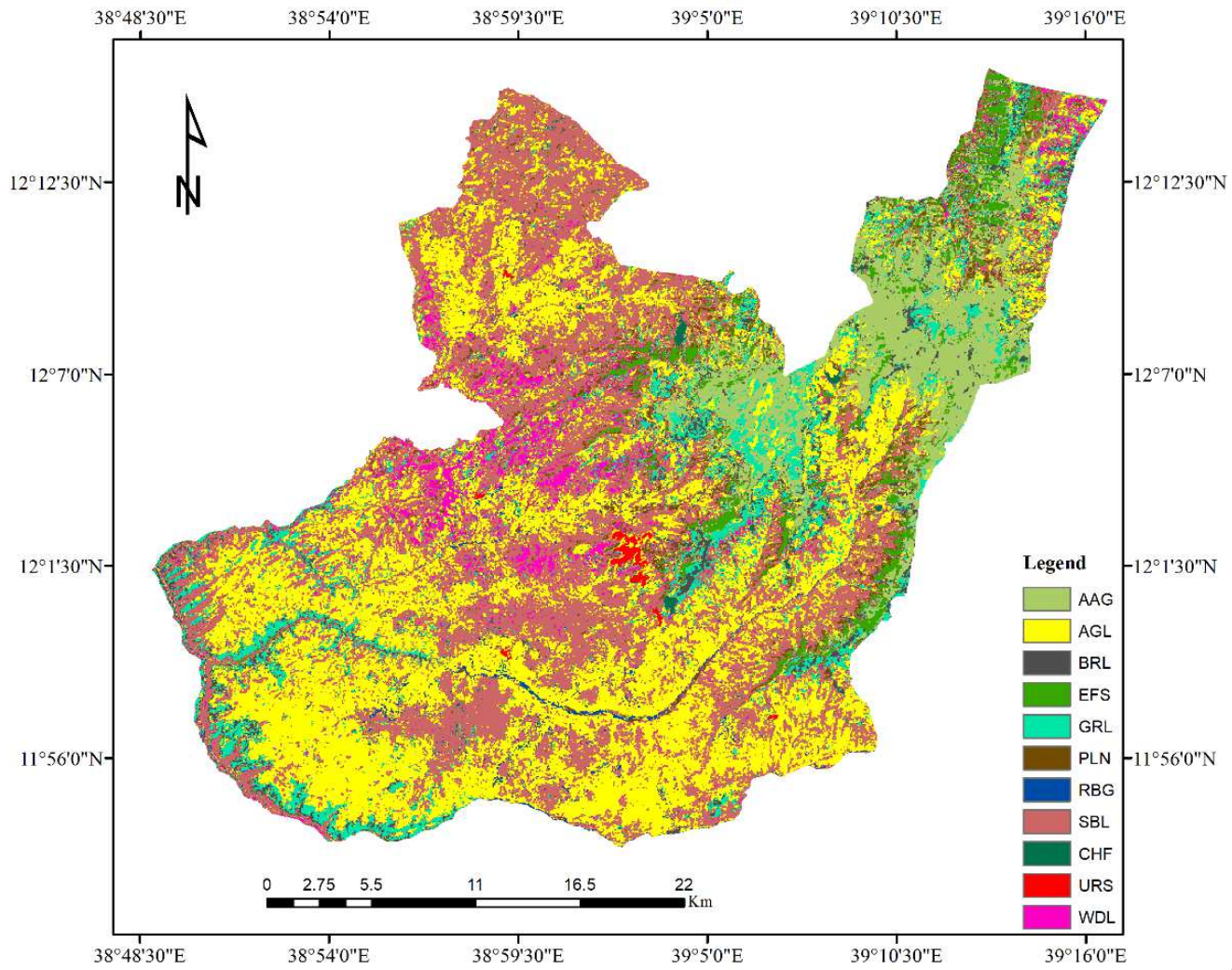
map, the only well-established urban settlement recognized was Lalibela. However, in the 2017 map, there were four additional small urban settlements. The urban settlements expanded at the expense of agricultural land and shrubland. The agricultural land, however, expanded mostly at the expense of Afroalpine grassland, shrubland, and grazing land (Table 19).

Table 19. LULC change matrix (1986-2017)

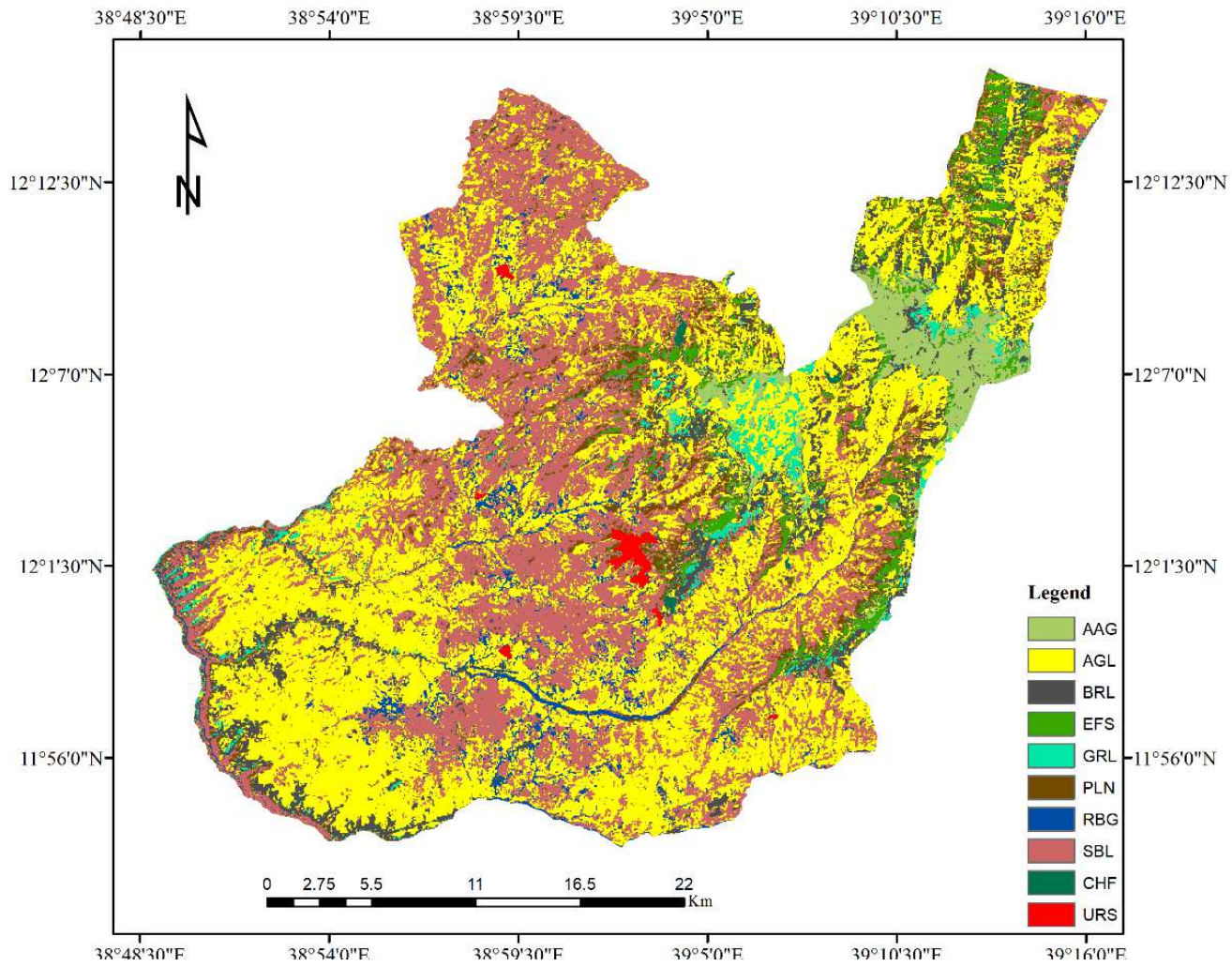
	LULC class	Area (ha) 1986										
		AAG	AGL	BRL	EFS	GRL	PLN	RBG	SBL	CHF	URS	WDL
Area (ha) 2017	AAG	3700	0	0	0	0	0	0	0	0	0	0
	AGL	5000	35900	700	100	2600	0	0	4300	0	0	200
	BRL	1800	300	3700	0	3100	0	0	0	0	0	0
	EFS	0	0	0	3200	0	0	0	0	0	0	0
	GRL	0	0	0	0	2200	0	0	0	0	0	0
	PLN	0	500	500	0	0	2500	0	1200	0	0	0
	RBG	0	1500	500	0	0	0	1100	600	0	0	0
	SBL	0	0	0	0	0	0	0	29300	0	0	3700
	CHF	0	0	0	0	0	0	0	0	200	0	0
	URS	0	100	0	0	0	0	0	100	0	300	0
	WDL	0	0	0	0	0	0	0	0	0	0	0

Church forests experienced no change at all. However, the Ericaceous forest/shrubland is the least affected LULC class. Only 100 ha was converted to other LULC classes, particularly, agricultural land and barren land. On the other hand, the plantation forest dramatically increased from 2, 500 ha to 4, 700 ha from 1986 to 2017 respectively.

The grazing land which covered 7, 900 ha in 1986 decreased to 2, 200 ha in 2017 being converted mainly into agricultural land and barren land. In contrast to grazing land, the cover of barren land increased from 5, 400 ha in 1986 to 8, 900 ha in 2017. The area coverage of rivers, riverbeds and gullies also increased from 1, 100 ha to 3, 700 ha in 1986 and 2017 respectively. The cover of rivers, riverbeds, and gullies increased at the expense of mostly agricultural land followed by barren land.



A



B

Figure 177A & B. LULC Map of 1986 and 2017

2.1.1. Major drivers of LULCC dynamics

2.1.1.1. Population

Ethiopia has conducted a population census in 1984, 1994, and 2007. It is not possible to get the census data of the study area for 1984 because the National population census was done at the zonal level. Even though the National population census of 1994 was done at the district level, the study area was merged with other kebeles (lowest governmental administrative structure) in Bugina district. The only population data that match the current administrative boundary is Lalibela town with a population of 8, 484 (CSA, 1994) which almost doubled to 17, 367 in 2007 (CSA, 2007). The total population of the study area is about 117, 777 of which 58, 451 are men and 59, 326 women. Only 17, 367 or 14.75% are urban inhabitants (CSA, 2007). This shows that there is a tremendous increase in population of the district in the defined period. Population in turn demands a resource for their existence. Hence, pressures such as land use changes, for example agricultural expansion, are inevitable to feed the ever-growing population. Consequently, conversion of natural vegetation into other land use types is a common phenomenon.

2.1.1.2. Temperature and Rainfall variability

The monthly maximum temperature in 1993 was 19.9 °C (March) and the minimum was 16.2 °C (July). In 2015, the monthly maximum and minimum temperature was 21.7 °C (April) and 16.4 °C (August) respectively. In 1994, the monthly maximum precipitation was 476 mm (July) and the minimum precipitation was 0 mm (January). In 2015, monthly maximum and minimum precipitation was 168.8 (August) and 0 mm (October) respectively. In contrast to temperature, precipitation followed a decreasing pattern (Figure 18a-c).

