Addis Ababa University

Department of Plant Biology and Biodiversity Management

Ecological Study of the Vegetation and Land use/ Land cover Change Analysis in Dega Damot District, West Gojjam Zone, Amhara Region, Northwestern Ethiopia

Ph.D. Dissertation

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Ecological Study of the Vegetation and Land use/ Land cover Change Analysis in Dega Damot District, West Gojjam Zone, Amhara Region, Northwestern Ethiopia

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This is to certify that the thesis prepared by Liyew Birhanu Baylie, entitled ***Ecological Study of the Vegetation and Land use/Land cover Change Analysis in Dega Damot District, West Gojjam Zone, Amhara Region, Northwestern Ethiopia***, and submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Plant Biology and Biodiversity Management complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

The rising of deforestation and habitat fragmentation due to the conversion of forests to other land use/ land cover types and the increasing human population are major environmental concerns in the northwestern dry Afromontane forest of Ethiopia. Understanding floristic diversity along environmental factors is essential in the management of the forest patches. The objective of the study is to investigate the Ecology of the vegetation and to study Land use/ Land cover change in Dega Damot district forest patches of Northwestern Ethiopia. Vegetation and environmental data were collected from 86 plots (30 m × 30 m). A total of 46 plots were used for the collection of the soil seed bank and aboveground vegetation. Soil samples were collected for the soil bank study from within the small plots measuring 10 cm × 10 cm from four soil layers. Shannon Weiner index and evenness were used to assess the species diversity and richness of the forest. The similarities between forest patches and between plant communities of the study area were computed using Sorenson's similarity index. Density, Diameter at Breast Height (DBH), basal area, frequency, and importance value indices (IVI) of woody species were computed to characterize the vegetation structure of the forest. Hierarchical cluster analysis and redundancy analysis (RDA) were used to identify plant communities and analyze the relationship between plant community types and environmental variables. This study used Landsat TM, Landsat ETM + and OLI data from 1986, 2003 and 2017 to map land use/land cover (LU/LC) in a study area. LU/LC maps were created using supervised classification, and LU/LC change the mapping for the 1986-2003 and the 2003-2017 period determined using post-classification comparisons. Results indicate the presence of 176 plant species belonging to 80 families. Asteraceae and Fabaceae were the dominant families, and herbs and shrubs were predominant growth forms. The Shannon diversity index and evenness values of the study area were 2.79 and 0.95 respectively. The total basal area and density of woody species were 51 m^2 ha^{-1} and 2679 $individual^{-1}$, respectively. The most dominant species as indicated by their important value index (lVI) were prunes africana(17), Schefflera abyssinica (15) and Ficus sur (14). Five plant community types were identified: Erica arborea - Osyris quadripartita, Discopodium penninervium - Echinops pappii, Olea europaeasubsp.cuspidata-Scolopia theifolia, Euphorbia abyssinica-Prunus africana, Dodonaea anguistifolia-Acokanthera schimperi. The RDA result showed that the variation of species distribution and plant community formation were significantly related to altitude, organic matter, moisture content, slope, pH, EC, clay and phosphorus. A total of 2133 seedlings belonging to 44 species and 27 families were identified from the soil seed bank, with a viable seed density of 4636 $seeds/m^{2.}$ The species composition of the seed bank was dominated by 29 herb species (66%) compared to 2 tree species which accounted for only 5 percent of the total number of species. The similarity between soil seed bank species composition and aboveground vegetation was low and conclude that the regeneration potential of the forest from seed bank was limited. The results of the study showed that *agricultural land increased from 85% of the total area in 1986 to 93% in 2017. This increase coincided with a 4% decrease in a forested area, a 2% decrease in grazing land and a 2% decrease in shrubland. LU/LC was changed significantly due to rapid human populations and expanding agricultural activities in the study area. Therefore, this study provides baseline information for the conservation of forest in the study area.*

Key-words/phrases: *Floristic composition, habitat fragmentation, vegetation structure, plant communities, soil seed bank, Land use/ land cover change*

Dedication

I dedicate this thesis to the people of Dega Damot district for their entire all-out efforts in various ways.

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LIST OF ACRONYMS

AA____ Afro-Alpine vegetation

ACB Acacia-Commiphora woodland and Bushland

ANOVA Analysis of variance

ASTER GDEM Aster Global Digital Elevation Map

BA Basal area

CCA Canonical Correspondence Analysis

CEC Cation Exchange Capacity

CSA Central Statistical Agency of Ethiopia

CTW *Combretum–Terminalia* Woodland and wooded grassland

DAF Dry evergreen Afromontane forest and grassland complex vegetation

DBH Diameter at Breast Height

DEM Digital Elevation Model

DSS Desert and Semi-desert Scrubland

EC Electrical Conductivity

EEFRI Ethiopian Environment and Forest Research Institute

EFAP Ethiopian Forestry Action Program

EB Ericaceous Belt

EROS Earth Resources Observation and Science.

FAO Food and Agriculture Organizations of the United Nations

FLV Freshwater Lakes Vegetation

FRC Forestry Research Center

GIS Geographic Information System

GPS Global Positioning System

ISA	Indicator Species Analysis
IUCN	International Union for the Conservation of Nature
IVI	Importance Value Index
Landsat 7 ETM+	Landsat Enhanced Thematic Mapper Plus
Landsat TM	Landsat Thematic Mapper
MAF	Moist evergreen Afromontane Forest
Masl	Meter above sea level
OLI	Operational Land Imager
OM	Organic matter
RDA	Redundancy analysis
RDE	Relative density
RDO	Relative dominance
RFR	Relative frequency
RV	Riverine Vegetation
SSB	Soil Seed Bank
SS	Sørensen Similarity coefficient
TRF	Transitional Rain Forest
USGS	United States Geological Survey
WGG	Wooded Grassland of the western Gambella region

1. INTRODUCTION

1.1 Background

Conserving biodiversity provides numerous direct and indirect services to human beings (Gaston and Spicer*,* 2004). Human activities have direct and indirect impacts on biodiversity and ecosystems, which in turn affects the ecosystem services that they provide, and human survival **(**Armenteras *et al.*, 2009). According to the Millennium Ecosystem Assessment (2005), ecosystem services can be categorized into four main types that contribute to human well-being. These services are provisioning services are the products from ecosystems such as food, fresh water, wood, fiber and medicines; regulating services (the benefits obtained from the regulation of ecosystem processes such as climate regulation, natural hazard regulation, water purification and waste management); cultural services (non-material benefits that people obtain from ecosystems such as recreation, aesthetic enjoyment, and spiritual fulfillment) and supporting services (some examples include photosynthesis, soil formation and retention, nutrient cycling and water cycling).

Ethiopia is one of the most biologically rich countries (Vivero *et al*., 2005). It has a very diverse set of vegetation types. This is due to the variation in climate, topography and soil (Friis *et al*., 2010). The highland area of Ethiopia was once covered by the wide coverage of forest resources than at present (Alemayehu Wassie *et al*., 2005; Haile Yineger *et al.*, 2008). However, the country has lost these resources due to human-related disturbances (Ermias Aynekulu, 2011). According to FAO (2007), due to firewood collection, overgrazing and use of forest wood for building material, the country loses about 141,000 hectares of natural forest cover each year. Overall, one of the primary causes of rapid deforestation in the country is increasing human population growth. For instance, population growth is directly related to increasing natural forests for various forest products and agricultural land (Friss, 1992; Tamrat Bekele, 1994; Taye Bekele *et al*., 1999).

Currently, most of the remaining forests are confined to remnant forest patches and found in the southern and southwestern parts of the country and patches in conservation sites, churches and sacred areas in the country (Friis, 1992; Alemayehu Wassie *et al*., 2005). These forests have mostly disappeared and are fragmented into small patches, and as a result, the forest structure and composition remain influenced by this fragmentation, habitat loss, and human activities (Echeverria *et al*., 2006; Tamrat Bekele, 1994).

The existence of plant communities is due to the interaction between plant species and their environment (Chapin *et al*., 2002). Plant community distribution pattern is influenced by many environmental factors such as climate, soil nutrients and topographic features (Liu *et al.,* 2003, Pugnaire *et al.,* 2011). Consequently, the relationship between the distribution of plant communities and environmental factors is one of the most important research problems in plant ecology (Burke, 2001; Yavitt *et al*., 2009).

At regional and global scales, plant species responses are related to climatic factors (Liu *et al*., 2007; Jarema *et al*., 2009), while at local scales, topographic and edaphic factors play critical roles in controlling plant community formation (Wijesinghe *et al*., 2005; Katabuchi*et al*, 2012; Fadrique and Homeier, 2016). According to Poulos *et al*. (2007) and Solon *et al*. (2007), soil and topography are known as important factors affecting vegetation distribution. Therefore, environmental variables are important not only in identifying plant community structure and species distribution variations at a spatial scale but also in providing insight into the environmental requirements of the plant species needed for successful ecological restoration and biodiversity protection (Toledo *et al*., 2012).

There are different ways of natural regeneration in forests, for instance, the seed bank is important in areas with obvious seasonal variations in a climate such as tropical dry forests for the regeneration of the forests. The occurrence of viable soil seed banks could be regarded as insurance against local loss of populations during unfavorable periods (Thompson, 1987).

The conversion of forest to other land uses such as agriculture is becoming a serious problem, especially in the dry Afromontane forest of Ethiopia (Demel Teketay, 1997). Anthropogenic Land use changes and high human and livestock population pressure have led to harsh land degradation (Binyam Alemu, 2015). This has further degradation such as global warming, loss of biodiversity, soil erosion, forest fragmentation, alter ecosystem services and increase natural disasters, such as flooding (Lambin *et al.,* 2001; Geist and Lambin, 2001, 2002; Mas *et al*., 2004; Dwivedi *et al.,* 2005). This describes global notice for continuous observing of the changes (Gebiaw Ayele *et al*., 2016).

Most previous published papers have shown that the Ethiopian highland is changed to farmland because of the population increase (Gete Zeleke and Hurni, 2001) since human drivers are direct and major (Woldeamlak Bewket, 2002). Besides, the LU/LC change may also be a result of various climate and physiographic conditions of an area and felt after an extended period (Woldeamlak Bewket, 2002). Thus, this study only considered topographic variables including elevation and slope gradient. Slope and elevations are major environmental variables that produce landscape patches (Sarma and Barik, 2010).

Ethiopia has experienced significant land use/ land cover change during the second half of the 20th century (Selamyihun Kidanu, 2004). The major causes of land use/ land cover change activities in Ethiopia are human population growth and agricultural expansion (Gete Zeleke and Hurni, 2001). As well, the LU/LC change is more severe in the Ethiopian highland due to high population pressure and a very long history of rigorous agriculture (Hurni, 1988; Zewdu and Peter, 2000; Gete Zeleke and Hurni, 2001; Mengistie Kindu*et al.,* 2013; Tesfay Gebretsadkan *et al.*, 2013; Solomon Gebreyohannis *et al*., 2014). Currently, in most Ethiopian highlands agriculture has gradually extensive from gently sloping land to the steeper slopes. In a few areas, the increase of farmland, commonly into steeper slopes and marginal areas, may have been done without appropriate conservation measures (RahelAsres *et al*., 2016). Consequently, this type of farming in the area, consecutively, aggravates soil erosion. A study conducted by Lulseged Tamene (2005) reported that the Ethiopian highlands have experienced high rates of soil erosion, deforestation and sediment accumulation in downstream reservoirs and rivers.

Due to deforestation and habitat fragmentation, the forest converted to other land use types (Edwards and Ensermu Kelbessa, 1999; Lunt and Spooner, 2005). Because the increasing human population has enforced people to clear forest for cultivation and gain of economic benefit from the forest (Girmay Gebresamuel *et al*., 2010). There is also a direct interaction between LU/LC changes and the hydrological cycle (Mohammed Assen, 2011). Land under little forest cover is subject to high surface runoff and low water retention (Woldeamlak Bewket, 2002). The deforested slopes of the area are less capable of absorbing and holding the rainfall and consequently, the large part of the rainfall runs down from the steep slopes. Similarly, the removal of forest cover leads to exposing the land to soil erosion (Tsehaye Gebrelibanos and

Mohammed Assen, 2013). This process accelerates the elimination of soil particles and increased gully formation.

1. 2 Statement of the Problem

The rich biodiversity resources, including forests, are being destroyed at an alarming rate largely due to human-related disturbances (Ermias Aynekulu, 2011). Population growth in the highlands exerts great pressure on the natural forests. As a result, northwestern highlands of Ethiopia have only fragments of forest patches scattered and confined to inaccessible and sacred places (Alemayehu Wassie *et al*., 2005). In Ethiopia, different plant ecological studies have been conducted floristic composition, vegetation structure and diversity of forests (e.g. Alemayehu Wassie *et al*., 2005; Alemnew Alelign *et al.,* 2007; Haileab Zegeye *et al.,* 2011; Desalegn Tadele *et al.,* 2014; Abiyot Berhanu, 2017; Abiyot Berhanu *et al*., 2017). The distribution of plant community types associated with environmental factors, including locally variable/topographic factors (elevation and slope), soil also have been conducted (e.g. Tewolde Berhan Gebre Egziabher, 1988; Zerihun Woldu *et al*., 1989; Tamrat Bekele, 1993, 1994; Demel Teketay and Tamrat Bekele, 1995; Haile Adamu *et al*., 2012). However, the northwestern parts of Ethiopia particularly the forest patches of the Dega Damot district have not been investigated except one study on the floristic study of a single forest patch in the study area (Liyew Birhanu *et al*., 2018). While a study on Amoro forest in Dega Damot district mainly focuses on only woody species composition and structure, research has mainly ignored studies on diversity and not included herbaceous species, which are important to the understanding of a comprehensive list of plant species diversity in the study area. Besides, the plot analysis is restricted to only 2432-2728m while the altitudinal distribution of the study area lies between 1738-3586 m. Thus, the floristic data in this single forest patch is limited.

Detailed information on floristic composition, species diversity and vegetation structure, associated with environmental factors is lacking for the forest patches in Dega Damot district that this study targeted. The present study will contribute to a better understanding of the structure, composition and floristic diversity of the forest patches of the study area, the relationships between environmental factors and plant species distribution and community formation, and allow for a comparison with other similar studies conducted in a dry Afromontane forest of Northwestern Ethiopia. It is further hoped that the results of this research will provide baseline data for the proper management of those forest patches in the study area.
Although the dry Afromontane forest has almost disappeared, there are remaining fragments or patches of forest (Alemayehu Wassie *et al*., 2005). If the present trend of deforestation continues, these remaining forests will disappear very soon (Demel Teketay, 1992; Tamrat Bekele, 1993, 1994). Together with this change, the density and composition of the species in the soil seed bank gradually changed too (Belay Assefa *et al.,*2014). Thus, to manage the remaining forest patches and make a future restoration measure, it is essential to obtain information on species composition, seed density and depth distribution in the soil seed bank.

Various scientific studies have been conducted to analyze LU/LC changes in different parts of the Ethiopian highlands (Solomon Abate, 1994; Menale Wondie *et al*., 2011). However, a degree of expansion or reduction in the LU/LC size differs depending on the geographical location (Rindfuss *et al*., 2004); time considered (Weng, 2002), slope and altitude (Poyatos *et al.,* 2003, Mengistie Kindu *et al*, 2013).

There was a rapid expense of forest cover and the expansion of cultivated land in various parts of the country. For example, Gete Zeleke and Hurni (2001) reported that an increase of cultivated land and decrease natural forest cover between 1957 and 1995 in the Dembecha area of northwestern Ethiopia. Another study reported by Belay Tegene (2002) in South Wello, micro-catchment, north-central Ethiopia detected an increase in cultivated land and a decrease in natural vegetation cover between 1957 and 1986. In Kalu district, grazing and shrubland replaced a large area of forests (Kebrom Tekle and Hedlund, 2000). Morever, Woldeamlak Bewket (2002) reported that cultivated land expanded at the riverine vegetation cover for Chemoga watershed in northwestern highlands of Ethiopia over the period 1957-1998.

Most of the above studies have focused on how the land was used in the past and what types of changes are to be expected in the future. Understanding how topographic factors (elevation and slope) affect land use and land cover is critical to the effective design and implementation of policies that promote the development and sustainable natural resource management (Emiru Birhane*et al*., 2019). So far, very few studies have been carried out in the highland of Ethiopia to add a better understanding of the extent to which land-use conversion processes are occurring and how they vary across elevation and slope gradients (eg. Menale Wondie *et al*., 2012; Mengistie Kindu *et al.*2013; Emiru Birhane*et al*., 2019). However, the impact of elevation and slope on LU/LC change has not been well documented in the highland of Ethiopia. Therefore, one of the objectives of this study was to analyze the land use/ land cover change for the last 31 years (1986-2017) and to examine how elevation and slope gradient contributed to LU/LC. The results of the present study give information to help with land use planning and sustainable land resource management in the highlands of Ethiopia.

1.3. Objectives of the Study

1.3.1 General objective

The general objective of this study is to investigate the Ecology of the vegetation and to study Land use/ Land cover change in Dega Damot district forest patches of Northwestern Ethiopia.

1.3.2. Specific objectives

- To study the floristic composition, vegetation structure and species diversity of the selected forest patches.
- To investigate the relationships between plant communities and some environmental factors.
- To study the soil seed bank and species composition in forest patches.
- To study the land use/ land cover change along elevation and slope.

1.4 Research Questions

- What is the floristic composition, vegetation structure and species diversity of the forest patches?
- Which environmental factors influence plant species distribution and community formation?
- Does the soil seed bank have a contribution to the regeneration of forest patches?
- What is the magnitude of Land use/Land cover change in relation to elevation and slope gradient in the study area?

2. LITERATURE REVIEW

2.1 Biodiversity and Ecosystem services

Most directly, biodiversity is 'the variety of life' at species, genetic, and ecological levels. There are many definitions of Biodiversity (Gaston and Spicer,2004). The most widely used definition is that adopted by the parties to the Convention on Biological Diversity (CBD, 1992**):** the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species**,** between species and of ecosystems.

Biodiversity is affected by direct and indirect drivers of change and also is a cause modifying ecosystem function. As well, Biodiversity contributes directly and indirectly to the provision of ecosystem services. According to Millennium Ecosystem Assessment (2005), there are four main types of ecosystem services: 1) provisioning services (goods) which means the products obtained from ecosystems; 2) cultural services include non-material benefits delivered by ecosystems,3) Regulating services are the benefits obtained from regulating ecosystem processes. Supporting services are that allow for the other ecosystem services to be present (Figure 1).

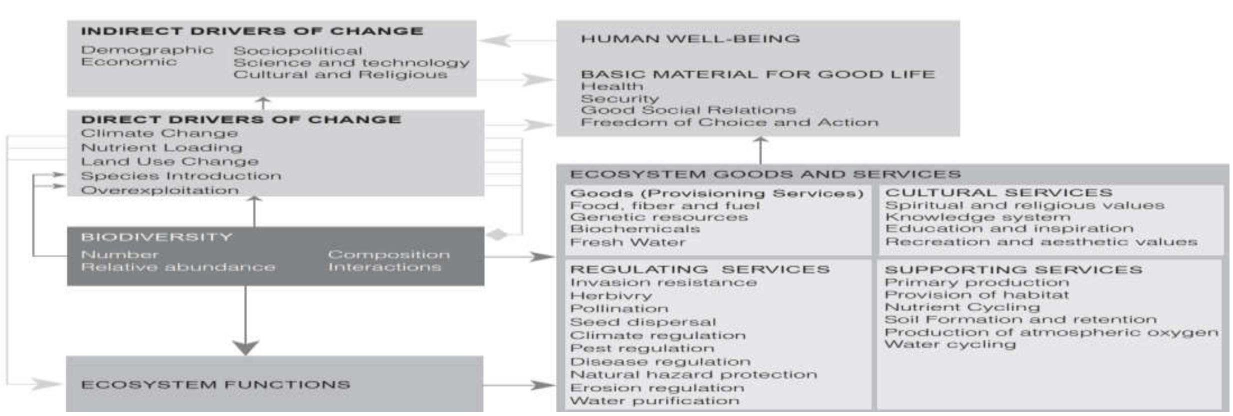


Figure1. Biodiversity, ecosystem services & functioning and drivers of change (source: Ninan, 2009

2.2 Dry Evergreen Afromontane Forest and Grassland Complex Vegetation

Ethiopia has great geographical diversity with micro-climatic variability (Ensermu Kelbessa *et al.*, 1992; Zerihun Woldu, 1999). As a result, the country is regarded as one of the most important countries concerning the endemism of plant and animal species in tropical Africa.

The vegetation of Ethiopia is extremely complex in consequence of its great variations in altitude, moisture, and temperature (Zerhihun Woldu, 1999; Friis, 2009; Friis *et al*., 2010). The country has twelve major vegetation types (Friis *et al.,* 2010) namely: Desert and semi-desert scrubland (DSS), *Acacia-Commiphora* woodland and Bushland (ACB), wooded grassland of the western Gambella Region (WGG), *Combretum–Terminalia* woodland and wooded grassland (CTW), dry evergreen Afromontane forest and grassland complex (DAF), moist evergreen Afromontane forest (MAF), transitional rainforest (TRF), ericaceous belt (EB), Afro-alpine vegetation (AA), riverine vegetation (RV), freshwater lakes (including lakeshores, marshes, swamps, and floodplain vegetation) (FLV/MFS) and saltwater lakes (including lake shores, salt marshes and pan vegetation (SLV).

The Ethiopian highlands encompass over 50% of the African land area covered by Afromontane vegetation (Tamrat Bekele, 1993), of which dry Afromontane forests are dominant (Tamrat Bekele, 1993; Demel Teketay, 2005). The dry evergreen Afromontane forests are found in much of the highlands in the northern, northwestern, central, southern, southeastern and southwestern parts of the country at altitudes between 1800 and 3000 m asl (Friis *et al.,* 2010). This vegetation represents a complex system of successions involving extensive grasslands rich in legumes, shrubs and small to large trees to closed forests. The vegetation of the study area belongs to the categories of dry evergreen Afromontane forest and grassland vegetation type (Friis *et al*., 2010). The forest patches are dominated by trees including *Juniperus procera*, *Olea europaea* subsp. *cuspidata, Allophylus abyssincus, Apodytesdimidiata*, and *Bersama abyssinica.* The shrub species such as *Carissaspinarum*, *Discopodium penninervium, Dombeya torrida*, *Lobelia giberroa*, *Myrsine africana* and *Pittosporum viridiflorum* were dominant. The most dominant liana in the forest is *Urera hypselodendron. Arundinaria alpina* (bamboo), and *Eucalyptus* species also found in the study area.