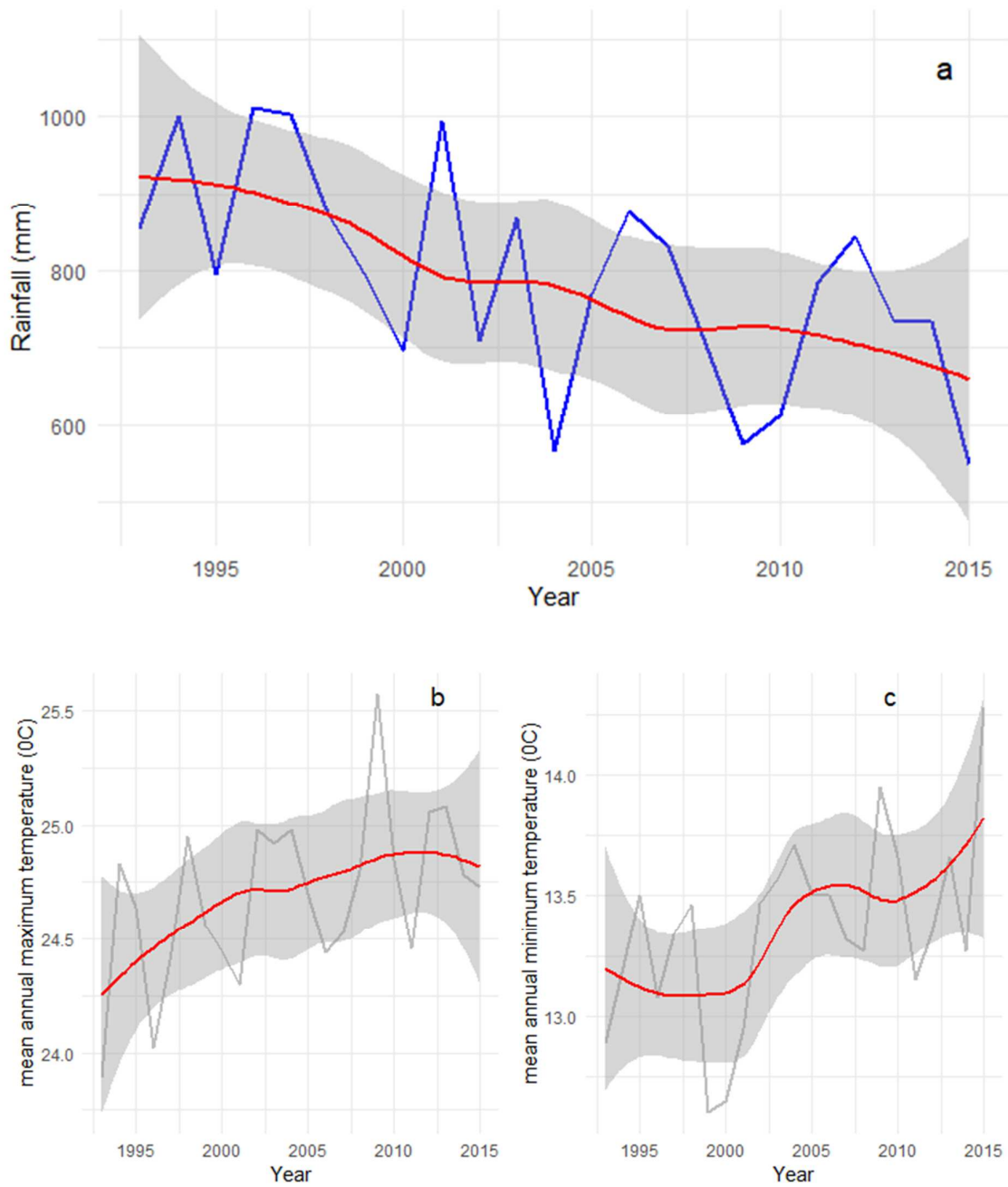


Figure 18a-c. Temperature and Precipitation variability (a) mean annual rainfall (b) mean annual maximum temperature and (c) mean annual minimum temperature

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1. DISCUSSION

5.1.1. Taxonomic composition, structure and plant community

Asteraceae and Poaceae are among the most species rich vascular plant families standing the first and the fifth in the world. These are also species rich families, ranked third and second, following Fabaceae in Ethiopia (Ensermu Kelbessa & Sebsebe Demissew, 2014). These are also widely distributed in the present study area. This could be attributed to the diverse dispersal and pollination mechanisms. The outcrossing behavior of the Asteraceae inflorescence and the diverse pollination mechanisms (generalist, specialist, and wind), dispersal by pappus bristles probably made the family cosmopolitan and widespread (Judd *et al.*, 2008). The ability to adapt to a diverse environment and withstand disturbances could also have a crucial role in their wider distribution. These families are also the top species-rich families distributed worldwide (Judd *et al.*, 2008; Stevens, 2018).

The lowest taxonomic richness was recorded in Welo floristic region (WU) next to Afar floristic region (AF) though it is undoubtedly mentioned the WU is understudied (Friis *et al.*, 2001; Friis *et al.*, 2005; Vivero *et al.*, 2006). Similarly, the single region endemic taxa richness is also lowest next to AF and Ilubabor (IL) floristic region (Hedberg *et al.*, 2009). However, with the new records documented to the WU floristic region, the taxonomic diversity and record of endemic vascular plants could be higher.

The mean basal area for tropical forests which is highly correlated to large trees but not compensated with density effects is estimated to be 35 m² ha⁻¹ (Midgley & Niklas, 2004). The basal area in the present study showed almost two-fold lower than the basal area estimated for tropical forests by Midgley & Niklas (2004). The main reason being that the forests in the study

area are degraded due to selective tilling and low recruitment as the result of trampling by livestock. Furthermore, the trees are neither large nor have high density. Consequently, the basal area was found very low. However, study from southern Ethiopia, Rira forest in Bale mountain, reported a lower basal area ($14 \text{ m}^2 \text{ ha}^{-1}$) than the present study (Young *et al.*, 2017). This could be attributed to the low tree diversity, which is dominated by either small or medium sized trees. Furthermore, anthropogenic disturbances, such as selective removal of tree species, could have also a detrimental impact on the basal area.

The population structure of trees that are continuously recruiting young individuals and gradually losing older individuals exhibits a reverse-J frequency distribution pattern indicating a relatively stable population without the need of management actions to ensure its persistence (Young *et al.*, 2017). On the other hand, the episodic recruitment and the J-shape population structure may be attributed to the removal of previously established cohorts, through herbivory, timber harvesting, or other anthropogenic influences and a particular set of conditions for reproduction respectively (Johansson, 2013; Young *et al.*, 2017). Species that revealed such population structures are showing the species are vanishing as a result immediate intervention is required. Enriching with seedlings and saplings could be the best possible options.

5.1.2. Plant community classification, diversity and evenness

The P value associated with the test statistic evaluates if the observed differences among groups are due to chance and the chance-corrected within-group agreement (A) measures within-group homogeneity. When all items within groups are identical, then $A = 1$, the highest value for A . $A = 0$ when the heterogeneity within groups equals the expectation by chance while $A < 0$ when there is less agreement within groups than expected by chance (McCune and Grace 2002). In community ecology an $A > 0.3$ is fairly high. Hence, in the present study the chance-corrected within-group agreement in the plant community is high showing within group homogeneity.

Community 1 and 2 are highly associated with higher elevation and are found in the Afroalpine grassland which is dominated by either herbaceous plants or subshrubs. Community

3 is relatively widely distributed. Even though the p - value of the indicator species and the chance-corrected within group homogeneity (A) showed there is sharp separability, the specificity and fidelity of community 3 is poorly determined. On the other hand, community 4 and 5 are found in the church forest and Ericaceous forest and associated with slope.

Community 1 and 2 are found above the treeline. Although shrub encroachments into high mountain grasslands (Dullinger *et al.*, 2003; Young *et al.*, 2008; Eldridge *et al.*, 2011) are getting due attention these days, this ecosystem is naturally dominated by herbs and shrubs/subshrubs. Plant communities at higher elevations, particularly above the treeline, are characterized by plants of lower stature, associated with different functional traits that can withstand stressful environments which cause slow plant growth rate (Whittaker, 1956; Körner, 1999).

Being less accessible and favorable to agriculture (Kflay Gebrehiwot *et al.*, 2018) and less accessible to large herbivores/grazers makes the steep area a refugia for forests in general and trees in particular (Nüchel *et al.*, 2019). Furthermore, although it lacks a natural explanation, tree cover/density is highly associated with slope (Nüchel *et al.*, 2019). Thus, community 4 and 5 can be considered as refugia for trees in the study area.

Plant communities along elevation gradient are mainly regulated by temperature because it directly affects photosynthesis, metabolism, and nutrient mineralization (Hoch & Körner, 2012; Sundqvist *et al.*, 2013). Nevertheless, other abiotic variables such as moisture availability and soil physicochemical properties; and biotic components such as soil fauna and pollinators also have a detrimental effect on shaping plant communities along elevation gradient (Sundqvist *et al.*, 2013).

5.1.2.1. Vascular plants species richness and diversity

The value of Shannon diversity index usually lies between 1.5 and 3.5, although in exceptional cases, the value can exceed 4.5 (Kent, 2012). Thus, it can be depicted that the study area has high community diversity which followed a monotonic decline towards higher elevation. Most

studies showed that diversity is high at mid-elevations which corresponds to the optimum variables at this elevation (Rahbek, 2005). However, the diversity pattern usually varies due to the variations in climatic components and level of anthropogenic disturbances. Similar to the present study, Puff & Sileshi Nemomissa (2001) reported a decline in diversity along elevation gradient.

The high diversity and evenness in community five correspond to the high species richness, relatively similar abundance and moderate disturbances. The relatively low diversity and evenness in community 1 and 2 corresponds to the low species richness and shows some species are dominating the community. Low evenness often indicates high anthropogenic impact (Hillebrand *et al.*, 2008).

5.1.2.2. Vascular plant species turnover (β -Diversity)

Beta diversity of the study area is very high. This shows there is high vascular species turnover between and within the vegetation types along elevation gradient. This also shows there is high species diversity in the study area (Ricotta, 2017), in which the vegetation types have almost distinctive species composition. Similar vegetation types and near sites could share similar species composition which leads to low beta diversity. On the contrary, different vegetation types and extreme sites may not share high species composition that could lead to high beta diversity.

High beta diversity of extreme elevation pairs was reported from northern Ethiopia (Ermias Aynekulu *et al.*, 2012). Apart from the spatial scale, sites within the same vegetation types could have high beta diversity due to topographic and microclimatic variations. Soil texture, elevation, and aspect are (for example) some of the variables, which influenced 100% replacement of species composition in the Afroalpine grassland. Geographical distance and microclimate have a crucial impact on beta diversity (Mantilla-Contreras *et al.*, 2012; Fitzpatrick *et al.*, 2013; Opedal *et al.*, 2015).

5.1.3. Multivariate numerical analysis

5.1.3.1. Canonical correspondence analysis

The variance explained by the first and second CCA axes is very low. This could possibly be emanate from the unexplored topographical, environmental, soil and climate variables that determine composition, diversity and spatial distribution pattern of vegetation. Furthermore, Kent (2012) and McCune and Grace (2002) claimed that the statistics are misleading in that they are often interpreted as the amount of variation in the community data that is explained by the environmental variables which is not usually the case.

The CCA result showed that the topographical variables (elevation, slope, and slope aspect), soil variables (pH, TN, avP, SOC, and clay) and disturbances variable (logging) influenced the plant communities. Elevation, pH, slope aspect, TN, SOC are correlated with axis 1. Axis 2, on the other hand, is correlated with bulk density, slope, logging, avP, and SOC. The coefficient of determination of the variables revealed that the environment-disturbance variables influenced plant distribution. Since the range of eigenvalues is between 0 and 1 indicating values closer to 1 most important axis, the eigenvalue of the first axis which is closer to 0.9 depicts the distribution of the species along the axis is good (Legendre & Legendre, 2012).

In ordination analysis, axis one is often the most influencing component. This revealed that topography governs the species distribution in the present study. Similar to this study, Friis *et al.* (2005) depicted topography has a crucial role in governing plant distribution and diversity particularly in the Horn of Africa. Irl *et al.* (2015) and Méndez-Toribio *et al.* (2016) reported that complex topography shapes plant species richness, diversity, speciation process, and distribution pattern though its impact is pronounced in determining plant endemic richness pattern. Although topography is not a resource gradient, the possible reason for this could be the direct or resource gradients including edaphic factor are majorly influenced by topography.

Elevation as an explanatory variable with the highest contribution was discussed in several studies (Irl *et al.*, 2015; Khan *et al.*, 2017). Although species richness decreases along elevation

gradient, endemic plant species richness is higher at higher elevations than lower elevations (Irl *et al.*, 2015). Since the difference between the maximum and minimum elevation was more than 1500 m a.s.l., it could obviously induce significant differences in precipitation and temperature which leads to different vegetation associations and diversity.

The impact of slope aspect on plant species richness, diversity and distribution pattern was less profound than elevation in the present study. The possible reason could be due to the conversion of vegetation of some slope aspects, particularly the eastern and east-related slope aspect, in the relatively lower elevations either to agriculture or to barren land. Furthermore, solar energy exposure in the tropics is not as significant as the temperate region. However, although the Ethiopian mountains are a few degrees from the equator, the solar radiation differs between the south and north aspects as a result of complex topography (Rosqvist, 1990). The explanatory contribution of slope aspect in the present study could have rather emanated from the very complex topography characterized by patches in the pocket of the mountain. The impact of slope aspect was found, thus, to be determinant in the plateau with higher elevation and samples from relatively different slope aspects.