2.3 Threats to Dry Afromontane Forest

Due to habitat fragmentation and habitat loss**,** forests have been fragmented into small patches (Echeverria, 2006). Deforestation and fragmentation of tropical forests continue at alarming rates, resulting in serious problems including irreversible loss of genetic resources. Tropical dry forests are among the most exploited forest ecosystems of the world and loss of biodiversity in the process of deforestation and fragmentation (Cabin *et al*., 2002). The fragmentation results in small stands of forests bordered by open, often agricultural lands (Fleury and Galetti, 2004).

Besides, deforestation in Ethiopia is one of the major challenges that threaten biodiversity (Mamo Kibret, 2008). Most of the forests in Ethiopia disappeared and fragmented into small due to continuous deforestation. This process continues, and FAO (2007) estimated an annual loss of about 141,000 ha forest in Ethiopia. Sayer *et al.* (1992) reported that a continuous decline from the original 35% forest covers in 1950 to 2.4% in 1992. Recent statistics suggest 2.65% (2.91 million ha) of the forest cover of the country was deforested between 1990 and 2010 (FAO, 2010). Similarly, the dry Afromontane forests of Ethiopia have faced vast exploitation and almost all these forests have been converted to agricultural lands (EFAP, 1994a and Demel

Teketay, 1996) except for small fragments that are left in the most inaccessible areas or around churches (Alemayehu Wassie *et al*., 2005).

Overall, the dry Afromontane forests are occupied by the majority of the Ethiopian population and a long history of agriculture (Friis *et al.,* 2010). High population growth and the associated ever-increasing demand on natural forests for various forest products and agricultural land have put the remnant forest patches on the verge of disappearance (Tamrat Bekele, 1994).

2.4 Plant Communities

The plant community can be defined as a group of plant species living together with mutual tolerance and beneficial interaction in a natural area (Kent and Coker, 1992; Kent, 2012). The floristic composition of vegetation includes all species occurring within a plant community (Mueller - Dombois and Ellenberg, 1974). Plant communities consist of many different plant species that are not distinctive to a particular community. Therefore, it is common to use the dominant species in naming plant communities (Kent and Coker, 1992). Regarding the structure of plant communities, two different views have been presented in the past. These are organism (discrete) and individualistic (continuum) community concepts. According to Clements (1916), plant communities as one big organ (organismic concept) composed of various species, which repeats itself with regularity over a given region. Contrary to the discrete community concept, Gleason (1926) viewed plant communities as continuous entities. The community represents simply an assemblage of species with similar environmental conditions.

However, differences still exist among ecologists on the concepts of plant communities (Callaway, 1997). Plant ecologists who favor vegetation classification follow the approach of

Clements and thus, group species into communities. On the other hand, those plant ecologists do not support organismic community concept follow the continuum theory and arrange plant species along with environmental factors, using ordination methods (Kent and Coker, 1992; Kent, 2012. At present views of both Clements and Gleason's view are important about the view of plant community structure (Crawley, 1997; Leps and Smilauer, 2003).

2.5 Species Diversity and Richness

The description of the plant community involves the study of species diversity, evenness and similarity(Magurran, 2004). The concept of species diversity involves two components, several species in a community or plots (species richness) and relative abundance within the sample or community (species evenness) (Kent and Coker, 1992; Kent, 2012). The two components may be examined separately or combined in some form of an index like the Shannon diversity index.

2.6 Environmental factors and Vegetation Distribution

The relationships between vegetation and environmental parameters are one of the most fundamental questions contributing to understanding plant species composition and structure in a particular habitat, landscape, and region (Burke, 2001; Yavitt *et al*., 2009). Human-induced pressure in combination with environmental variables including soil, slope, and elevation explains the main vegetation distribution pattern (Walter,1985). Soil and topography are known as important factors affecting the vegetation distribution (Lorenzoa *et al.,* 2007; Poulos *et al*. 2007; Solon *et al*., 2007). Vegetation distribution is affected by soil moisture (Walker and Langridge, 1996), soil fertility (Dong *et al*., 2005), soil acidity (Bruelheide and Udelhoven 2005), historical land use (Alard *et al.,* 2005) and elevation (Grytnes and Beaman, 2006). The distribution, pattern and abundance of plant species have been related to environmental variables and anthropogenic disturbance (Enright *et al.,* 2005).

Thus, the ordination techniques examine relationships between species distributions and the distribution of associated environmental factors and gradients (ter Braak, 1987; Zerihun Woldu, 2017). Ordination can be viewed as constrained ordination (direct gradient analysis) and unconstrained ordination (indirect gradient analysis). Constrained ordinations are directly influenced by a set of environmental factors while unconstrained ordination techniques are not constrained by environmental factors (Zerihun Woldu, 2017).

In general, there are two types of ordination methods: eigenvalue-based and distance-based. Eigenvalue based ordination is calculating their eigenvalues and scores of samples and species along these axes. PCA, CA, DCA, CCA, and RDA are examples of eigenvalue-based. While a distance-based deal with distances between samples, measured by compositional similarity/dissimilarity measures, and projecting these distances into two or three-dimensional ordination diagrams; examples are MDS or NMDS (Zerihun Woldu, 2017).

Relationships between vegetation and environmental factors have been studied by many researchers in Ethiopia, for example, Tewolde Berhan Gebre Egziabher, 1988; Zerihun Woldu *et al*., 1989; Tamrat Bekele, 1993, 1994; Demel Teketay and Tamrat Bekele, 1995; Haile Adamu *et al*., 2012.

2.7 Seed bank and Regeneration Potential of the Forest

The seed bank is the aggregations of viable seed in the soil capable of replacing adult plants (Simpson *et al*., 1989). It can also be defined as all viable seeds present on or in the soil or associated litter constitute the soil seed bank. Most of the seeds in the seed bank come from the surrounding flora (Solomon Tefera, 2011). Seeds incorporated into the soil under a plant community represents not only the present vegetation growing in the area but also a memory of the past vegetation that occurred nearby (Bakker *et al*., 1996).

There are two types of seed bankes based on their seed longevity (Simpson *et al*., 1989). These are persistent and temporary seed bankes. Persistent seed banks are composed of seeds that have more than one year of age and reserves of seeds remain in the soil year after year, generally buried in the soil. If seed bank no longer exists, recolonization is slow as the seed has to be carried to the site by wind, water or animals. Thus, the persistent seeds are the source of genetic material accumulated over time ensuring the continuous re-colonization of plant species on a site after disturbances (Scott *et al*., 2010). On the other hand, Temporary seed bankes are composed of seeds that germinate within a year of their initial dispersal (Garwood, 1989; Thompson *et al*., 1993).

The density of seeds in the seed bank varies due to different sessions, at different depths, seed proximity from the parent plant, seed persistence or state of dormancy (Walck *et al.*, 2005), and physiological state and dispersal units. The regeneration of plant communities from seed depends on seeds being in the right physiological state to germinate in the right place at the right time (Simpson *et al*., 1989; Saatkamp *et al*., 2014). The seed populations of several species behave in different ways for germination. There are different external and internal factors prevent seeds from germination. The external factors are, soil water content and temperature (Simpson *et al*., 1989; McLaren and McDonald, 2003) while the internal factors the most common, are the presence of a seed coat, biochemical inhibitor in the seed, and an immature embryo. The seed longevity in the soil varies among species, depth of seed burial, soil type, crop rotations and climatic conditions (Simpson *et al*., 1989).

Different factors affect the distribution of seeds in the soil. Climate, herbivory and disturbances vary and consequently change in soil seed bank density (Simpson *et al*., 1989; Saatkamp *et al*., 2014). Soil fertility can affect soil seed bank density. For instance, nitrate promotes the germination of seeds of many plant species (Saatkamp *et al*., 2014). Those plant species found in dry habitats have short-lived seeds bankes in water-logged soils and it is because of lack of oxygen is the direct cause of seed mortality (Wagner and Mitschunas, 2008). On the contrary, some long-lived seed banks are found in waterlogged soils, which are sometimes related to the occurrence of physical dormancy in these habitats. Closed canopy covers prevent germination of some seed (Kruk *et al*., 2006) whereas open canopy promotes the germination of seeds.

Seed predation and the dispersal mechanism of seeds are variable in both space and time, with their abundance and activity (Koprdová et al., 2010). The ground-dwelling arthropods such as millipedes, isopods and beetles are the most effective seed predators, and consume a large number of seeds in a short time. Birds and rodents feed on large seeds, while invertebrates frequently show favorite for smaller seeds of species (Koprdová et al., 2010). Earthworm abundance and activity are not equal among soil types and specifically depends on temperature, moisture and acidity (Curry, 2004), their interaction with seeds is likely to create heterogeneity among habitats in seed density. Fungi, either carried by the seed itself or originating from the soil, can strongly decrease soil seed viability and change seed germination (Wagner and Mitschunas, 2008).

Several studies have been reported on the high similarities between soil seed banks and aboveground vegetation (Leck and Graveline, 1979; Henderson *et al*., 1988; Levassor *et al.,* 1991), On the other hand, other studies reported that fewer similarities in species composition between soil seed bank and the aboveground vegetation (Bakker and Berendse, 1999; Mulugeta Lemenih and Demel Teketay, 2006). The similarity between seed bank and standing vegetation is expected to decrease with increasing community stability because lack of disturbance creates sites for germination from the seed bank (Bakker *et al*., 1996). Plant species found in stable habitats do not produce long-lived seeds (Lee, 2004). This dissimilarity is the result of the frequent occurrence of perennial grasses and woody species in aboveground vegetation (Tessema Zewdu *et al.* 2012; Solomon Tefera, 2011).

The soil seed bank plays an important role in the composition of different plant communities and especially in their conservation (Stromberg *et al*., 2008). Seed banks and their relationships to vegetation have received much attention in the field of seed back studies (Amiaud and Touzard, 2004). Understanding the potential of a seed bank to influence the composition of forest plant communities, and its potential for restoring species-rich ecosystems and maintaining floristic diversity is essential (Bakker *et al*., 2002. The relationship between soil seed banks and original plants is the key point in evaluating the revegetation potential (Lu *et al,* 2010).

The soil seed bank is important for a regeneration potential in many plant assemblages (Zhou *et al*., 2005). As a potential, soil seed bank plays an important role in the research of plant ecology, as well as one of the hot research topics in vegetation ecology. Seed bank studies provide fundamental information on seed densities and floristic composition as well as an indication of the regeneration potential from stored seeds in the seedbanks (Simpson *et al*., 1989; Khurana, and Singh, 2001).

2.8 Land use/ Land cover change

The terms land cover and land use are often used interchangeably but their actual meanings are not synonymous. Land cover refers to the physical and biological cover over the surface of the earth, including water, vegetation and soil (Chrysoulakis*et al*., 2004).On the other hand, Land use refers to the intended use or management of the land cover type by human beings (Olson and Maitima, 2006). LU/LC change refers to the human modification and conversion of the earth terrestrial surface (Lambin *et al.,* 2003). Modification occurs when the change affects only the characteristics of the land cover without causing a complete shift from one LU/LC type to the other. On the other hand, the conversion of LU/LC occurs when one LU/LC type is completely replaced by another (Turner *et al.,* 1995; Lambin *et al.,* 2003).