Slope has a strong influence on determining the soil chemical and physical property. It also indirectly shapes the water retention of plants depending on how steep or flat the environment is. Topography, particularly slope, can reasonably cause accumulation and export of soil nutrients, thereby indirectly impacting plant distribution (Wang *et al.*, 2016). The explanatory contribution of slope on vegetation associations was found to be crucial in several ecological studies (Irl *et al.*, 2015; Méndez-Toribio *et al.*, 2016; Wang *et al.*, 2016; Khan *et al.*, 2017). Furthermore, Nogues-Bravo *et al.* (2008) stated that human activities have generally affected worldwide the lower and upper slopes more than the mid-elevational habitats.

In addition to topography, soil variables also play a vital role in plant development, diversity, and distribution. Edaphic factors such as pH, TN, SOC, Bulk density, clay, and avP plays a vital

role in plant species distribution (Wang *et al.*, 2016). Apart from the type of vegetation cover and geological history, topography has a vivid influence on soil chemical and physical properties; and soil water characteristics (Dinku Dessalegn *et al.*, 2014).

Anthropogenic disturbances such as livestock grazing and logging have an impact in changing the richness, diversity, distribution pattern, and vegetation structure in an ecosystem. The magnitude of their influence depends on the severity of the disturbance. Tree/shrub logging is only associated with the Ericaceous forest. Since the Ericaceous forest is privately managed and with relatively dense trees and shrubs, it is reasonable that logging is associated with this community. The other communities are either in the church forest in which cutting trees is religiously prohibited or in the grassland with relatively better management and dominated by few shrub/subshrub species, particularly, *Euryops pinifolius*. Logging induces changes in species composition and resource availability which could aggravate ecosystem transformation (Hogan *et al.*, 2016). The impact of tree cutting/logging on vegetation structure and associations were reported in Ethiopia and somewhere in the world (Haileab Zegeye *et al.*, 2006; Naudiyal & Schmerbeck, 2017; Birks *et al.*, 2018). Significant impact of tree logging, particularly, on woody and herbaceous climbers was reported in temperate forest of Xiaolong Mountain (Guo *et al.*, 2019). Management type has an undeniable impact on tree/shrub logging and further on ecosystem functioning (Naudiyal & Schmerbeck, 2017).

5.1.4. Elevation gradient vascular species richness pattern comparison between the vegetation types

The vascular plants elevational range of occurrence is the result of several factors. However, it is mainly explained by the ability of a species to withstand broader extreme conditions towards higher elevation such as moisture, temperature, and wind velocity (Morin & Lechowicz, 2011).

The monotonic decline in species richness with increasing elevation in the present study is attributed mainly to the management intensifications because people's livelihood is strongly connected to montane ecosystems (Martinelli, 2007). The DAF is managed by the EOTC for

Centuries. The EB, on the other hand, is managed privately. Furthermore, the EB is found in a very steep terrain which is not suitable for human activities such as settlement and agriculture. On the contrary, the Afroalpine grassland has a very short history of management, as community-based conservation, which is not as effective as the DAF and EB. Although it is not statistically significant, grazing is one of the disturbances happen in the Afroalpine grassland. The local climatic conditions highly wet in the higher elevation while drier in the lower elevations, and lower and higher temperature in the higher and lower elevations respectively could also affect the pattern of species richness. Furthermore, climate, biotic processes, environmental heterogeneity, and evolutionary history could also derive species richness patterns (McCain & Grytnes, 2010).

A monotonic decline in species richness with increasing elevation was reported (Mallencooper & Pickering, 2008; Sharma *et al.*, 2009; Trigas *et al.*, 2013; Yang *et al.*, 2014; Zhang *et al.*, 2016). However, most researches on elevational pattern of species richness revealed a hump-shaped (Acharya *et al.*, 2011; Ermias Aynekulu *et al.*, 2012; Ren *et al.*, 2012; Guo *et al.*, 2013; Lee *et al.*, 2013; Manish *et al.*, 2017). This could be attributed to the favorable mild environmental conditions for plant growth at middle elevation (Zhang *et al.*, 2016) despite the management and disturbance levels along elevation gradient. The mid-domain effect which displays hump-shaped pattern is highly pronounced in the transition of montane forests to Afroalpine vegetation types (Becker *et al.*, 2007). The non-generality in vascular plants species pattern along elevation gradient may be emanated from the spatial design, extent, and proportion of the gradient sampled (Rahbek, 2005; Nogues-Bravo *et al.*, 2008).

The higher Shannon diversity in the DAF and EB corresponds to the higher vascular plant species richness in these vegetation types than the AA. Although it is not necessarily, always true, high Shannon diversity is attributed to high species richness and relative abundance. Species richness is also negatively correlated with elevation (Sharma *et al.*, 2009). The higher

endemic plants richness in the AA might be associated to the isolation of the mountain zones and extreme climatic variables at the higher elevation than the lower elevations (Steinbauer *et al.*, 2016; Manish *et al.*, 2017).

Considering the elevation overlap and geographical affinity between the dry evergreen Afromontane forest and Ericaceous forest in Ethiopia in general and the current study in particular, higher similarity is expected. A floristic comparison on woody species composition of the flora of Ethiopia and Eritrea reported similar results (Friis *et al.*, 2010).

5.1.4.1. Pattern of vascular plants endemism along elevation gradient

Spatial heterogeneity and extreme microclimates such as moisture and temperature host higher endemic plants. Specialists with a very narrow niche are found in such environments. Monotonic decrease of species richness towards higher elevation doesn't necessarily reflect the monotonic decrease in endemic vascular plant species. High endemic plants at high elevation is attributed to isolation of mountain zones and high species richness at a lower elevation is attributed to evolution and dispersal (Vetaas & Grytnes, 2002; Steinbauer *et al.*, 2016). High endemic plants at a higher elevation (Steinbauer *et al.*, 2016) and mid-elevation (Wang *et al.*, 2007; Trigas *et al.*, 2013; Manish *et al.*, 2017) were reported in different continents.

5.1.4.2. Elevation gradient pattern of Growth forms

The present study revealed that tree abundance is higher at lower elevation though they also can be affected by the anthropogenic disturbance levels. Similar results were reported from eastern Himalaya (Acharya *et al.*, 2011), Tibetan Plateau (Mao *et al.*, 2018), Baekdudaegan Mountains (Lee *et al.*, 2013) and Ethiopia (Abiyot Berhanu *et al.*, 2016). Trees are often absent at higher elevation due to several constraints such as environmental, intrinsic characteristics of a species, or a multitude of disturbances (Körner, 2012).

Shrub species richness pattern followed a similar pattern to tree species richness, a monotonic decrease along elevation gradient. This could be attributed to the open canopy cover

and biotic homogenization (Zhang *et al.*, 2016; Mori *et al.*, 2018). This is supported by reports from Mountain forests of northern China (Zhang *et al.*, 2016) and sub-alpine mountainous zone in central Japan (Tsujino & Yumoto, 2013). Selective cutting of trees for different purposes such as construction, timber, and firewood together with the local climatic variation could have also contributed to the higher shrub species richness.

The inverted hump-shaped pattern of the herbaceous plant species richness could be attributed to inter-specific competition, may be the main driver of plant community assembly in the middle elevations (Zhang *et al.*, 2016). Furthermore, this shows the mountain range is rich in herbaceous plants which can adapt to extreme environments. Herbaceous plants due to their reproductive characteristics can adapt extreme environments 10 fold than woody species (Smith & Beaulieu, 2009). The lower elevation (DAF) has relatively lower moisture and higher temperature than the higher elevation Afroalpine grassland which entertains very low temperature and high moisture. As perfectly described by Hedberg (1964) the Afroalpine grassland is “*summer every day and winter every night*”. The herbaceous plants in the Afroalpine grassland have almost completely different life forms from the lower elevation plants. These include giant rosette, tussock grasses, acaulescent and cushion plants.

The pattern of Liana richness corresponds to the pattern of trees because lianas often climb on trees and rarely on shrubs. Consequently, no liana was recorded in the Afroalpine grassland whereas in the DAF and Ericaceous forest very few lianas were recorded.

5.1.5. Plant conservation status

The IUCN conservation status revealed that the majority of the plants are not assessed following the IUCN criteria. Globally only 8% of the described plant species are assessed (IUCN, 2017). In comparison to the globally IUCN assessed, less than 8%, the percentage of plants included in the IUCN Red List from the present study are higher. However, the IUCN assessed plants wouldn't be near sufficient while one-third of the plants are facing extinction risk (Pimm & Joppa, 2015). Furthermore, except the Extinct and Endangered, at least a single

species was found in all the IUCN Red List categories in the present study. This shows several plants in the mountain range are in need of prioritized conservation.

Habitat conversion into agricultural land, fragmentation and overexploitation could have led the plants to be threatened (Honnay *et al.*, 2005; Brummitt *et al.*, 2015). These are major threats to plants, particularly, in the tropics and least developed countries. Overgrazing, firewood collection, and soil erosion were also reported as threats somewhere else in the world (Din *et al.*, 2016). Furthermore, stochastic processes (Boyce, 1992; Pärtel *et al.*, 2005) and climate change (Keith *et al.*, 2014; Trull *et al.*, 2017) could have a predictable impact conservation status species. However, IUCN (2012) argued that anthropogenic threats by far outweighs the natural threats to plant extinction. Besides all the aforementioned causes, phenology-pollinator mismatches emanated from climate change would have a particular impact on the status of plants in one or other way. Significant impact of climate change on local extinction of plants were found to be profound somewhere else in the world (Buse *et al.*, 2015).

In contrast to the global conservation status, the local rarity of the vascular plants in the mountain range revealed that most of the species entertained different forms of rarity. This could be possibly due to either the mountain range is highly fragmented, degraded and encompasses major threats such as habitat conversion and fragmentation or the robustness of the method used. Because deciding the cut-off point between rare and common species, particularly, the local species range and abundance is subjective and to some extent biased. Furthermore, one of the rarity components, habitat specificity, had a strong influence on determining the rarity of the species. For example, *Lobelia rynchopetalum* is definitely restricted in the Afroalpine vegetation. Hence, even if the density of mature individuals are abundant and have wide species local range it will definitely fall into one of the rarity forms.

From a strict ecological point of view taking abundance into account, most species are rare and few are common (Spellerberg, 1992). The small population paradigm pertains to the risk

of extinction for species that are rare (Rabinowitz, 1981). However, high population alone can't be a guarantee to escape vulnerability.

In addition to population density, species range and habitat specificity also play a crucial role in determining rarity. Habitat specificity and species range are the first and second determinants of species extinction (Harnik *et al.*, 2012). However, the species range and habitat specificity are also influenced by species intrinsic behavior such as dispersal success and success to colonize a new area. Species with wider realized range and habitat specificity have less predispose to extinction than their counterparts. Species with highly abundant population but very restricted range and habitat amplitude might be prone to anthropogenic disturbances (Regan *et al.*, 2004) and stochasticity.

The species that fall in either of the rarity forms are by far greater than the common species. Several researches globally reported similar reports. A study in Switzerland by Broennimann *et al.* (2005) reported only 14% of the plants assessed were common. Furthermore, research on tree species in the southern Brazilian Atlantic rainforest revealed about 41% of the species are rare (Nasser *et al.*, 2010). A study of woody plant species rarity in different types of tropical forests Bolivia showed up to 54% of the plants are rare (Arellano *et al.*, 2014). The worst of all rarity forms is the low density of matured individuals, narrow species local range, and restricted habitat specificity, which is rarity form 7 in the present case. This is because due to their local rarity, these species are predisposed to extinction risk since demographic and environmental stochasticity will wipe out populations, and a restricted distribution means that all or most individuals will probably experience adverse conditions simultaneously (Gaston, 1998). Hence, countries with limited resources for conservation might focus on this rarity type to halt “double jeopardy” of the species (Lawton, 1993).

Locally rare plant is not necessarily a threatened plant. The reverse might be true because rarity is conditioned on the geographic scale of interest (Flather & Sieg, 2007). However, since

small populations are liable to natural and anthropogenic disturbances, rare species will have a greater extinction risk than those that are common (Boyce, 1992; Matthies *et al.*, 2004).

The causes of plant extinction risk, land transformation, per se habitat loss and fragmentation are reported to be the leading causes of rarity (Wilcove *et al.*, 1998; Honnay *et al.*, 2005; Flather & Sieg, 2007; Brummitt *et al.*, 2015). Even, Sisk *et al.* (1994) boldly claimed habitat loss has an important role in determining extinction than species commonness and rarity.