LU/LC change can be caused by several factors related to the complex interaction between social, political, economic, technological and biophysical variables (Geist and Lambin,2002). Commonly the causes of LU/LC change can be categorized as direct (proximate) or indirect drivers. The direct causes comprise human activities that could arise from the continuous use of land and directly alters the driving forces, for instance, urbanization, deforestation, agriculture expansion, wood extraction. On the other hand, the indirect causes are fundamental forces that strengthen more direct causes of LU/LC changes that including economic, biophysical, political/institutional, socio-cultural and technology (Geist and Lambin, 2002; Rahdary *et al.,* 2008).

In developing countries, including Ethiopia, a large proportion of the human population depends almost entirely on natural resources for their livelihoods, mainly from natural vegetation to farming practices and human settlement (Mengistie Kindu *et al*., 2013). The land cover dynamics are more severe in the highlands because of higher population density and continuous agricultural activities for millennia compared to the lowlands (Menale Wondie *et al.,* 2012). Gete Zeleke and Hurni (2001) reported a sharp decrease in forest cover in the Ethiopian highlands. Population growth was found to be the main driver for the expansion of cultivated land, forest and marshland and the reductions of shrublands, grassland and riverine trees in Chemoga watershed during 1957-1998 periods (Woldeamlak Bewket, 2002).

At present, global warming, soil erosion loss of biodiversity at genetic, species and ecosystem levels, can be related to the destruction of natural forests as a result of land-use/ Land change (Jenkins, 2003 Dwivedi et al., 2005).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was carried out in a dry Afromontane forest patches in Dega Damot district, Amhara Regional State, in the Northwestern part of Ethiopia. The major nearby town is Feresbet which is 399 km away Northwestern of Addis Ababa. The district is bordered by Dembecha (in the south), JabiTehnan (in the southwest), Quarite (in the west), HuletIju Enesie(in the north) and Bibugn (in the east) districts.The study area extends between 10°44′41.69″N and 11°00′10.56″N, and 37°26′58.43″E and 37°42′35.42″E (Figure 2). Degadamot district covers approximately 83,124 hectares of land area (Liyew Birhanu *et al,* 2018). The district has forest patches. Of them, five forest patches were selected for the study which are relatively undisturbed in the district.

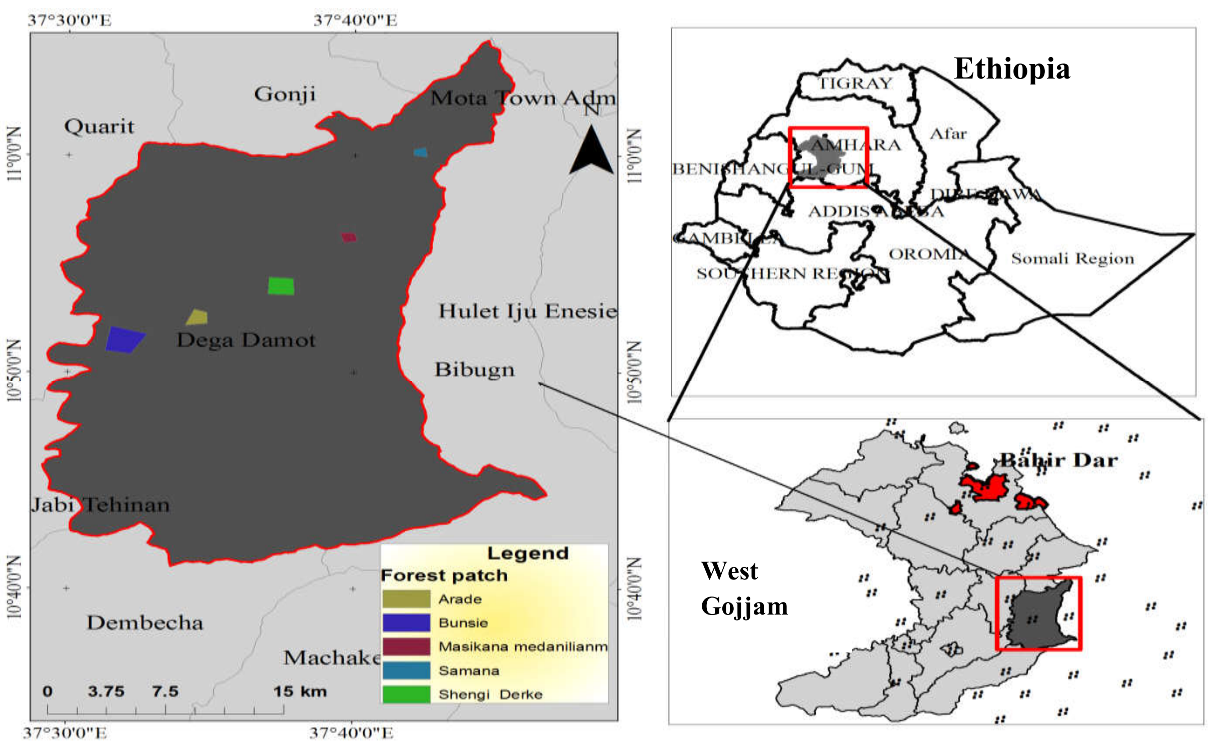


Figure 2. Location of forest patches in Dega Damot district, the star shows the small towns in the zone and in the district.

3.1.2 Topography and soil

Topographically the study area consists of mountainous areas, undulating, valleys and plains (Liyew Birhanu *et al*, 2018, 2019). The elevation of the study area ranges from 1738 to 3586 ma.s.l. (Figure 3). The district is characterized by gentle to steep slopes (Figure 4).

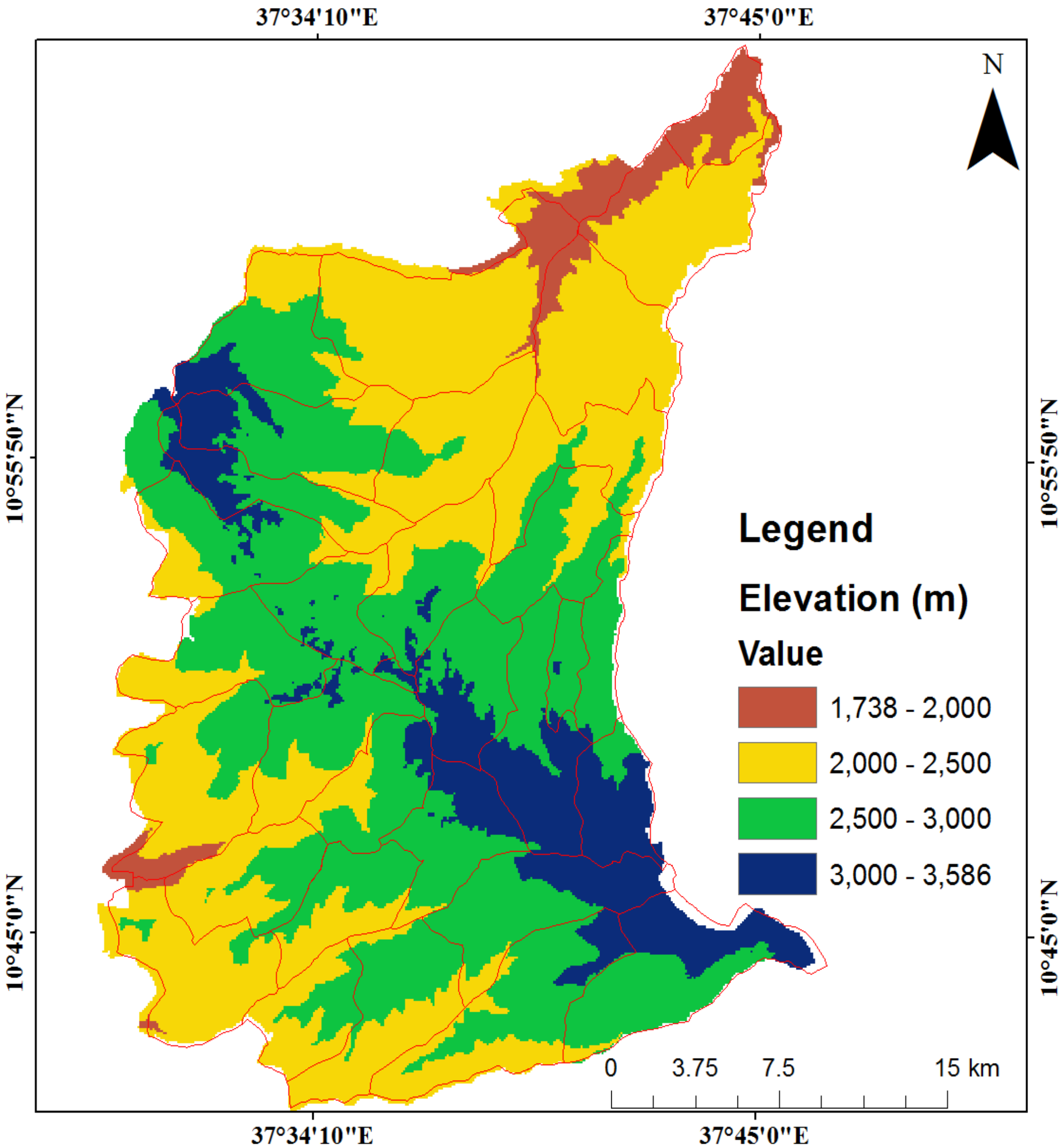


Figure 3. The elevation map of the study area (data source:http://gdex.cr.usgs.gov/gdex/)