Several reports showed that exotic and invasive species are also the main causes of rarity next to habitat destruction (Wilcove *et al.*, 1998). Nevertheless, this is not the case in the present study. Because very few exotic species within a restricted habitat were recorded. However, it could not be ignored in future researches.

Direct exploitation when alternatives are missing is common practice in developing countries such as Ethiopia. However, countries in Europe such as Estonia also face such challenges. Pärtel *et al.* (2005) claimed that direct exploitation, particularly plant collection, by humans is the cause for 31% of the rarity somewhere in Estonia.

Although it lacks ecological justification to blame intrinsic characteristics of a species as the only reason for rarity (Flather & Sieg, 2007), it can predispose a species to elevated extinction risk (Pärtel *et al.*, 2005). This includes intrinsic behavior of a species such as low growth rates and few reproductive episodes such as *Lobelia rhynchopetalum* which are monocarpic plants, and intrinsic behavior of an ecosystem such as inherently low carry capacity.

Hence, habitat specificity, availability of suitable habitat, together with dispersal capability affect the potential rarity of a species (Flather & Sieg, 2007). Continuous vegetation that pronounces ecological networks such as dispersal and pollination plays an important role in determining species rarity. Despite the field observation of jeopardized ecological networks with extremely discontinuous vegetation, empirical data on the dispersal and pollination is required to conclude about the intrinsic traits of the habitat specificity available, suitable

habitats and dispersal capability of the species in the mountain range.

5.1.6. Land use and Land cover change

5.1.6.1. LULCC Dynamics

An overall accuracy level of 85% was introduced by Anderson *et al.* (1976) and it is now widely accepted and used as a standard in map accuracy assessment. The overall accuracy assessment in our analysis is higher than the accepted standard, and feel comfortable making recommendations based on this analysis.

Throughout Ethiopia, agricultural land is expanding at the expense of other land use types. Binyam Tesfaw *et al.* (2015) showed that 75% of the agricultural land today was covered by vegetation, and indicated that sparse vegetation and grassland were least affected by the agricultural expansion. However, our results revealed that Afroalpine grassland is one of the most rapidly changing land use and land cover classes in Abune Yosef mountain range. This could be due to the grasslands are becoming the target for agricultural expansion. Research in a similar ecosystem reported agricultural expansion at higher elevation took place at the expense of Afroalpine grassland (Yohannes Kidane *et al.*, 2012; Ermias Teferi *et al.*, 2013; Aramde Fetene *et al.*, 2014; Jacob *et al.*, 2015b; Sisay Hailemariam *et al.*, 2016). The increasing trend of agricultural land and urban settlements cover is observed throughout Ethiopia (Yohannes Kidane *et al.*, 2012; Ermias Teferi *et al.*, 2013; Kefyalew Sahle *et al.*, 2016; Sisay Hailemariam *et al.*, 2016; Tesfa Worku *et al.*, 2016). The Agricultural land expanded mostly at the expense of Afroalpine grassland and shrubland. The urban settlements were expanded at the expense of agricultural land and shrubland. As shown in the previous section, the population of the study area has increased tremendously which is the reason for the expansion of agricultural land and urban settlements.

Global warming could have also contributed to the expansion of agriculture to higher elevations by making those areas more hospitable to crops. The areas above 3200 m a.s.l. were

very cold and didn't support crop growth except for varieties of barley (e.g., *Hordeum vulgare*). However, today even other crops such as beans and lentils that are normally cultivated at much lower elevation - are being grown in higher elevation, implying that the Afroalpine area is becoming warmer.

Conversion of a large portion of shrubland into agricultural land has been reported throughout Ethiopia (Sisay Hailemariam *et al.*, 2016) and this trend holds in Abune Yosef mountain range as well. Deforestation is an important issue in the study area, though different forest types are changing at different rates and for different reasons. The shrubland was found in low and medium elevations in the study area, which have historically been productive agricultural areas – thus, these would have been cleared early on for agricultural land. The open woodlands that existed in 1986 were converted almost entirely into shrubland. This could be attributed to the reliance that the people living in this region have on woodland and shrubland resources for their construction and firewood needs – there are no other land use and land cover classes that provide suitable substitutions. The overwhelming decline of woodlands were reported in different parts of the country (Ermias Teferi *et al.*, 2013; Adenew Taffa *et al.*, 2015; Binyam Alemu *et al.*, 2015; Kefyalew Sahle *et al.*, 2016). Similar to the present study, a total transformation of woodlands was reported in Gubeta-Arjo, central rift valley of Ethiopia (Efrem Garedew *et al.*, 2009). These results are in contrast to a previous study (Sisay Hailemariam *et al.*, 2016) which claimed woodland is one of the least affected LULC classes and increased woodland cover (Lemlem Tadesse *et al.*, 2017).

The remnant dry evergreen montane forests in the study area are found in the surroundings of EOTC. These forests persist likely because harvesting trees is prohibited in the church forests. Alemayehu Wassie & Demel Teketay (2006) described EOTC forests as a safe haven for biodiversity, and indeed, there has been no significant church forest cover change in the present study. However, Ericaceous forest showed very slight declines. Erica forest is found at

high slopes, which may have prevented its conversion to agriculture, as these areas are not conducive to growing crops. The importance of hilly terrain for preserving vegetation was also reported in southcentral Ethiopia (Alemayehu Wassie & Demel Teketay, 2006). Forest change detection study based on historical images in Lib Amba mountain showed a loss of 63% forest between 1982 and 2010 as a result of the increasing population (Jacob *et al.*, 2015a).

In contrast to the other forest types in the study area, plantation forest showed a dramatic increase in its cover. This is likely due to two reasons. These are the loss of woodlands and shrinkage of shrubland, and the fact that some conservation and restoration practices have prohibited the utilization of woody plants from shrublands, both of which may have caused local people to plant more plantations forests. The increasing trend of plantations (mainly *Eucalyptus* spp.) has been reported throughout Ethiopia (de Mûelenaere *et al.*, 2014; Jacob *et al.*, 2015b).

Conversion of communal grazing lands into agricultural lands were reported in Ethiopia (Tesfa Worku *et al.*, 2016; Hiwet Gebremedhin *et al.*, 2018), and this is also occurring in the study area. Most of the grazing land that existed in 1986 was converted into agricultural lands mainly due to the need for securing food for the rapidly growing population. The remnant grazing land is found in very small fragments in higher elevations, and some of it has already been converted into barren land. Overgrazing and/or trampling by livestock tends to disturb the herbaceous layer and is likely a driver of conversion into barren land.

The increased cover of the barren land in the study area is attributed to the volcanic and rocky nature of the mountains, extensive soil erosion, and scarce vegetation. These results contradict with Tesfa Worku *et al.* (2016) who reported a decreasing trend of barren land in the Beressa watershed northern central highland of Ethiopia. In 1986, gullies were restricted to large rivers and riverbeds. In 2017, however, gullies had expanded everywhere including into agricultural land. The gullies correspond to land use change and deforestation. Apart from

changing the landscape mosaics, gullies can cause loss of cropland, accelerate aridification by increasing the drainage (Nyssen *et al.*, 2004; Valentin *et al.*, 2005). The increasing trend of riverbeds was reported by Jacob *et al.* (2015b) in Lib Amba mountain northern Ethiopia.

5.1.1.1. Major drivers of LULCC

In the era of Anthropocene, rapid population growth and climate change have a strong influence on LULCC dynamics. Nevertheless, failure to use ecosystem services sustainably could have also a crucial role. The causes of LULCC dynamics are examined and explained.

Experts in the field attributed the LULCC dynamics to the rapidly growing population (Meyer, 1990; Meyer & TurnerII, 1992; TurnerII *et al.*, 1994, 1995b; Jacob *et al.*, 2015b). The population in developing countries such as Ethiopia is almost entirely dependent on natural resources which leads to resource deterioration and deforestation. The population of the study area showed a tremendous increase in three decades. Although rapid population growth is one of the primary drivers of LULCC, it is not necessarily the root cause of LULCC rather it is a failure to sustainably utilize natural resources and the absence of land use policy that engages conservation efforts and practices.

In Africa, deforestation and unsustainable utilization of natural resources are the main causes of LULCC (Waweru *et al.*, 2016). Agricultural expansion and settlements at the expense of other natural land use types and deforestation without restoration are some examples of unsustainable land management. The complete conversion of woodland into shrubland in the present study is a typical example of unsustainable utilization.

Human-induced climate change has also its own share. Recently published article by Guo *et al.* (2018) revealed that land use change interacts with climate. Analysis of temperature trend in Ethiopia for the year 1983-2013 showed that temperature has already increased by 0.0265 to 0.1112 °C per year in Ethiopian highlands since 1983 (Tamene Mekonnen, 2017). Precipitation also showed a decreasing trend. The variability was pronounced in mountains

with elevation >2000 m a.s.l. Thus, human-induced climate change is also affecting the LULC, particularly vegetation cover, of the study area due to the temperature and rainfall variability.

Although the Afroalpine vegetation is designated as a community conservation area, the response of the people in the community and the government is very limited. During the course of the study, we noticed that conservation and restoration practices, particularly, in the Afroalpine vegetation is ignored.

Lack of alternatives and absences of land-use policy, not lack of awareness is forcing the community to utilize resources in every possible way. Socio-economic survey research by Girma Eshete *et al.* (2015) showed that people living in the Afroalpine areas perceived the need of protecting the Afroalpine vegetation. However, the trade-off between ecosystem services and human population is not an easy task. It is the question of feeding the human population or conserving nature (Cazalis *et al.*, 2018).

5.2. CONCLUSION

This study presented a quantitative data analysis of vascular plant species composition, plant community, and the vegetation-environment-disturbance relationship. In total 199 vascular plant species belonging to 64 families and 155 genera distributed in five plant community types were recorded. Furthermore, 13 species were recorded outside the sample plots. Twenty one percent of the floristics were found to be endemic plants. Abune Yosef mountain range is endowed with a very complex topography and wide elevation range. Consequently, it is significantly influenced by a combination of topographic variables. The canonical correspondence analysis revealed that topographic variables have a profound influence on species distribution.

Although the pattern of diversity, endemic plants richness, and growth form showed a different pattern, vascular plant species richness pattern along elevation gradient was found to be monotonically decreasing towards higher elevation. The high elevation, Afroalpine grassland, was found to host higher endemic plants while entertaining lower species richness. Five percent of the vascular plants are globally threatened. Extremely high portion, about 91.46%, of the vascular plants in the study area entertained six forms of rarity forms locally.

All LULC classes except church forests in the study area showed either positive or negative changes. Generally, agricultural land, barren land, urban settlements, plantation, and rivers, riverbeds, and gullies showed an increasing trend. On the contrary, shrubland, woodland, grazing land, and Afroalpine grassland showed a decreasing trend. Ericaceous forest/shrubland, however, showed modest change. Rapid population growth and climate variability are the main drivers of LULCC dynamics. Pressures such as settlements, agricultural expansion, deforestation and unsustainable utilization of resources affected the ecosystem, which is manifested in the loss of vegetation cover and LULC transformation. Particularly, the shrinkage of the Afroalpine grassland is due to loose land use and conservation policy.

5.3. Recommendation

The vegetation cover of the study area, particularly the Afroalpine grassland, is externally declined. Furthermore, the local conservation status of the plants revealed that most of the plants are rare. To develop conservation and management plan, the following recommendations were made:

- Floristic survey of the whole WU, particularly the lowland, should be conducted to have a complete floristic list of the floristic region.
- Most of the vascular plants in the present study are rare. Hence, the conservation status of the endemic plants at national level should be assessed following either the IUCN Red List criteria or by integrating IUCN Red list criteria with other rarity models. In addition, since the majority of the plants are rare in the mountain range, landscape-level conservation approach by establishing dispersal corridors (habitat connectivity) between the vegetation types to maintain ecological and evolutionary processes is recommended.
- The vascular plants with critically endangered (CR) and Vulnerable (VU) status needs urgent attention. Hence, National and regional Botanical gardens should take the initiative to improve the population of these species.
- The ecosystem threat status, particularly, the Afroalpine ecosystem should be assessed following the guidelines of IUCN Criteria for ecosystem assessment.
- The encroachment of the shrub/subshrub, *Euryops pinifolius*, to the Afroalpine grassland and its impact on the plant diversity should be investigated.
- The Afroalpine ecosystem is critically shrinking over time. This would definitely have a pronounced impact on the vascular plants and the people who rely their livelihood on it. The management intensity of the Afroalpine grassland should get due attention. Hence, cautiously protecting the environment by establishing a buffer zone is recommended. The Amhara Regional State government and the local community

should collaborate for the better management of the grassland.