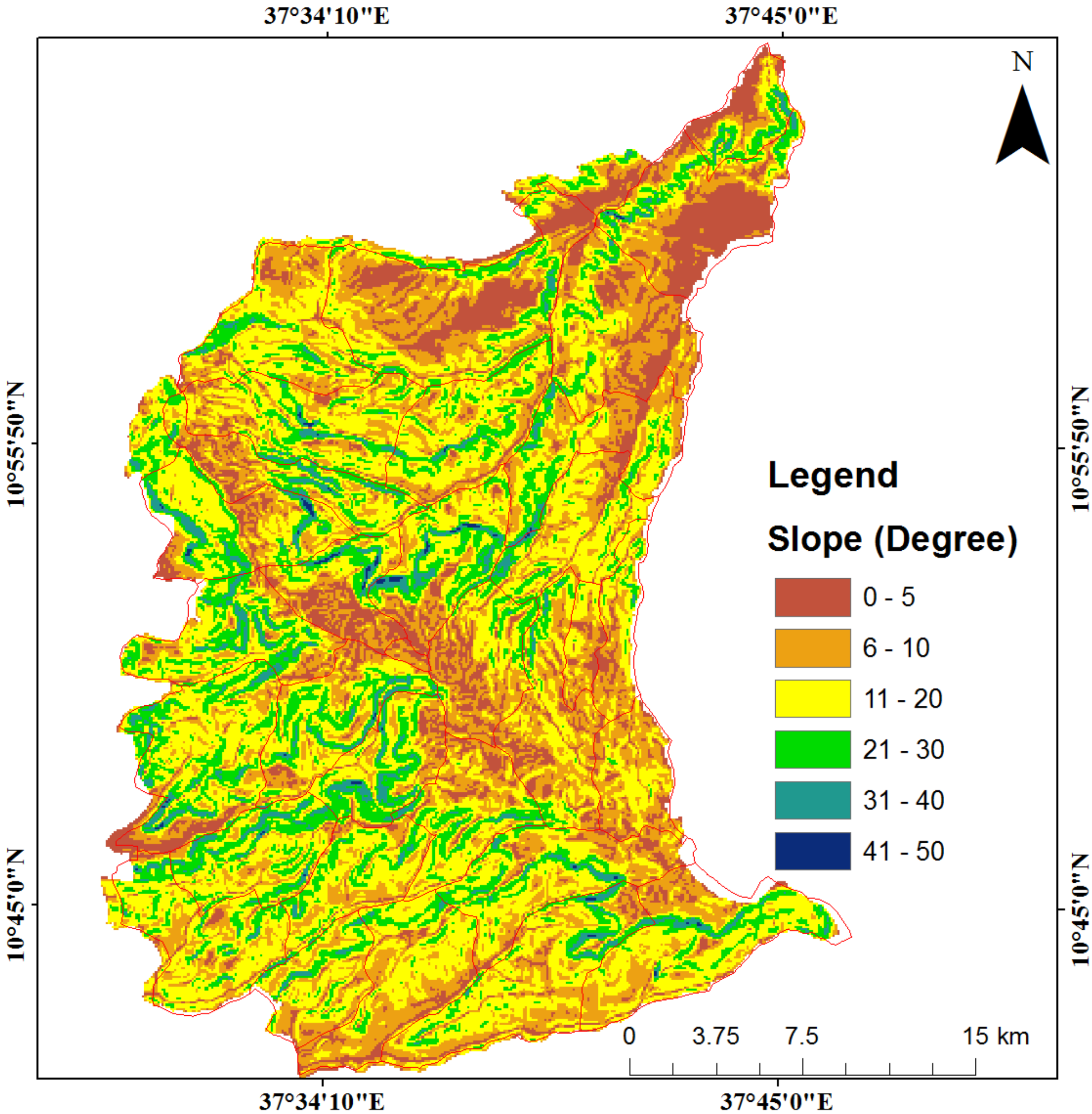


Figure 4. Slope classes of the study area (data source:http://gdex.cr.usgs.gov/gdex/)

According to the data obtained from the Geographic Information System (GIS) department of the Ministry of Water, Irrigation and Electricity (MoWIE), the dominant soil type of the study area are Luvisols (28523.31ha) and Cambisols (17552.81 ha) (See Figure 5 and Table 1).

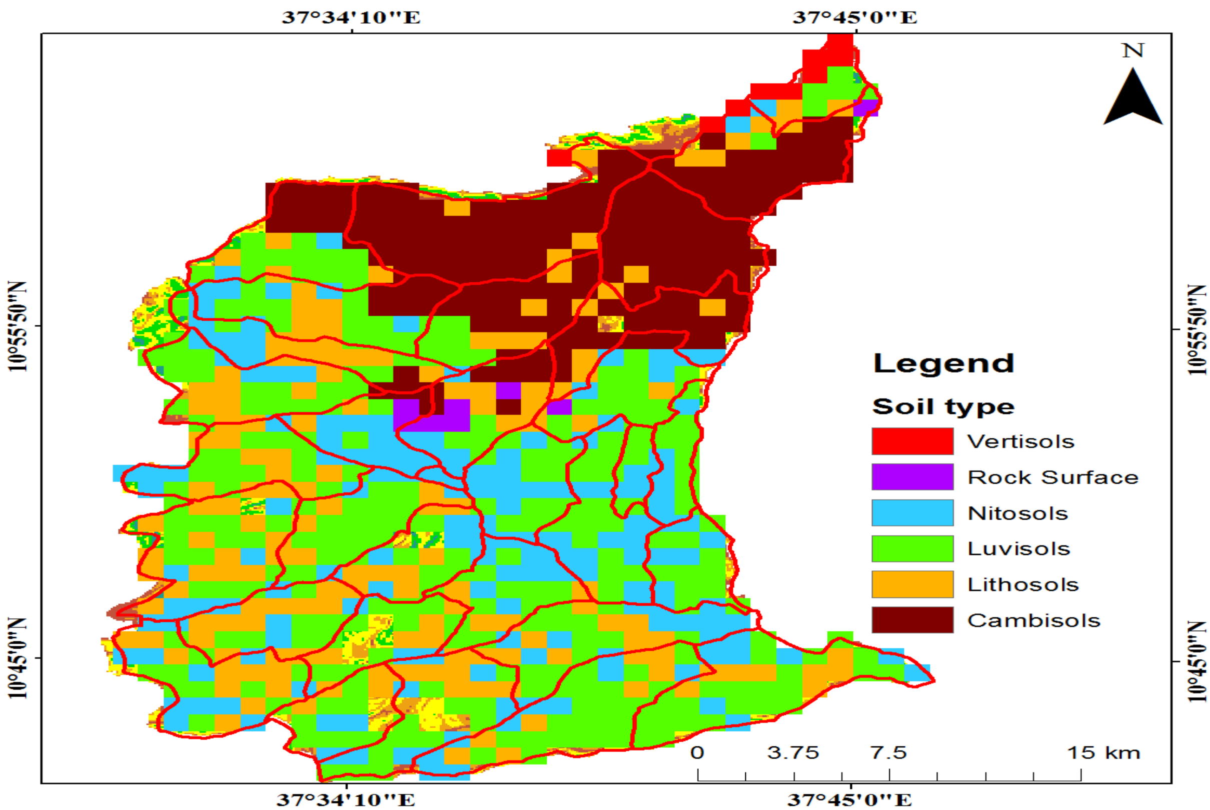


Figure 5. Soil map of Dega Damot district (data source: MoWIE)

Table 1.Soil types and area coverage of the study area

No	Major soil types	Area (ha)
1	Vertisols	897.59
2	Nitosols	16256.29
3	Luvisols	28523.31
4	Cambisols	17552.81
5	Rock surface	797.85
6	Lithosols	16455.76

Furthermore, the sampling plots of the soil texture is mostly clay loam and loam (Figure 6).

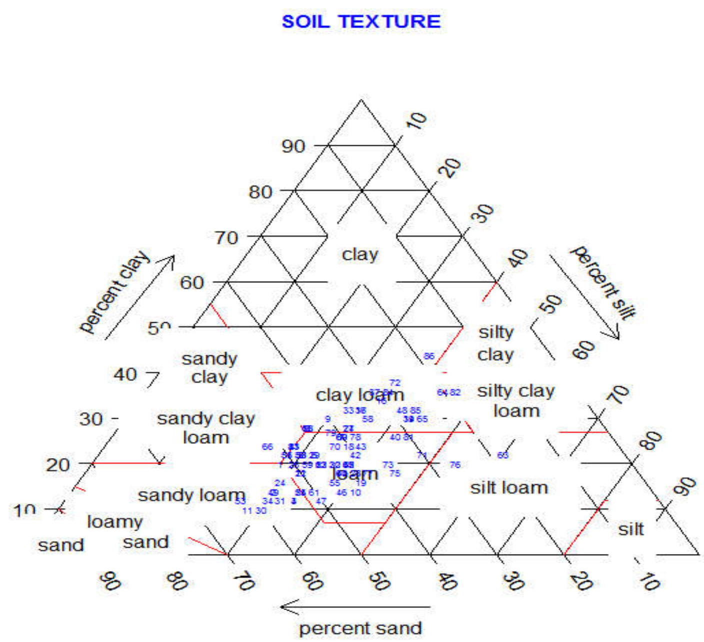


Figure 6. Soil textural triangle of the sampling plots in the study area

3.1.3 Climate

The 21 years of climate data (1997-2017) for the Dengayber station was obtained from the National Meteorological Services Agency (NMSA, 2018), and used to draw the climadiagram of the study area. R statistical software version 3.5.2 (R Core Team, 2018) and the package climatol (Zerihun Woldu, 2017) were used during the analysis. The mean annual rainfall of the District is 2113 mm. The study area has a long rainy period from May to October, of which the highest rainfall is recorded in June and August. The area gets a small amount of rainfall from December to April. The mean minimum and maximum temperature of the study area are 9.1 ^{0}C and 24.7 ^{0}C, respectively while the mean annual temperature is about 15.9 ^{0}C (Figure 7).

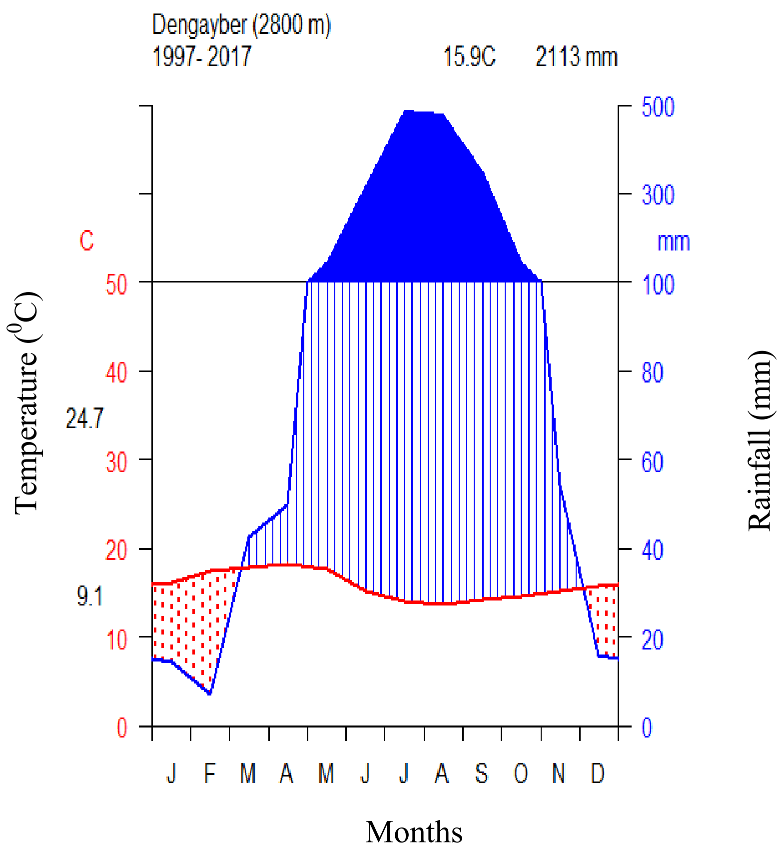


Figure 7. Climate diagram of Dengayber (data Source: NMSA, 2018)

3.1.4 Land use and Agriculture

The most common crops cultivated in the study area are *Hordeum vulgare* (barley), *Triticum sp*. (wheat), *Vicia faba* (faba bean), *Eragrostis tef* (teff), *Zea mays* (maize) and *Solanum tuberosum* (potato) (Liyew Birhanu *et al.,* 2018, 2019). The area is covered by agricultural lands, settlements, forest land, shrubland, bare lands and grazing lands.

3.2 Data Collection

3.2.1 Reconnaissance survey and sampling technique

A reconnaissance survey was made in January 2017 across the forest patches to get an impression of the site conditions and identify the sampling sites in the study area. The forest patches were located at different altitudes, ranging from 1881-2947 m and also occupy different sizes ranging from 50 ha to 405 ha (Table 2). The actual fieldwork was conducted between February and November 2017. A systematic sampling technique was used for vegetation and environmental data collection. Sampling sites were arranged along transects from the forest patches. The first transect and plot were selected purposely which are free from any anthropogenic disturbances. A total of 22 line transects (6 each in Shangi Derke and Busie forest patches, 4 in Aradie forest patch and 3 each in Masikana and Samana forest patches) were laid along elevation gradients. The number of plots per transect differs depending on the length of the transect (Table 2).

The elevation between two consecutive plots and transect were 50 and 200 ma.s.l. apart in the forests, respectively. Accordingly, a total of 86 sampling plots of each 30 m x 30 m (900 m^2) plots were established in each of five forest patches. Five smaller subplots of 2 *2 m^2, four at the corner, one at the center of the main plot were established for herbaceous plant species collection.

Table 2. Size, number of plots, transect and altitudinal range of forest patches

No	Name of forest patch	Area (Ha)	No of plots	No transect lines	Length	Altitudinal range (m)	
						Minimum	Maximum
1	Shangi Derke	225	29	6	2.2 km	2475	2947
2	Arade	132	10	4	0.5 km	2688	2912
3	Bunsie	405	32	6	2.5 km	2517	2906
4	Masikana medanilianm	75	9	3	0.6 km	2375	2732
5	Samana	50	6	3	0.4 km	1881	2110

3.2.2 Vegetation data collection

In each plot, all individual trees and shrubs with a diameter at breast height (DBH at 1.30 m above ground) >2.5 cm were measured for DBH classes using a measuring tape. The height of woody individual species with > 3m height was measured using Suunto Clinometers. Within each plot, the cover/abundance values were estimated for all plant species. Three-column data tables were constructed in Microsoft Excel 2007 and saved in the CSV (comma delimited) format. The first, second, and third columns represented by plots, species and abundance of species, respectively. After that, the percent cover of each species was transformed to ordinal scales and assigned to one of the nine cover-abundance classes according to the modified 1-9 Braun-Blanquet scale (van der Maarel, 1979). The scales for cover-abundance values are 1 ≤ 0.1%, 2 = 0.1 to 1%, 3 = 1 to 2%, 4 = 2 to 5%, 5 = 5 to 10%, 6 = 10 to 25%, 7 = 25 to 50%, 8 = 50 to 75%, and 9 >75%. Finally, the three-column data of the cover-abundance value of each species were imported to R statistical software version 3.5.2 (R Core Team, 2018) and matrified to carry out the cluster analysis and other parameters such as for ordination, diversity and evenness. The packages labdsv'' and vegan'' were used to transform the cover values of the vegetation data into the modified Braun Blanquet 1-9 scale and matrified the abundance data.

Moreover, species occurring outside the plots were also recorded to obtain a complete floristic list of the study area. Voucher specimens were collected, coded, pressed and dried for subsequent identification and verification at the National Herbarium (ETH), Addis Ababa University, using Volumes 1- 8 of Flora of Ethiopia and Eritrea.

3.2.3 Environmental data collection

Geographical data (altitude, latitude, and longitude) were recorded using GPS for each plot in the forest patches. The slope of each sample plot was measured using Suunto clinometer.

Soil samples were collected from these 86 plots for soil analysis. From each plot, the soil samples were collected at five locations, one from the center and four from corners and these are mixed to produce a composite sample, each weighing about 1 kg. The samples were collected from topsoil (0-30 cm). The samples were air-dried, grounded, and passed through a 2-mm sieve to remove the stone pieces and large root particles before analysis. The soil analysis was assessed in a soil laboratory of Debremarkos soil research and fertility improvement center.

Soil texture, soil moisture content, bulk density, pH, EC, CEC, total nitrogen, organic matter and available phosphorus were measured for the soil data collected from the selected forest patches. Physicochemical analysis of the soil samples were conducted as follows:

- The soil bulk density (BD) was calculated as the ratio of oven-dried soil weight to the volume of the soil: BD = $\frac{wd}{v}$ (1)

  where wd is the weight of oven-dry soil (g) and vis the volume of the soil (cm^3). The volume was calculated from the volume of the core sampler.

- The soil texture was measured using the hydrometer method following Dewan and Freitas (1984).
- Soil pH was measured by taking a 1:2.5 soil/water suspension using a glass electrode pH-meter following Houba*et al.* (1989).
- The electrical conductivity of the soil sample was measured by preparing a 1:2.5soil/water suspension using a conductivity-meter following Chopra and Kanwar (1982).
- Organic carbon was determined by Walkely and Black method (Nelson and Sommers, 1982). The organic matter (OM) content was calculated by multiplying the OC content by 1.724 (OM=1.724 x OC).
- Total nitrogen was ascertained by the Kjeldhal procedure after digestion with concentrated H_2SO_4 (Dewan and Admasu Nigussie,1987).
- Available phosphorus (P) was determined following the Olson method (Olsen and Dean, 1965).
- Cation exchange capacity (CEC) was determined using ammonium acetate method following (Van Reeuwijk, 1992).

3.2.4 Soil seed bank sampling method

To compare the soil seed bank flora with the standing vegetation in the forest patches, of the total 86 plots of standing vegetation 46 plots were randomly selected in the forest patches. The soil seed bank samples were taken from five subplots measuring 10cm X 10 cm (one at the center and four at the corners) of each 46 sample plots. The samples were collected from four successive layers, litter, upper (0–3 cm), middle (3–6 cm), and lower (6–9 cm) layers using a digger and labeled metal rods. Similar layers from these five points within a plot were mixed to form a soil composite and kept separately in paper bags. A total of 184 soil samples (4 vertically successive layers x 46 plots) were collected and transported to the greenhouse of the Forestry Research Center (FRC) of the Ethiopian Environment and Forest Research Institute (EEFRI) in Addis Abeba, for the germination experiment. The soil samples were air-dried and spread on plastic trays, with perforations at the bottom. The trays were then placed on a bench in random order in a greenhouse with a clear plastic roof and they were watered until saturated to stimulate the germination of seeds. The seedling emergence method was used in this study to determine the species composition of the soil seed bank, assuming that the number of seedlings detected by this method is the number of the buried viable seed which would indicate the number of the readily germinable seed in the soil. The first seedlings started to emerge after one week.

The identified seedlings were counted, recorded and then removed to avoid the suppression of germination of other seeds in the soil by these seedlings. Those which are difficult to identify were transplanted and observed until flowering for correct identification. The seed bank soil was stirred twice a month to promote the germination of seeds that might have remained buried or shaded, to increase the possibility of seeds to be exposed to light. The germination monitoring was ended at the end of 6 months when no more new seedlings were emerging. Voucher specimens were collected and identification and verification were done at the National Herbarium (ETH), Addis Ababa University, using Volumes 1- 8 of Flora of Ethiopia and Eritrea.

3.2.5 Land use/ land cover data

This study aimed to analyze LU/LC change along elevation and slope gradient in Dega Damot district during the periods of 1986, 2003 and 2017. The study years were selected purposely to correspond with remote sensing data availability in the study area and regime change and subsequent policy shift in the country in the 1990s. Because most of the deforestation in the forests in Ethiopia took place with a change in government (the downfall of the Derg regime) that led to the illegal destruction of protected forests and grasslands for agriculture by farmers. Finally, to know the current LU/LC changes, the study preferred to use 2017 as a third reference year.

As a result, three satellite images (Landsat-5 TM 1986, Landsat-7 ETM+2003 and Landsat-8 OLI- 2017) were used to analyze the LU/LC change of the study area. The images with a spatial resolution of 30 m were downloaded from the United States Geological Survey (USGS) Earth Explorer (source: http://earthexplorer.usgs.gov). The satellite images taken in January and March with no cloud cover were considered for analysis. Details of the characteristics of the image are described in Table 3.

Table 3. Landsat data used in the land use/land cover change analysis

Landsat Type	Date of acquisition	Path and Row	Spatial Resolution
Landsat 5 TM	January 28, 1986	P169/r52& P169/r53	30m
Landsat 7 ETM+	March 08, 2003	P169/r52& P169/r53	30m
Landsat8 OLI	January 17, 2017	P169/r52& P169/r53	30m

3.2.5.1 Topographic data (elevation and slope)

To study the relationship between LU/LCtypes with that of the slope and elevation gradient of the study landscape, ASTER GDEM with 30 m cell size was obtained from Aster Global Digital Elevation Map (http://gdex.cr.usgs.gov/gdex/). Consequently, the altitude was computed by considering the DEM that was downloaded from the ASTER GDEM site. Then, it was clipped and the value ranged from 1738-3586 m elevation in the study area. According to Qasim *et al.* (2013), LU/LCchanges appear significantly related to topographical factors such as slope and elevation. Agriculture and settlement areas are mostly found in the low elevation zone. Accordingly, the elevation of the study area was classified into four classes, < 2000 m, 2000-2500 m, 2500-3000 m and 3000-3586.

Similarly, the slope (degree) was extracted from DEM. The values range between 0 and 50°. The slope gives an indication of the different land-use purposes for example forestlands are on the higher and steeper areas while building land often moved to the flat areas. By considering this, the slope gradient of the study area was classified into six classes, 0-5°,6-10°,11-20°,21-30°,31-40°,41-50°.

3.3 Data Analysis

3.3.1 Vegetation structure

Density, basal area, frequency, IVI and DBH class distributions were calculated for each woody plant species used for the description of vegetation structure. Thus, the following formulas were used to calculate frequency, density and basal area of woody species.

$$Frequency(F) = \frac{Numberofplotsinwhichaspeciesoccurs}{Totalnumberofplots} \times 100 \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (5)$$

$$Density = \frac{Totalnumberofstemsofalltrees}{Samplesizeinhectare} \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (6)$$

$$BA = \left(\frac{DBH}{2}\right)^2 \times \pi \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (7)$$

($\pi = 3.14$), Diameter at breast height (DBH)

An importance value index (IVI) was computed for all woody species based on their relative density (RD), relative dominance (RDO) and relative frequency (RF). This index is used to decide the overall importance of each species in the forest system (Kent and Coker, 1992).

The importance value index (IVI) for each woody species was determined based on using the following formula.

$$RDO = \frac{BA}{TBA} \times 100 \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (8)$$

Where, RDO = relative dominance, BA= Basal area, TBA= total basal area

$$\text{Relative Density} = \frac{\text{Number individuals of each species per ha}}{\text{Total number of individuals of all species per ha}} \times 100\_\_\_\_\_\_\_\_(9)$$

$$\text{Relative Frequency} = \frac{Number of sampleplots containing a species}{Sampleunits for all species of the sample} \times 100\_\_\_\_\_\_\_\_ \quad (10)$$

$$\text{IVI} = \text{Relative Density} + \text{Relative Dominance} + \text{Relative Frequency}\_\_\_\_\_\_ \ (11)$$

3.3.2 Plant community classification

Cluster analysis helps to group a set of observations (plots or vegetation samples) based on their attributes or floristic similarities (McCunne and Grace, 2002; Kent, 2012). In this study, an agglomerative hierarchical clustering (AHC) was employed using a similarity ratio (SR) and Ward method (Minimum-variance clustering) to identify plant communities. The abundance data of the species were used in this analysis. R statistical software version 3.5.2 (R Core Team, 2018) and the packages Cluster and Vegan (Oksanen *et al.,* 2013; Zerihun Woldu, 2017) were used during cluster analysis.

An indicator species analysis (ISA) was performed using the indicator value (IndVal) method in R package cluster, Vegan andLabdsv (De Caceres, 2013; ZerihunWoldu, 2017) to identify diagnostic species for the naming of plant communities. The indicator value index (IndVal) is based on the abundance of a given species and its occurrence within a given set of samples. The statistical significance of the indicator values for each species was assessed by a Monte Carlo (randomization) test procedure. In this analysis, species with a significant indicator value of

P<0.05 is considered to be an indicator species of a community. Finally, the plant community types were named after two of the dominant species that had an indicator value of p< 0.05.