- Abune Yosef though its nomenclature is a community conservation area, it is managed by the local government. Either the community or the government, like other protected areas in the country, should take a responsibility to safeguard Abune Yosef Afroalpine vegetation.
- Protected areas in Ethiopia often focus on a large area. However, small fragments or patches harbor significant biodiversity and have a crucial contribution to ecosystem services and functions. It is this fragments which connects the landscape. Hence, the Ericaceous forest as a small biodiversity reserve is recommended.
- Phytogeographic and taxonomic research on *P. decaisnei* is recommended.

Research outcomes

The major outcomes of the study were:

- ✎ The floristic composition of the study area investigated and herbarium specimens documented;
- ✎ Species population structure of selected trees analyzed;
- ✎ Community types of the study area identified;
- ✎ Vegetation-environmental relationships explored;
- ✎ Land use and land cover change map of the area produced
- ✎ Articles published and submitted in/to peer-reviewed journals.

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Appendix I. Floristic composition of Abune Yosef mountain range

Abbreviations: DAF = Dry evergreen Afromontane Forest, EB = Ericaceous Forest, AA = Afroalpine vegetation, T= Tree, S = Shrub, H = Herb, L = Liana, *** = no local name, CR = Critically Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, I** and R** = possibly threatened, NA = Not assessed, N-WU = new record to Welo floristic region

Voucher code: KG = collector's name, A = Afroalpine, E = Ericaceous forest, D = Dry evergreen Afromontane forest (Example. KG-DEA-16 shows KG = Kflay Gebrehiwot, DEA = the plant is distributed in the DAF, Ericaceous forest, and Afroalpine grassland, 16 = voucher number)

No.	Species	Family	Growth Form	Origin	Distribution	Local Name (Amharic)	Voucher Code	IUCN Red List status	Remark
1	<i>Achyranthes aspera</i> L.	Amaranthaceae	H		DAF	Tulinjit: ጡሊንጂት	KG-D-1	NA	
2	<i>Adiantum poiretii</i> Wikstr.	Adiantaceae	H		DAF, AA	***	KG-DA-2	NA	
3	<i>Aeonium leucoblepharum</i> A. Rich.	Crassulaceae	S		DAF, EB	Aguashir: አጓሽር	KG-DE-3	NA	N-WU
4	<i>Agrocharis melanantha</i> Hochst.	Apiaceae	H		AA	***	KG-A-4	NA	
5	<i>Agrostis quinqueseta</i> (Hochst. ex Steud.) Hochst.	Poaceae	H		AA	***	KG-A-5	NA	N-WU
6	<i>Alchemilla abyssinica</i> Fresen.	Rosaceae	H		AA	Yemidir-Koso, የምድር ኮሶ	KG-A-6	NA	
7	<i>Alchemilla pedata</i> A.Rich	Rosaceae	H		DAF, EB, AA	Yemidir-Koso, የምድር ኮሶ	KG-DEA-7	NA	
8	<i>Alisma plantago-aquatica</i> L.	Alismataceae	H		EB	***	KG-E-8	LC	
9	<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Sapindaceae	T		EB, DAF	Embis: እምብስ	KG-DE-9	LC	
10	<i>Aloe debrana</i> Christian	Aloaceae	H		DAF	Ret: ሬት	KG-D-10	LC	
11	<i>Anchusa affinis</i> R.Br. ex	Boraginaceae	H	Endemic	AA	Yewusha-Milas, የዉሻ	KG-A-11	NA	

	DC.					ምላስ			
12	<i>Andropogon abyssinicus</i> Fresen.	Poaceae	H		DAF	***	KG-D-12	NA	N-WU
13	<i>Andropogon lima</i> (Hack.) Stapf	Poaceae	H		AA	***	KG-A-13	NA	N-WU
14	<i>Anthemis tigreensis</i> J. Gay ex A. Rich.	Asteraceae	H		AA	C'iqugn, ጭቁኝ	KG-A-14	NA	
15	<i>Anthospermum herbaceum</i> L.f	Rubiaceae	H		EB	***	KG-E-15	NA	
16	<i>Arabis alpina</i> L.	Brassicaceae	H		DAF,EB,AA	***	KG-DEA-16	NA	
17	<i>Arisaema polydactylum</i> Riedl	Araceae	H	Endemic	DAF	***	KG-D-17	NA	N-WU
18	<i>Artemisia abyssinica</i> Sch. Bip. ex A. Rich.	Asteraceae	H		AA	C'iqugn, ጭቁኝ	KG-A-18	NA	
19	<i>Artemisia schimperi</i> Sch. Bip. ex Engl.	Asteraceae	H	Endemic	AA	C'iqugn, ጭቁኝ	KG-A-19	NA	N-WU
20	<i>Asparagus africanus</i> Lam.	Asparagaceae	S		DAF,EB	Kestenicha: ቀስተንቻ	KG-DE-20	NA	
21	<i>Asplenium aethiopicum</i> (Burm.f.) Bech.	Aspleniaceae	H		DAF,AA	Joro Asfit: ጆሮ አስፊት	KG-DA-21	R**	
22	<i>Astragalus atropilosulus</i> (Hochst.) Bunge	Fabaceae	H	Endemic	DAF	***	KG-D-22	LC	N-WU
23	<i>Avena abyssinica</i> Hochst.	Poaceae	H		DAF	ግንጭ: Ginch	KG-D-23	LC	N-WU
24	<i>Bartsia decurva</i> Hochst. ex Benth.	Scrophulariaceae	S		EB,AA	***	KG-EA-24	NA	N-WU
25	<i>Becium grandiflorum</i> (Lam.) Pic.Serm.	Lamiaceae	S	Endemic	DAF	Ment'esie: ሞንጠሴ	KG-D-25	NT	
26	<i>Bersama abyssinica</i> Fresen.	Meliantaceae	T		DAF	Azamir: አዛምር	KG-D-26	LC	

27	<i>Berula erecta</i> (Hudson) Coville	Apiaceae	H		AA	***	KG-A-27	LC	N-WU
28	<i>Bidens macroptera</i> (Sch. Bip. ex Chiov.) Mesfin	Asteraceae	H	Endemic	AA	Adey-Abeba, አደይ አበበ	KG-A-28	NA	
29	<i>Buddleja polystachya</i> Fresen.	Loganiaceae	S		EB,DAF	Ashkuar: አሽኪር	KG-DE-29	LC	
30	<i>Calpurnia aurea</i> (Ait.) Benth.	Fabaceae	S		DAF	Digit'a: ድግጣ	KG-D-30	LC	
31	<i>Campanula edulis</i> Forssk.	Campanulaceae	H		AA	***	KG-A-31	NA	
32	<i>Cardamine hirsuta</i> L.	Brassicaceae	H		AA	***	KG-A-32	NA	
33	<i>Carduus macracanthus</i> Sch. Bip. ex Kazmi	Asteraceae	H	Endemic	AA	Dendero: ደንደሮ	KG-A-33	NA	N-WU
34	<i>Carex peregrina</i> Link	Cyperaceae	H		EB	Sent'qo: ሰንጠቆ	KG-E-34	NA	N-WU
35	<i>Ceropegia sankurensis</i> Sehltr.	Asclepiadaceae	H		DAF	***	KG-D-35	NA	
36	<i>Cheilanthes farinosa</i> (Forssk.) Kaulf.	Sinopteridaceae	H		DAF	***	KG-D-36	NA	N-WU
37	<i>Chenopodium murale</i> L.	Chenopodiaceae	H	Exotic	DAF	***	KG-D-37	NA	N-WU
38	<i>Cineraria sebalii</i> Cufod.	Asteraceae	H	Endemic	EB,AA	***	KG- EA-38	NA	
39	<i>Clematis simensis</i> Fresen.	Ranunculaceae	L		DAF,EB	Yeazo-Hareg, የአዙ ሐረግ	KG-DE-39	NA	
40	<i>Clutia lanceolata</i> Forssk.	Euphorbiaceae	S		DAF,EB	Fiyel Fej: ፍየል-ፈጅ	KG-DE-40	NA	
41	<i>Colutea abyssinica</i> Kiunth & Bouche	Fabaceae	S		DAF,EB	Duaduate: ዲዲቲ	KG-DE-41	NA	
42	<i>Commelina benghalensis</i> L.	Commelinaceae	H		DAF	***	KG-D-42	LC	
43	<i>Conium maculatum</i> L.	Apiaceae	H		EB	***	KG-E-43	NA	N-WU

44	<i>Conyza bonariensis</i> (L.) Cronq.	Asteraceae	H		DAF	***	KG-D-44	NA	
45	<i>Conyza pedunculata</i> (Oliv.) Wild.	Asteraceae	H		DAF	***	KG-D-45	NA	
46	<i>Conyza hochstetteri</i> Sch. Bip. ex A. Rich.	Asteraceae	H		DAF	***	KG-D-46	NA	
47	<i>Conyza stricta</i> Willd.	Asteraceae	H		DAF	***	KG-D-47	NA	N-WU
48	<i>Cotula abyssinica</i> Sch. Bip. ex. A. Rich.	Asteraceae	H		AA	***	KG-A-48	NA	N-WU
49	<i>Crepis foetida</i> L.	Asteraceae	H		AA	***	KG-A-49	NA	N-WU
50	<i>Crepis rueppellii</i> Sch. Bip.	Asteraceae	H		EB	***	KG-E-50	NA	N-WU
51	<i>Crotalaria laburnifolia</i> L.	Fabaceae	H		DAF	***	KG-D-51	LC	N-WU
52	<i>Crotalaria quartiniana</i> A. Rich.	Fabaceae	H		DAF	***	KG-D-52	LC	N-WU
53	<i>Cyathula polycephala</i> Bak.	Amaranthaceae	H		DAF	***	KG-D-53	NA	N-WU
54	<i>Cynoglossum coeruleum</i> Hochst. ex A. DC. in DC.	Boraginaceae	H	Endemic	DAF	***	KG-D-54	NA	N-WU
55	<i>Cyperus elegantulus</i> Steud.	Cyperaceae	H		DAF	ሰበዥ:Sebez:	KG-D-55	NA	N-WU
56	<i>Delphinium dasycaulon</i> Fresen.	Ranunculaceae	H		DAF	***	KG-D-56	NA	
57	<i>Dicrocephala alpina</i> R.E. Fries	Asteraceae	H		AA	***	KG-A-57	NA	N-WU
58	<i>Dicrocephala chrysanthemifolia</i> (Bl.) DC.	Asteraceae	H		DAF	***	KG-D-58	NA	
59	<i>Dipsacus pinnatifidus</i> Steud. ex A. Rich.	Dipsacaceae	H		EB	Ras Kimir: ራስ ክምር	KG-E-59	NA	N-WU

60	<i>Discopodium penninervium</i> Hochst.	Solanaceae	T		EB	Gujit: ጉጅት (Qelewa: ቀለዋ)	KG-E-60	LC	
61	<i>Dodonaea angustifolia</i> L.f.	Sapindaceae	S		DAF,EB	Kitkita: ክትክታ	KG-DE-61	NA	
62	<i>Dombeya torrida</i> (J. F. Gmel.) P. Bamps	Sterculiaceae	T		DAF	***	KG-D-62	LC	
63	<i>Dregea schimperi</i> (Decne.) Bullock	Asclepiadaceae	H		DAF	***	KG-D-63	NA	N-WU
64	<i>Dryopteris schimperiana</i> (Hochst. ex A.Br) C.Chr.	Dryopteridaceae	H		EB	***	KG-E-64	NA	N-WU
65	<i>Echinops macrochaetus</i> Fresen.	Asteraceae	H		DAF,EB	Kushele: ኩሽሌ	KG-DE-65	NA	
66	<i>Epilobium stereophyllum</i> Fresen.	Onagraceae	H		AA	***	KG-A-66	NA	N-WU
67	<i>Erica arborea</i> L.	Ericaceae	T		EB	Asta: አስታ	KG-E-67	LC	
68	<i>Eriochloa fatmensis</i> (Hochst. & Steud.) W. D. Clayton	Poaceae	H		DAF	***	KG-D-68	NA	N-WU
69	<i>Euphorbia petitiana</i> A. Rich.	Euphorbiaceae	H		DAF	Antarfa: አንታርፋ	KG-D-69	NA	
70	<i>Euphorbia schimperiana</i> Scheele	Euphorbiaceae	H		DAF	Antarfa: አንታርፋ	KG-D-70	NA	
71	<i>Euryops pinifolius</i> A. Rich.	Asteraceae	S	Endemic	AAB	C'ifra/Qirshiba/C'iranfe, ጭፍራ/ቅርሽባ/ጭራንፌ	KG-A-71	VU	
72	<i>Felicia dentata</i> (A. Rich.) Dandy	Asteraceae	H		DAF	***	KG-D-72	I**	N-WU
73	<i>Festuca abyssinica</i> Hochst. ex A. Rich.	Poaceae	H		AA	Guassa, ዳሳ	KG-A-73	NA	N-WU
74	<i>Festuca macrophylla</i>	Poaceae	H		EB,AA	Sent'eqo; ሰንጦ	KG-EA-74	NA	N-WU

	Hochst. ex A. Rich.								
75	<i>Festuca richardii</i> Alexeev	Poaceae	H		AA	Guassa, ዳሳ	KG-A-75	NA	N-WU
76	<i>Festuca simensis</i> Hochst. ex A. Rich.	Poaceae	H		DAF	Guassa, ዳሳ	KG-D-76	NA	N-WU
77	<i>Ficus sycomorus</i> L.	Moraceae	T		DAF	Shola: ሸላ	KG-D-77	LC	
78	<i>Ficus vasta</i> Forssk.	Moraceae	T		DAF	Warka: ዋርካ	KG-D-78	LC	
79	<i>Filago abyssinica</i> Sch. Bip. ex A. Rich.	Asteraceae	H		EB	***	KG-E-79	NA	N-WU
80	<i>Galinsoga quadriradiata</i> Ruiz & Pavon	Asteraceae	H	Exotic	DAF	Shermut'a: ሸርጭጥ	KG-D-80	NA	
81	<i>Galium aparinoides</i> Forssk	Rubiaceae	H		DAF	Ashekit: አሸክት	KG-D-81	NA	
82	<i>Galium simense</i> Fresen.	Rubiaceae	H		EB,AA	Ashekit: አሸክት	KG-EA-82	NA	N-WU
83	<i>Gastridium phleoides</i> (Nees & Meyen) C.E. Hubb	Poaceae	H		EB	Ayne Wega: አይነ ወጋ	KG-E-83	NA	N-WU
84	<i>Geranium arabicum</i> Forssk.	Geraniaceae	H		DAF,EB,AA	***	KG-DEA-84	NA	N-WU
85	<i>Gerbera piloselloides</i> (L.) Casso.	Asteraceae	H		DAF	***	KG-D-85	NA	N-WU
86	<i>Gladiolus abyssinicus</i> (Brongn. exLemaire) Goldblatt & deVos	Iridaceae	H		DAF	Ziwaga: ዝዋጋ	KG-D-86	NA	
87	<i>Gnaphalium tweedieae</i> Hilliard	Asteraceae	H		AA	***	KG-A-87	NA	
88	<i>Hagenia abyssinica</i> (Bruce) J.F.Gmelin	Rosaceae	T		EB	Koso: ኮሶ	KG-E-88	LC	
89	<i>Halleria lucida</i> L.	Scrophulariaceae	L		EB	Yefiyel zagol: ዩፍየል ዛጎል	KG-E-89	LC	

90	<i>Haplocarpha rueppellii</i> Sch. Hip.) Beauv.	Asteraceae	H		AA	Getin, ገትጎ	KG-A-90	NA	N-WU
91	<i>Haplosciadium</i> <i>abyssinicum</i> Hochst.	Apiaceae	H		AA	Jero-Asfit, ጃሮ አስፊት	KG-A-91	NA	
92	<i>Hebenstretia angolensis</i> Rolfe	Scrophulariaceae	H		EB,AA	***	KG-EA-92	NA	
93	<i>Hedbergia abyssinica</i> (Hochst. ex Benth.) Molau	Scrophulariaceae	H		AA	***	KG-A-93	NA	
94	<i>Helichrysum citrispinum</i> Del.	Asteraceae	S		AA	T'onch: ጦጎች	KG-A-94	NA	N-WU
95	<i>Helichrysum schimperi</i> (Sch.Bip. ex A. Rich) Moeser.	Asteraceae	S		DAF,EB		KG-DE-95	NA	
96	<i>Helichrysum</i> <i>sclerochlaenum</i> Moeser	Asteraceae	H	Endemic	DAF	***	KG-D-96	NA	N-WU
97	<i>Helichrysum splendidum</i> (Thunb.) Less.	Asteraceae	S		EB	***	KG-E-97	NA	
98	<i>Herniaria abyssinica</i> Chaudhri	Caryophyllaceae	H	Endemic	AA	***	KG-A-98	NA	N-WU
99	<i>Hyparrhenia dichroa</i> (Steud.) Stapf	Poaceae	H		DAF	Senbelet': ሰንበሌጥ	KG-D-99	NA	N-WU
100	<i>Hyparrhenia hirta</i> (L.) Stapf	Poaceae	H		DAF	Senbelet': ሰንበሌጥ	KG-D-100	NA	
101	<i>Hypericum quartinianum</i> A. Rich.	Hypericaceae	T		EB	Amija: አምጃ	KG-E-101	NA	
102	<i>Hypericum revolutum</i> Vahl	Hypericaceae	T		EB	Amija: አምጃ	KG-E-102	LC	
103	<i>Hypoestes forskoolii</i> (Vahl) R. Br.	Acanthaceae	H		DAF	***	KG-E-103	NA	

104	<i>Hypoestes triflora</i> (Forssk.) Roem & Schult.	Acanthaceae	H		DAF	***	KG-D-104	NA	
105	<i>Impatiens rothii</i> Hook. F	Balsaminaceae	H	Endemic	DAF	Gushrit': ጉሸርጥ	KG-D-105	NA	N-WU
106	<i>Indigofera atriceps</i> Hook. f.	Fabaceae	H		EB	***	KG-E-106	NA	
107	<i>Inula confertiflora</i> A. Rich.	Asteraceae	S	Endemic	DAF,EB	Weynagift: ወይናግፍት	KG-DE-107	NT	
108	<i>Juniperus procera</i> Hochst. ex Endl.	Cupressaceae	T		DAF,EB	Tid: ጥድ	KG-DE-108	LC	
109	<i>Justicia schimperiana</i> (Hochst. ex Nees) T. Anders.	Acanthaceae	S		DAF	Simiza: ስሚዛ	KG-D-109	NA	
110	<i>Kalanchoe petitiana</i> A. Rich.	Crassulaceae	H	Endemic	DAF,EB	Endehula: እንደሁላ	KG-DE-110	NA	
111	<i>Kalanchoe schimperiana</i> A. Rich.	Crassulaceae	H	Endemic	DAF,EB	Endehula: እንደሁላ	KG-DE-111	R**	
112	<i>Kniphofia foliosa</i> Hochst.	Aspholidaceae	H	Endemic	AA	Ashendye, አሸንድዮ	KG-A-112	NA	
113	<i>Laggera crispata</i> (Vahl) Hepper & Wood	Asteraceae	H		DAF	***	KG-D-113	LC	N-WU
114	<i>Laggera tomentosa</i> (Sch. Bip. ex A. Rich.) Oliv. & Hiern	Asteraceae	H	Endemic	DAF	Keskese: ከስከሴ	KG-D-114	NA	
115	<i>Launaea hafunensis</i> Chiov.	Asteraceae	H		AA	***	KG-A-115	NA	
116	<i>Lavatera abyssinica</i> Hutch. & Bruce	Malvaceae	H	Endemic	DAF	***	KG-D-116	NA	
117	<i>Lippia adoensis</i> Hochst. ex Walp.	Verbenaceae	S	Endemic	DAF	***	KG-D-117	NA	
118	<i>Lobelia rhynchopetalum</i> Hemsl.	Lobeliaceae	H	Endemic	AA	Jebera, ጆበራ	KG-A-118	NA	N-WU

119	<i>Maesa lanceolata</i> Forssk.	Myrsinaceae	S		DAF	Qelewa: ቀለዋ	KG-D-119	NA	
120	<i>Malva verticillata</i> L.	Malvaceae	H		DAF,AA	Lit, ልት	KG-AD-120	NA	
121	<i>Maytenus arbutifolia</i> (A. Rich.) Wilczek	Celastraceae	S		DAF,EB	At'at': አጣጥ	KG-DE-121	NA	
122	<i>Maytenus obscura</i> (A. Rich.) Cuf.	Celastraceae	S		DAF,EB	Kumbel: ኩምበል	KG-DE-122	NA	N-WU
123	<i>Mentha pulegium</i> L.	Lamiaceae	H		AAB	***	KG-A-123	LC	N-WU
124	<i>Mikaniopsis clematoides</i> (Sch. Bip. ex A. Rich.) Milne-Redh.	Asteraceae	H	Endemic	DAF,EB	Gobez asfi: ጎበዝ አስፊ	KG-DE-124	NA	
125	<i>Minuartia ellenbeckii</i> (Engl.) M. Gilbert	Caryophyllaceae	H		EB	***	KG-E-125	NA	N-WU
126	<i>Minuartia filifolia</i> (Forssk.) Mattf.	Caryophyllaceae	H		AA	***	KG-A-126	NA	
127	<i>Mukia maderaspatana</i> (L.) M.J. Roem.	Cucurbitaceae	H		EB	Nec' Hareg: ነጭ ሐረግ	KG-E-127	NA	
128	<i>Myrica salicifolia</i> A. Rich.	Myricaceae	T		EB	Shinet: ሽነት	KG-E-128	NA	
129	<i>Myrsine africana</i> L.	Myrsinaceae	S		DAF,EB	Qec'emo: ቀጫሞ	KG-DE-129	LC	
130	<i>Nepeta azurea</i> R. Br. ex Benth.	Lamiaceae	H		AA	Kermo-Ayned, ከርሞ አይነድ	KG-A-130	NA	
131	<i>Nothoperanema squamiseta</i> (Hook) Ching	Dryopteridaceae	H		DAF	***	KG-D-131	NA	
132	<i>Nuxia congesta</i> R.Br. ex Fresen.	Loganiaceae	T		EB	Ashkuar: አሽኪር	KG-E-132	LC	
133	<i>Oenanthe palustris</i> (Chiov.) Norman	Apiaceae	H		EB	***	KG-E-133	NA	N-WU
134	<i>Olea europaea</i> L. subsp.	Oleaceae	T		DAF,EB	Weyra: ወይራ	KG-DE-134	LC	

	<i>cuspidata</i> (Wall. ex G.Don) Cif								
135	<i>Oplismenus hirtellus</i> (L.) P. Beauv.	Poaceae	H		DAF	Qey sar: ቀይ ሳር	KG-D-135	NA	N-WU
136	<i>Oreophyton falcatum</i> (A.Rich) O.S. Schulz	Brassicaceae	H		AA	***	KG-A-136	NA	N-WU
137	<i>Osyris quadripartita</i> Decn.	Santalaceae	S		DAF,EB	Qeret: ቀረጥ	KG-DE-137	LC	
138	<i>Otostegia fruticosa</i> (Forssk.) Schweinf ex Penzig.	Lamiaceae	S		EB	Nec'ilo:ነጭሎ	KG-E-138	NA	N-WU
139	<i>Panicum coloratum</i> L.	Poaceae	H		DAF	Yeqqoqe Sar: የቆቅ ሳር	KG-D-139	NA	N-WU
140	<i>Papaver aff. decaisnei</i> Hochst. ex Steud	Papaveraceae	H		AA	Yemariam wanc'a: የማርያም ዋንጫ	KG-A-140	NA	N-FEE
141	<i>Pelargonium glechomoides</i> Hochst.	Geraniaceae	H		EB	***	KG-E-141	NA	
142	<i>Pentarrhinum abyssinicum</i> Decne	Asclepiadaceae	H		EB	Yeayit' Hareg: የአይጥ ሐረግ	KG-E-142	VU	N-WU
143	<i>Periploca linearifolia</i> Quart.-Dill. & A. Rich.	Asclepiadaceae	L		DAF	***	KG-D-143	NA	
144	<i>Phagnalon abyssinicum</i> Sch. Bip. ex A. Rich.	Asteraceae	H	Endemic	DAF,EB,AA	Nihode: ንሆዴ	KG-DEA-144	NA	
145	<i>Pimpinella oreophila</i> Hook. J	Apiaceae	H		DAF	***	KG-D-145	NA	N-WU
146	<i>Plantago lanceolata</i> L.	Plantaginaceae	H		EB	***	KG-E-146	VU	
147	<i>Plectranthus garckeianus</i> (Vatke) J.K. Morton	Lamiaceae	H	Endemic	DAF	***	KG-D-147	NA	N-WU
148	<i>Polygala steudneri</i> Chod.	Polygalaceae	H		DAF	***	KG-D-148	NA	
149	<i>Polypogon monspeliensis</i>	Poaceae	H		AA	***	KG-A-149	LC	N-WU