3.3.3 Species diversity

Shannon-Wiener diversity indices and Shannon's evenness were computed to describe species diversity, richness and evenness of the study area, sites and plant communities (Kent and Coker, 1992).

$$H' = -\sum_{i=1}^{s} Pi \ln pi \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (2)$$

Where H' = Shannon diversity index

s = number of species,

pi = proportion of ith species, , ln = the natural logarithm.

Shannon's evenness index (J) was also calculated by using: $J = {}^{H'}/_{H'max}$ ______________ (3)

where H' = Shannon–Wiener Diversity Index; and H' max = lns where s is the number of species in the plot.

Sørensen's similarity coefficient (Sørensen, 1948), was used for comparing the similarity of two communities or forest patches.

$$Ss = \frac{2a}{2a+b+c} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (4)$$

where b and c are the no_of species in communities, forest patches or study areas b and c; a - the number of species common to both and Ss is the Sørensen's similarity coefficient.

3.3.4 Ordination

Ordination is a multivariate method that articulates the relationships between species, plotes and environmental variables in a low-dimensional space using ordination diagrams (McCune and

Grace, 2002). A preliminary analysis of the data by Pearson's correlation coefficient was calculated to find a significant correlation between environmental variables and to remove auto-correlated variables from the ordination analysis using SAS software.

Redundancy Analysis (RDA) ordination method was used for this analysis for testing the vegetation and environmental variables relationships (Zerihun Woldu, 2017). RDA was selected due to its better visualization of the graph. In this analysis, 86 sample plots, 163 species and 10 environmental variables (altitude, slope, bulk density, moisture content, clay, pH, EC, available Phosphorus, CEC, and OM) were included. Adonis test was performed to determine the significance of the environmental variables on plant community distribution. Consequently, RDA ordination was plotted using cover-abundance values of plant species and data of significant environmental variables.

One-way ANOVA followed by post-hoc Tukey HSD test was used whether there were significant mean differences among plant communities about environmental variables, species richness, diversity and evenness.

3.3.5 Seed bank data analysis

The density of seeds (number of emerged seedlings) was calculated by dividing the total number of seeds of each species with the total sampling area (i.e., seeds/m^2). Jaccard's Coefficient of Similarity (JCS) (Krebs, 1989) was used to calculate the floristic similarity between seed bank and aboveground vegetation.

$JCS\frac{c}{c+b+a}$ __________ (12), a = the number of plant species found in standing vegetation

b = the number of plant species found in the seed bank and c is the number of species found both above ground and seed bank. If the value of Jaccard's similarity coefficient ranges from zero (no number of species in common) to one (identical set of species).

3.3.6 Land use/ land cover change

3.3.6.1 Image classification

Supervised image classification with a maximum likelihood algorithm was used to classify the images (Campbell and Wynne, 2011). Image classification was done to assign different spectral signatures from the Landsat datasets to different LU/LC, with aid of ground-truthing points collected from the Google Earth in the study area for the year of 2017. However, the classification of the past year images (1986 and 2003) was a challenge in the study area due to unavailability of past ground truth datasets. The proposed calibration in this study is based on comparing of the reflectance of each land use types since spectral signiture curve of a feature does not change with time in a specific wavelength. Accordingly, a total of 300 GPS points (50 GPS points in each LU/LC) were used for supervised classification. The description of each LU/LC type is presented in Table 4. LU/LC maps are produced for the years 1986, 2003 and 2017 to examine changes that occurred between these periods. Satellite images of the study years classified in ArcGIS (version 10.4).

Table 4. LU/LC types in the Dega Damot district and their descriptions

LU/LC classes	Descriptions
Farmland/agricultural	Include areas used for perennial and annual crops and the scattered rural settlements. Since the low spatial resolution Landsat imagery difficult to separate the scattered rural settlements among agricultural lands.
Forest	Areas covered with trees forming closed or nearly closed canopies, in which trees higher than 5 meters and a canopy cover of more than 10% (FAO, 2014). It also include eucalyptus trees
Shrubland	Areas covered with small trees, in which shrubs are the dominant vegetation.
Grassland	Areas covered by grasses (both communal and\or private grazing lands) that are used for livestock grazing.
Settlement	Areas occupied by buildings and towns
Bareland	Areas that have small or no vegetation cover, mostly with typical gullies and exposed rocks

3.3.6.2 Detection of land use/ land covers change

Post-classification image comparison technique was employed to detect changes from 1986 to 2003 and from 2003 to 2017 within the study area. Using the following calculation has been employed to detect the percentage of LU/LC change.

$$\text{Percentage LULC Change} = \frac{Area\ of\ intial\ year - Areaofintial\ year}{Areaofintialyear} \times 100\_\_\_\_\_\_\_\_(13)$$

Positive values indicate an increase whereas negative values show a decrease in the extent of LU/LC.

3.3.6.3 Accuracy assessment

Accuracy assessment was carried out to see to what extent the produced classification is compatible with what exists on the ground (Congalton, 1991). In this study, the accuracy was assessed for the year of the Landsat image of 2017. The reference data (latitude and longitude), were collected for each land-use type of 2017 classified images from corresponding Google earth images. Accordingly, a total of 300 validation points were taken for six land use/land cover classes (50 validation points for each). Consequently, the classified images were compared with reference images by using error matrices. Besides, the Kappa test was used for assessing classification accuracy as it not only accounts for diagonal elements but all the elements in the confusion.

3.3.6.4 LU/LC change distribution along slope and elevation

Finally, the three LU/LC maps were combined with DEM or slope map through the grid extension of Arc GIS software version 10.4. Through exporting the attribute table of the combined maps and calculating the elevation and slope gradient of different land-use types in different years, the changes of LU/LC can be detected.

4. RESULTS

4.1 Floristic Composition and Diversity

4.1.1 Floristic composition

A total of 176 species, belonging to 80 families were recorded in the study area both inside and outside the study plots. Consequently, 163 species were recorded within the plots while 13 species namely, *Arundo donax*, *Acaciaetbaica, Entada abyssinica, Momordica foetida, Vernonia leopoldi, Guizotia scabra, Salix subserrata, Euphorbia tirucalli*, *Ficus ingens, Lactuca inermis*, *Leonotis ocymifolia, Malva verticillata,* and *Sporobolus africanus* were recorded outside the plots (Appendix 1). Asteraceae was the most diverse family in the study area represented by 19 species (11%). The second and third most diverse families were Fabaceae with 13 species (7%), Lamiaceae and Poaceae with 9 species (5% each). Herbs primarily dominated the growth form composition comprising 70 species (40%) of the total species. Apart from herbs, shrubs are the next dominant growth forms and about 51 species (29%). 43 species (24 %) are tree and woody lianas are the least represented growth forms (13 species, 7 %) (Table 5, Figure 8).

Table 5. Ten families with the highest number of species

Family	No_ of sp.	**%**
Asteraceae	19	10.79
Fabaceae	13	7.38
Lamiaceae	9	5.11
Poaceae	8	4.54
Euphorbiaceae	6	3.40
Rubiaceae	5	2.84
Moraceae	4	2.27
Myrsinaceae	4	2.27
Rosaceae	4	2.27
Solanaceae	4	2.27

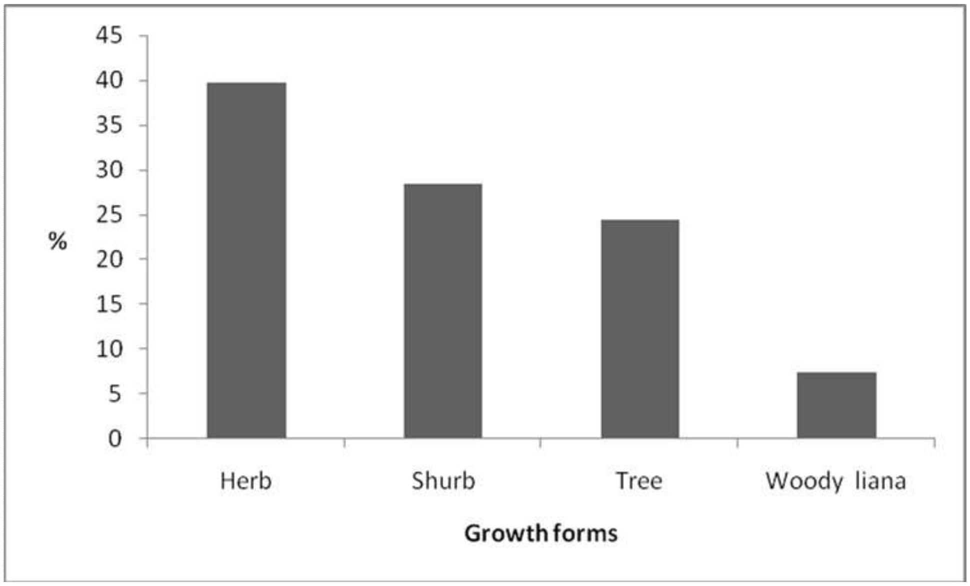


Figure 8. The growth forms of plant species in the study area

4.1.2 Floristic diversity

The overall Shannon diversity index and evenness of the study area were 2.79 and 0.95, respectively (Appendix 2). Among the forest patches, the highest Shannon index was observed in Shangi Derkie, followed by the Bunsie forest, Aradie, Masikana Medihanyalem and Samana (Table 6).

Table 6. Indices of diversity and evenness of the forest patches in the study area

Forest Patch	Richness	Evenness index (J)	Alpha Diversity index (H')
Shangi Derkie	21.9	0.96	2.93
Aradie	14.5	0.94	2.43
Bunsie	22.5	0.95	2.91
Masikana Medihanyalem	13	0.96	2.36
Samana	10.9	0.94	2.19
Overall (study area)		0.95	2.79

4.1.2.1 Species diversity and richness along an altitudinal range

Species richness ranged per plot from 5 to 40, the Shannon-Wiener index ranged from 1.42 to 3.54 and evenness ranged from 0.88 to 0.99 (Appendix 2) The plotted species richness, diversity and evenness against the altitudinal gradient, which was the one most important factor affecting forest and species distribution. Species richness and diversity increased gradually with increasing elevation, reaching a maximum close to the mid-altitude. Species richness and diversity showed significant correlations with elevation while the correlations of evenness with elevational gradient were not statistically significant, but the trends were similar to those for species richness and diversity (Table 7).

Table 7. Correlation of species richness, diversity, and evenness with altitude in the study area

		Richness	Diversity	Evenness
Altitude	Pearson correlation	0.416**	0.387**	0.078
	Sig. (2-tailed)	0.000	0.000	0.478

** Correlation is significant at the 0.01 level (2-tailed).

4.1.3 Floristic composition similarities between forest patches

The similarity between forest patches presented in Table 8. Accordingly, Shangi Derkie and Bunise forests exhibited the highest similarity. Moreover, the Aradie forest patch showed strong similarities with Shangi Derkie and Bunsie forest patches. Relatively the least similarity was observed between Samana with Shangi, Aradie and Bunise forest patches.