	(L.) Desf.								
150	<i>Ranunculus multifidus</i> Forssk.	Ranunculaceae	H		AA	***	KG-A-150	LC	
151	<i>Rhabdotosperma keniensis</i> (Mur.) Hartl	Scrophulariaceae	H		DAF	***	KG-D-151	NA	
152	<i>Rhamnus staddo</i> A. Rich	Rhamnaceae	S		EB	T'edo: ጠዶ	KG-E-152	LC	N-WU
153	<i>Rhus natalensis</i> Krauss.	Anacardiaceae	T		EB	Talo: ታሎ	KG-E-153	LC	
154	<i>Rhus retinorrhoea</i> Oliv.	Anacardiaceae	T		DAF,EB	Talo: ታሎ	KG-DE- 154	NA	
155	<i>Rhynchosia stipulosa</i> A. Rich.	Fabaceae	H		DAF	Hareg: ሓረግ	KG-D-155	R**	N-WU
156	<i>Roeperocharis urbaniana</i> Kraenzl	Orchidaceae	H	Endemic	DAF	***	KG-D-156	NA	N-WU
157	<i>Rosa abyssinica</i> Lindley	Rosaceae	S		DAF,EB	Qega: ቀጋ	KG-DE- 157	NA	
158	<i>Rumex nepalensis</i> Spreng.	Polygonaceae	H		DAF	Tult, ቱልት	KG-D-158	NA	
159	<i>Rumex nervosus</i> Vahl	Polygonaceae	S		DAF	Embuac' o, እምቧጭ	KG-D-159	NA	
160	<i>Sagina abyssinica</i> A. Rich.	Caryophyllaceae	H	Endemic	AA	***	KG-A-160	NA	N-WU
161	<i>Salvia merjamie</i> Forssk.	Lamiaceae	H		EB,AA	Dimba, ዲምባ	KG-EA- 161	NA	
162	<i>Satureja abyssinica</i> (Benth.) Briq.	Lamiaceae	H		DAF,AA	***	KG-DEA- 162	NA	
163	<i>Satureja imbricata</i> (Forssk.) Briq.	Lamiaceae	S		DAF,EB,AA	***	KG-DEA- 163	NA	N-WU
164	<i>Satureja paradoxa</i> (Vatke) Engl. ex Seybold	Lamiaceae	H	Endemic	AA	***	KG-A-164	NA	N-WU
165	<i>Satureja pseudosimensis</i> Brenan	Lamiaceae	H		AA	***	KG-A-165	NA	N-WU

166	<i>Satureja punctata</i> (Benth.) Briq.	Lamiaceae	H		AA	***	KG-A-166	NA	
167	<i>Scabiosa columbaria</i> L.	Dipsacaceae	H		DAF,EB,AA	***	KG-DEA-167	R**	
168	<i>Scleranthus annuus</i> L.	Caryophyllaceae	H		AA	***	KG-A-168	NA	
169	<i>Senecio farinaceus</i> Sch. Bip. ex A. Rich.	Asteraceae	H	Endemic	AA	Shebeta, ሸበታ	KG-A-169	NA	N-WU
170	<i>Senecio fresenii</i> Sch. Bip. ex Oliv. & Hiern	Asteraceae	H	Endemic	EB,AA	***	KG-EA-170	NA	N-WU
171	<i>Senecio nanus</i> Sch. Bip. ex A. Rich.	Asteraceae	H	Endemic	AA	***	KG-A-171	NA	N-WU
172	<i>Senecio schultzii</i> Hochst. ex A. Rich.	Asteraceae	H	Endemic	AA	Gime, ግጫ	KG-A-172	NA	N-WU
173	<i>Senecio subsessilis</i> Oliv. & Hiern	Asteraceae	H		DAF,EB	***	KG-DE-173	NA	N-WU
174	<i>Sida ternata</i> L.f.	Malvaceae	H		DAF	***	KG-D-174	NA	
175	<i>Silene macrosolen</i> A. Rich.	Caryophyllaceae	H		EB,AA	Wegert, ወገረት	KG-EA-175	NA	
176	<i>Solanum adoense</i> Hochst. Ex A. Rich.	Solanaceae	S		EB,DAF	Yemidir Embuay: የምድር እምቢይ	KG-DE-176	NA	N-WU
177	<i>Solanum anguivi</i> Lam.	Solanaceae	S		DAF	Yewusha Awut': የዉሻ አዉጥ	KG-D-177	NA	
178	<i>Solanum marginatum</i> L.f.	Solanaceae	S	Endemic	DAF	Embuay: እምቢይ	KG-D-178	NA	
179	<i>Solanum schimperianum</i> Hochst. ex A. Rich.	Solanaceae	S		DAF	***	KG-D-179	NA	N-WU
180	<i>Sonchus melanolepis</i> Fresen.	Asteraceae	H	Endemic	AA	Yeahiya wetet: የአሀያ ወተት	KG-A-180	NA	
181	<i>Sparmannia ricinocarpa</i> (Eckl. & Zeyh.) O. Ktze.	Tiliaceae	S		EB	***	KG-E-181	NT	N-WU

182	<i>Stellaria media</i> (L.) Vill.	Caryophyllaceae	H		AA	***	KG-A-182	NA	
183	<i>Swertia engleri</i> Gilg	Gentianaceae	H	Endemic	AA	***	KG-A-183	NA	
184	<i>Tagetes minuta</i> L.	Asteraceae	H	Exotic	DAF	***	KG-D-184	NA	
185	<i>Thalictrum schimperianum</i> Hochst. ex Schweinf.	Ranunculaceae	H	Endemic	DAF	***	KG-D-185	NA	N-WU
186	<i>Thymus schimperi</i> Ronniger	Lamiaceae	H	Endemic	DAF,EB,AA	T'osign, ጦስኝ	KG-DEA-186	NA	
187	<i>Trifolium arvense</i> L.	Fabaceae	H		DAF	Maget': ማገጥ	KG-D-187	LC	N-WU
188	<i>Trifolium rueppellianum</i> Fresen.	Fabaceae	H		DAF	Maget': ማገጥ	KG-D-188	LC	
189	<i>Trifolium schimperi</i> A. Rich	Fabaceae	H	Endemic	DAF	Maget': ማገጥ	KG-D-189	LC	
190	<i>Trifolium simense</i> Fresen.	Fabaceae	H		DAF	Maget': ማገጥ	KG-D-190	LC	N-WU
191	<i>Urera hypselodendron</i> (A. Rich.) Wedd.	Urticaceae	L		DAF	***	KG-D-191	NA	N-WU
192	<i>Urtica simensis</i> Steudel	Urticaceae	H	Endemic	DAF, EB, AA	Sama, ሰማ	KG-DEA-192	NA	
193	<i>Verbascum arbusculum</i> (A. Rich.) Hub.-Mor.	Scrophulariaceae	H		AA	***	KG-A-193	CR	N-WU
194	<i>Verbascum benthamianum</i> Hepper	Scrophulariaceae	H	Endemic	AA	***	KG-A-194	NA	N-WU
195	<i>Verbascum stelurum</i> Murb.	Scrophulariaceae	H	Endemic	EB	Qut'int'ina: ቁጢንጢን	KG-E-195	NA	N-WU
196	<i>Vernonia bipontini</i> Vatke var. <i>gonderensis</i> S. Wattimah & Mesfin	Asteraceae	S	Endemic	DAF,EB	T'ija C'enger: ጥቻ ጨንገር	KG-DE-196	NA	
197	<i>Vernonia rueppellii</i> Sch. Bip. ex Walp.	Asteraceae	T	Endemic	EB	T'ikur Gujit: ጥቁር ጉጅት	KG-E-197	NA	
198	<i>Veronica glandulosa</i>	Scrophulariaceae	H		AA	***	KG-A-198	NA	N-WU

	Hochst. ex Benth.								
199	<i>Zehneria scabra</i> (Linn.f.) Sond.	Cucurbitaceae	H		DAF,EB	Nec'-Hareg: ነጭ ሓረግ	KG-DE-199	NA	
Outside sample plots									
200	<i>Carex monostachya</i> A. Rich.	Cyperaceae	H		AA	Qirtan: ቅርጥን	KG-A-200	VU	N-WU
201	<i>Cheilanthes erythraea</i> Pic.Serm	Sinopteridaceae	H		AA	***	KG-A-201	NA	N-WU
202	<i>Delosperma abyssinica</i> (Regel) Schwantes	Aizoaceae	H		AA	Yelam-T'ut: የላም ጡት	KG-A-202	CR	N-WU
203	<i>Haplocarpha schimperi</i> (Sch. Rip.) Beauv.	Asteraceae	H		AA	Getin: ገትን	KG-A-203	NA	
204	<i>Hesperantha petitiana</i> (A. Rich.) Baker	Iridaceae	H		AA	***	KG-E-204	NA	N-WU
205	<i>Phytolacca dodecandra</i> L 'Herit.	Phytolaccaceae	S		EB	Endod: እንዶድ	KG-E-205	NA	
206	<i>Primula verticillata</i> Forssk. subsp. <i>simensis</i> (Hochst.) W.W.Sm. & Forest	Primulaceae	H	Endemic	AA	May may: ማይ ማይ	KG-A-206	NA	N-WU
207	<i>Rostraria cristata</i> (L.) Tzvelev	Poaceae	H		EB	Sent'eqo; ሰንጠቆ	KG-E-207	NA	
208	<i>Rumex abyssinicus</i> Jacq.	Polygonaceae	H		DAF	Meqemeq o: ሙቀሙቆ	KG-D-208	NA	N-WU
209	<i>Scolopia theifolia</i> Gilg	Flacourtiaceae	T		DAF	***	KG-D-209	NA	N-WU
210	<i>Solanecio gigas</i> (Vatke) C. Jeffrey	Asteraceae	S	Endemic	AA	Gime Kitel, ግሜ ቅጠል	KG-A-210	NA	
211	<i>Umbilicus botryoides</i> A. Rich.	Crassulaceae	H		AA	Misir-Qit'a, ምስር ቂጥ	KG-A-211	NA	N-WU
212	<i>Vulpia bromoides</i> (L.) S.F. Gray	Poaceae	H	NA-CL	AA	***	KG-A-212	NA	N-WU

Appendix II: Species rarity forms in Abune Yosef mountain range (DMI = Density of mature individuals)

Species	Geographic Range		Habitat specificity		DMI		Rarity Form
	Wide	Narrow	Wide spread	Restricted	Abundant	Scarce	
<i>Achyranthes aspera</i>		N		R	A		Form 6
<i>Adiantum poiretii</i> var. <i>poiretii</i>	W		WS			S	Form 1
<i>Aeonium leucoblepharum</i>		N	WS			S	Form 4
<i>Agrocharis melanantha</i>		N		R		S	Form 7
<i>Agrostis quinqueseta</i>		N		R		S	Form 7
<i>Alchemilla abyssinica</i>		N		R	A		Form 6
<i>Alchemilla pedata</i>	W		WS		A		Common
<i>Alisma plantago-aquatica</i>		N		R		S	Form 7
<i>Allophylus abyssinicus</i>	W		WS			S	Form 1
<i>Aloe debrana</i>		N		R		S	Form 7
<i>Anchusa affinis</i>		N		R		S	Form 7
<i>Andropogon abyssinicus</i>		N		R		S	Form 7
<i>Andropogon lima</i>		N		R		S	Form 7
<i>Anthemis tigreensis</i>		N		R		S	Form 7
<i>Anthospermum herbaceum</i>		N		R		S	Form 7
<i>Arabis alpina</i>	W		WS		A		Common
<i>Arisaema polydactylum</i>		N		R		S	Form 7
<i>Artemisia abyssinica</i>		N		R		S	Form 7
<i>Artemisia schimperi</i>		N		R		S	Form 7
<i>Asparagus africanus</i>		N	WS			S	Form 5
<i>Asplenium aethiopicum</i>		N	WS			S	Form 5
<i>Astragalus atropilosulus</i>		N		R		S	Form 7
<i>Avena abyssinica</i>		N		R		S	Form 7
<i>Bartsia decurva</i>	W		WS			S	Form 1

<i>Becium grandiflorum</i>		N		R	A		Form 6
<i>Bersama abyssinica</i>		N		R		S	Form 7
<i>Berula erecta</i>		N		R		S	Form 7
<i>Bidens macroptera</i>		N		R		S	Form 7
<i>Buddleja polystachya</i>	W		WS			S	Form 1
<i>Calpurnia aurea</i>		N		R		S	Form 7
<i>Campanula edulis</i>		N		R		S	Form 7
<i>Cardamine hirsuta</i>		N		R		S	Form 7
<i>Carduus macracanthus</i>		N		R		S	Form 7
<i>Carex peregrina</i>		N		R		S	Form 7
<i>Ceropegia sankurensis</i>		N		R		S	Form 7
<i>Cheilanthes farinosa</i>		N		R		S	Form 7
<i>Chenopodium murale</i>		N		R		S	Form 7
<i>Cineraria sebalzii</i>	W		WS		A		Common
<i>Clematis simensis</i>		N	WS			S	Form 5
<i>Clutia lanceolata</i>	W		WS		A		Common
<i>Colutea abyssinica</i>	W		WS			S	Form 1
<i>Commelina benghalensis</i>		N		R		S	Form 7
<i>Conium maculatum</i>		N		R		S	Form 7
<i>Conyza bonariensis</i>		N		R		S	Form 7
<i>Conyza hochstetteri</i>		N		R		S	Form 7
<i>Conyza pedunculata</i>		N		R		S	Form 7
<i>Conyza stricta</i>		N		R	A		Form 6
<i>Cotula abyssinica</i>		N		R	A		Form 6
<i>Crepis foetida</i>		N		R	A		Form 6
<i>Crepis ruppellii</i>		N		R	A		Form 6
<i>Crotalaria laburnifolia</i>		N		R		S	Form 7
<i>Crotalaria quartiniana</i>		N		R		S	Form 7
<i>Cyathula polycephala</i>		N		R		S	Form 7

<i>Cynoglossum coeruleum</i>		N		R		S	Form 7
<i>Cyperus elegantulus</i>		N		R	A		Form 6
<i>Delphinium dasycaulon</i>		N		R		S	Form 7
<i>Dicrocephala alpina</i>		N		R	A		Form 6
<i>Dicrocephala chrysanthemifolia</i>		N		R		S	Form 7
<i>Dipsacus pinnatifidus</i>		N		R		S	Form 7
<i>Discopodium penninervium</i>	W		WS			S	Form 1
<i>Dodonaea angustifolia</i>		N	WS			S	Form 5
<i>Dombeya torrida</i>		N		R		S	Form 7
<i>Dregea schimperi</i>		N		R		S	Form 7
<i>Dryopteris schimperiana</i>		N		R	A		Form 6
<i>Echinops macrochaetus</i>		N		R		S	Form 7
<i>Epilobium stereophyllum</i>		N		R	A		Form 6
<i>Erica arborea</i>		N		R	A		Form 6
<i>Eriochloa fatmensis</i>		N		R	A		Form 6
<i>Euphorbia petitiana</i>		N		R		S	Form 7
<i>Euphorbia schimperiana</i>		N		R		S	Form 7
<i>Euryops pinifolius</i>		N		R	A		Form 6
<i>Felicia dentata</i>		N		R		S	Form 7
<i>Festuca abyssinica</i>		N		R	A		Form 6
<i>Festuca macrophylla</i>	W		WS		A		Common
<i>Festuca richardii</i>		N		R		S	Form 7
<i>Festuca simensis</i>	W		WS			S	Form 1
<i>Ficus sycomorus</i>		N		R		S	Form 7
<i>Ficus vasta</i>		N		R		S	Form 7
<i>Filago abyssinica</i>		N		R		S	Form 7
<i>Galinsoga quadriradiata</i>		N		R	A		Form 6
<i>Galium aparinoides</i>		N		R	A		Form 6

<i>Galium simense</i>	W		WS		A		Common
<i>Gastridium phleoides</i>		N		R		S	Form 7
<i>Geranium arabicum</i>	W		WS		A		Common
<i>Gerbera piloselloides</i>		N		R		S	Form 7
<i>Gladiolus abyssinicus</i>		N		R		S	Form 7
<i>Gnaphalium tweedieae</i>		N		R	A		Form 6
<i>Hagenia abyssinica</i>		N		R		S	Form 7
<i>Halleria lucida</i>		N		R		S	Form 7
<i>Haplocarpha rueppellii</i>		N		R	A		Form 6
<i>Haplosciadium abyssinicum</i>		N		R		S	Form 7
<i>Hebenstretia angolensis</i>	W		WS		A		Common
<i>Hedbergia abyssinica</i>		N		R		S	Form 7
<i>Helichrysum citrispinum</i>		N		R		S	Form 7
<i>Helichrysum schimperii</i>	W		WS			S	Form 1
<i>Helichrysum sclerochlaenum</i>		N		R		S	Form 7
<i>Helichrysum splendidum</i>		N		R		S	Form 7
<i>Herniaria abyssinica</i>		N		R		S	Form 7
<i>Hyparrhenia dichroa</i>		N		R		S	Form 7
<i>Hyparrhenia hirta</i>		N		R		S	Form 7
<i>Hypericum quartinianum</i>		N		R		S	Form 7
<i>Hypericum revolutum</i>		N		R		S	Form 7
<i>Hypoestes forskalii</i>		N		R	A		Form 6
<i>Hypoestes triflora</i>		N		R	A		Form 6
<i>Impatiens rothii</i>		N		R		S	Form 7
<i>Indigofera atriceps</i>		N		R		S	Form 7
<i>Inula confertiflora</i>	W		WS		A		Common
<i>Juniperus procera</i>	W		WS		A		Common
<i>Justicia schimperiana</i>		N		R		S	Form 7

<i>Kalanchoe petitiiana</i>		N	WS			S	Form 5
<i>Kalanchoe schimperiana</i>		N	WS			S	Form 5
<i>Kniphofia foliosa</i>		N		R	A		Form 6
<i>Laggera crispata</i>		N		R		S	Form 7
<i>Laggera tomentosa</i>		N		R		S	Form 7
<i>Launaea hafunensis</i>		N		R		S	Form 7
<i>Lavatera abyssinica</i>		N		R		S	Form 7
<i>Lippia adoensis</i>		N		R		S	Form 7
<i>Lobelia rhynchopetalum</i>		N		R	A		Form 6
<i>Maesa lanceolata</i>		N		R		S	Form 7
<i>Malva verticillata</i>	W		WS		A		Common
<i>Maytenus arbutifolia</i>		N	WS			S	Form 5
<i>Maytenus obscura</i>	W		WS			S	Form 1
<i>Mentha pulegium</i>		N		R	A		Form 6
<i>Mikaniopsis clematoides</i>		N	WS			S	Form 5
<i>Minuartia ellenbeckii</i>		N	WS			S	Form 5
<i>Minuartia filifolia</i>		N		R		S	Form 7
<i>Mukia maderaspatana</i>		N		R		S	Form 7
<i>Myrica salicifolia</i>		N		R		S	Form 7
<i>Myrsine africana</i>	W		WS			S	Form 1
<i>Nepeta azurea</i>		N	WS		A		Form 4
<i>Nothoperanema squamiseta</i>		N		R		S	Form 7
<i>Nuxia congesta</i>		N		R		S	Form 7
<i>Oenanthe palustris</i>		N		R		S	Form 7
<i>Olea europaea</i> L. subsp. <i>cuspidata</i>	W		WS			S	Form 1
<i>Oplismenus hirtellus</i>		N	WS		A		Form 4
<i>Oreophyton falcatum</i>		N		R		S	Form 7
<i>Osyris quadripartita</i>		N	WS		A		Form 4
<i>Otostegia fruticosa</i>		N		R		S	Form 7

<i>Panicum coloratum</i>		N		R		S	Form 7
<i>Papaver aff. decaisnei</i>		N		R		S	Form 7
<i>Pelargonium glechomoides</i>		N		R		S	Form 7
<i>Pentarrhinum abyssinicum</i>		N		R		S	Form 7
<i>Periploca linearifolia</i>		N		R	A		Form 6
<i>Phagnalon abyssinicum</i>	W		WS		A		Common
<i>Pimpinella oreophila</i>		N		R		S	Form 7
<i>Plantago lanceolata</i>	W			R		S	Form 3
<i>Plectranthus garckeanus</i>		N		R		S	Form 7
<i>Polygala steudneri</i>		N		R		S	Form 7
<i>Polypogon monspeliensis</i>		N		R		S	Form 7
<i>Ranunculus multifidus</i>		N		R	A		Form 6
<i>Rhabdotosperma keniensis</i>		N		R		S	Form 7
<i>Rhamnus staddo</i>		N		R		S	Form 7
<i>Rhus natalensis</i>		N		R		S	Form 7
<i>Rhus retinorrhoea</i>		N	WS			S	Form 5
<i>Rhynchosia stipulosa</i>		N		R	A		Form 6
<i>Roeperocharis urbaniana</i>		N		R		S	Form 7
<i>Rosa abyssinica</i>	W		WS		A		Common
<i>Rumex nepalensis</i>	W		WS			S	Form 1
<i>Rumex nervosus</i>		N		R		S	Form 7
<i>Sagina abyssinica</i>		N		R		S	Form 7
<i>Salvia merjamie</i>	W		WS			S	Form 1
<i>Satureja abyssinica</i>		N		R	A		Form 6
<i>Satureja imbricata</i>		N	WS		A		Form 4
<i>Satureja paradoxa</i>		N		R		S	Form 7
<i>Satureja pseudosimensis</i>		N		R		S	Form 7
<i>Satureja punctata</i> subsp. <i>punctata</i>		N		R		S	Form 7
<i>Scabiosa columbaria</i>	W		WS		A		Common

<i>Scleranthus annuus</i>		N		R		S	Form 7
<i>Senecio farinaceus</i>		N		R	A		Form 6
<i>Senecio fresenii</i>	W		WS			S	Form 1
<i>Senecio nanus</i>		N		R	A		Form 6
<i>Senecio schultzii</i>		N		R	A		Form 6
<i>Senecio subsessilis</i>		N	WS			S	Form 5
<i>Sida ternata</i>		N		R	A		Form 6
<i>Silene macrosolen</i>	W		WS			S	Form 1
<i>Solanum adoense</i>		N	WS			S	Form 5
<i>Solanum anguivi</i>		N		R		S	Form 7
<i>Solanum marginatum</i>		N		R		S	Form 7
<i>Solanum schimperianum</i>		N		R		S	Form 7
<i>Sonchus melanolepis</i>		N		R		S	Form 7
<i>Sparmannia ricinocarpa</i>		N		R		S	Form 7
<i>Stellaria media</i>		N		R	A		Form 6
<i>Swertia engleri</i>		N		R		S	Form 7
<i>Tagetes minuta</i>		N		R	A		Form 6
<i>Thalictrum schimperianum</i>		N		R		S	Form 7
<i>Thymus schimperi</i>	W		WS		A		Common
<i>Trifolium arvense</i>		N		R		S	Form 7
<i>Trifolium rueppellianum</i>	W		WS		A		Common
<i>Trifolium schimperi</i>		N		R		S	Form 7
<i>Trifolium simense</i>		N		R	A		Form 6
<i>Urera hypselodendron</i>		N		R		S	Form 7
<i>Urtica simensis</i>	W		WS		A		Common
<i>Verbascum arbusculum</i>		N		R		S	Form 7
<i>Verbascum benthamianum</i>		N		R		S	Form 7
<i>Verbascum stelurum</i>		N		R		S	Form 7

<i>Vernonia bipontini</i> var. <i>gonderensis</i>		N	WS			S	Form 5
<i>Vernonia rueppellii</i>		N		R		S	Form 7
<i>Veronica glandulosa</i>		N		R	A		Form 6
<i>Zehneria scabra</i>		N	WS		A		Form 4

Declaration

I, the undersigned declare that this Dissertation is my original work and it has not been presented in other universities, colleges or institutes for a degree or other purpose. All sources of the materials used have been duly acknowledged.

Name: Kflay Gebrehiwot Signature: _____ Date: _____