Table 8. Floristic composition similarity indices of the five forest patches

	Shangi	Aradie	Bunise	Masikana	Samana
Shangi	-				
Aradie	0.63	-			
Bunise	0.72	0.59	-		
Masikana	0.53	0.60	0.57	-	
Samana	0.19	0.19	0.19	0.25	-

Note: Shangi: Shangi Derke, Masikana:Masikana Medihanyalm

4.1.4 Variation of environmental variables among forest patches

As shown in Table 9, slope and altitude varied among the different forest patches selected. The altitudinal range of the forest patches varied significantly ($P < 0.05$) from the lowest value (2021.33 m asl) in the Samana forest patch to the highest (2840.60 m asl) in Aradie forest patch. Concerning soil characteristics, the soils of the Samana forest patch showed significantly higher values of clay and lower values of MOC, OM, N, P contents in comparison with the other forest patches (Aradie, Shangi Derkie, Bunise, and Masikana Medahanyalem). For instance, the Bunise forest patch had higher MOC, OM, total nitrogen while the opposite was true for Samana forest patch ($P < 0.05$) (Table 9).

Table 9. Post-hoc comparison of means between environmental variables and forest patches

Environmental variables	Forest patches: Aradie	Shangi	Bunise	Masikana	Samana
Slope (%)	25^{c}	51.17^{ab}	54.98^{ab}	62.67^{a}	49.17^{b}
Altitude(ma.s.l)	2840.60^{a}	2765.38^{ab}	2691.47^{b}	2574.11^{c}	2021.33^{d}
MOC(%)	10.69^{b}	10.68^{b}	15.30^{a}	12.24^{ab}	4.70^{c}
BD(g/cm^3)	0.60^{b}	0.71^{b}	0.74^{b}	0.64^{b}	0.88^{a}
CLAY(%)	22.600^{b}	21.103^{b}	21.563^{b}	24.556^{b}	33.000^{a}
pH	6.29^{c}	6.36^{bc}	6.53^{ab}	6.50^{ab}	6.63^{a}
EC(mS/cm	0.06^{b}	0.05^{b}	0.10^{b}	0.20^{a}	0.06^{b}
OM (%)	7.59^{b}	7.32^{b}	10.50^{a}	9.43^{ab}	3.49^{c}
CEC (Cmol (+)/kg soil	62.94^{a}	63.03^{a}	68.93^{a}	61.20^{a}	51.09^{b}
TN (%)	0.37^{ab}	0.37^{ab}	0.43^{a}	0.34^{b}	0.16^{c}
P (mgP/kg soil)	22.00^{a}	8.70^{bc}	22.50^{a}	16.00^{ab}	6.17^{c}

Note MOC: Moisture content, EC: Electrical conductivity, BD: Bulk density, OM: Organic matter, CEC: Cation exchange capacity, TN: total nitrogen, P: phosphorus, values in a row with different letters are significantly different ($P<0.05$).

4.1.5. Endemic plant species

Of the total plant species composition of the forest, 18 (11%) species are endemic to Ethiopia and Eritrea (Table 10). Among the total endemics, nine species are shrubs, seven species herbs, and two species trees. Similarly, Asteraceae and Fabaceae were the most diverse families having seven and three endemic species respectively.

Table 10. Endemic plant species in the study area

No	Species	Family	Habit	IUCN category	Altitude (m)
1	*Acanthus sennii*	Acanthaceae	Shrub	NT	1700-3200
2	*Aloe pulcherrima*	Aloaceae	Shrub		
3	*Bidens macroptera*	Asteraceae	Herb		
4	*Bothriocline schimperi*	Asteraceae	Shrub	LC	1300-2820
5	*Crassocephalum macropappum*	Asteraceae	Herb		
6	*Crotalaria rosenii*	Fabaceae	Shrub	NT	1350-3000
7	*Erythrina brucei*	Fabaceae	Tree	LC	1200- 2900
8	*Impatiens rothii*	Balsaminaceae	Herb		
9	*Inula confertiflora*	Asteraceae	Shrub	NT	2500-3700
10	*Kalanchoe petitiana*	Crassulaceae	Herb		
11	*Kniphofia foliosa*	Asphodelaceae	Herb		
12	*Laggera tomentosa*	Asteraceae	Shrub		
13	*Lippia adoensis*	Verbenaceae	Shrub	LC	1900-2450
14	*Rhus glutinosa subsp.glutinosa*	Anacardiaceae	Tree	VU	1800-3300
15	*Solanecio gigas*	Asteraceae	Shrub	LC	1750-3350
16	*Urtica simensis*	Urticaceae	Herb	LC	1500-3400
17	*Trifolium decorum*	Fabaceae	Herb		
18	*Vernonia leopoldi*	Asteraceae	Shrub		

Source: Flora of Ethiopia and Eritrea Volumes (1-7) and Vivero, *et al*., 2005

4.2 Vegetation structure

4.2.1 Density and frequency of woody species

The total density of woody species in the study forest patches were 2679 individuals ha^{-1}. The species with the highest density was *Dodonaea anguistifolia (*225individuals ha^{-1}), followed by *Myrsine africana (*187 individuals ha^{-1}), *Vernonia myriantha* (146 individuals ha^{-1}) and *Olinia rochetiana (*145 individuals ha^{-1}) (Appendix 3).

The distribution of woody species in frequency class showed that higher proportions of species were found in the first frequency class and gradual decline towards the higher frequency classes (Figure 9). The species with the highest frequency were *Bersama abyssinica*, *Olinia rochetiana* and *Vernonia myriantha* (66% each), followed by *Rhus glutinosa* subsp. *glutinosa* (56%), *Maytenus arbutifolia* (55%), *Osyris quadripartita, Rosaabyssinica* (53% each) and *Dovyalis verrucosa* (51%).

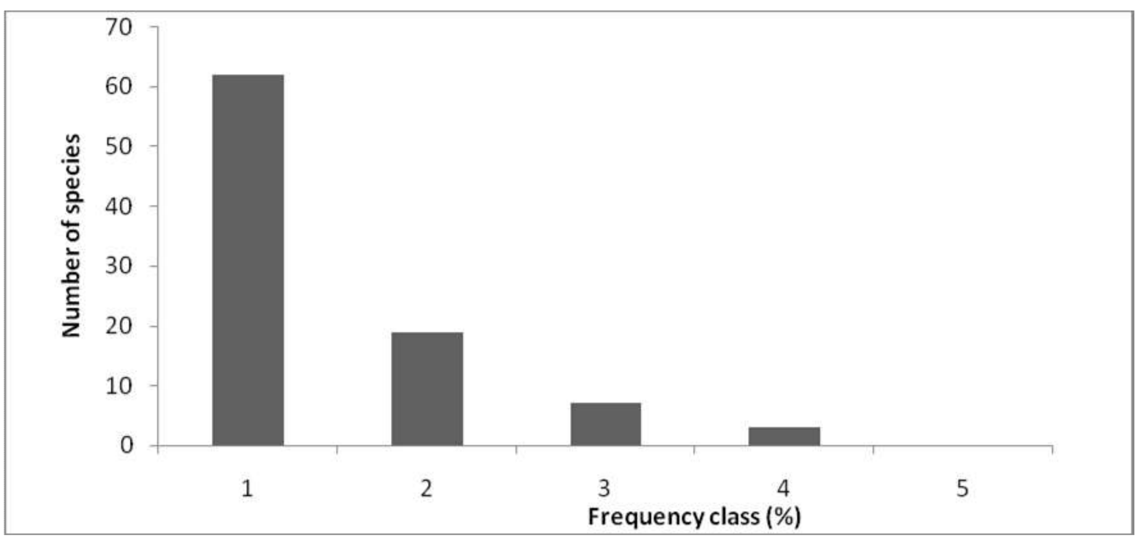


Figure 9. Frequency distributions of woody species in Dega Damot district
Frequency class 1 = 0 – 20, 2 = 20.1 – 40, 3 = 40.1 – 60, 4 = 60.1– 80 and 5 = 80.1– 100

4.2.2 Basal area and Importance value index of woody species

The total basal area of woody species in the study forest patches with DBH ≥ 2.5 cm in the study area was 51 m^2ha^{-1}. Bunsie forest had the highest basal area (25 m^2 ha^{-1}), followed by Shangi Derkie (16 m^2 ha^{-1}), Masikana Medihaniyalem (6 m^2 ha^{-1}), Samana (2.55 m^2 ha^{-1}) and Aradie (2.45 m^2 ha^{-1}) forests (Figure 10). The species with the highest basal area was *Ficus sur (*7.47 m^2 ha^{-1}) followed by *Prunus africana* (7.40 m^2 ha^{-1}), *Schefflera abyssinica (*6.82 m^2 ha^{-1}), *Rhus glutinosa* subsp. *glutinosa* (3.70 m^2 ha^{-1}), *Olea europaea* subsp.*cuspidata (*2.71 m^2 ha^{-1}) and *Oliniarochetiana (*2.36 m^2 ha^{-1}) (Appendix 3).

The importance value index (IVI) of species ranged from 0.08 to 17.97 (Appendix 3). The species *Prunus africana* had the highest IVI (17.97), followed by *Schefflera abyssinica* (15.14), *Ficus sur (*14.96), *Oliniarochetiana* (14.28), *Rhus glutinosa* subsp. *glutinosa* (13.31) and (10.33). 27 species had IVI less than 0.5.

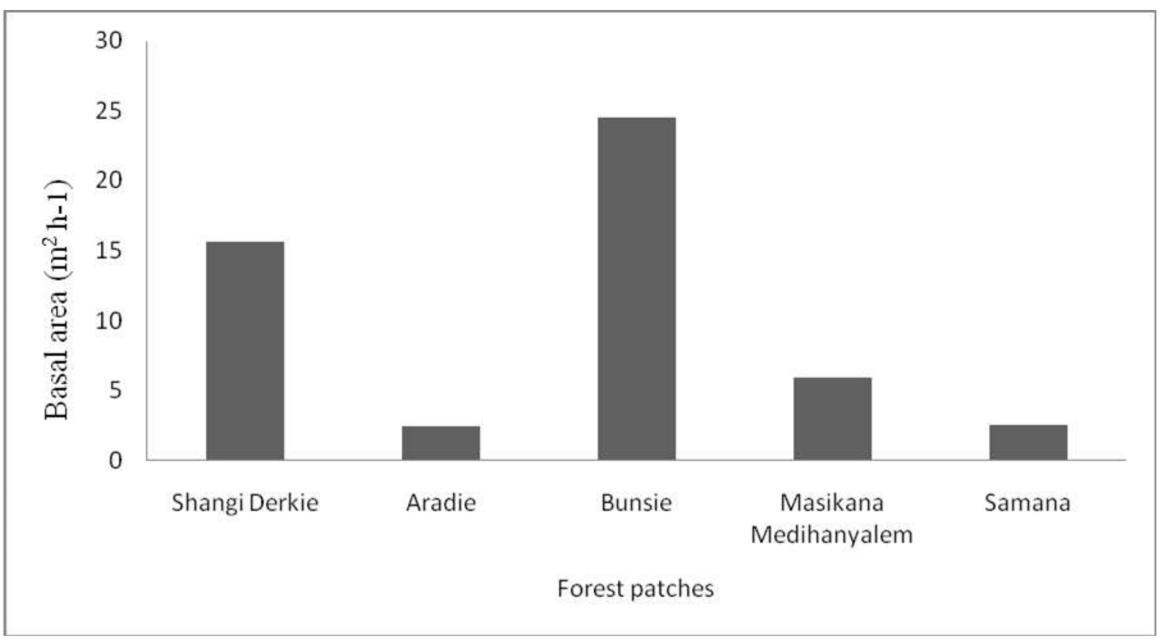
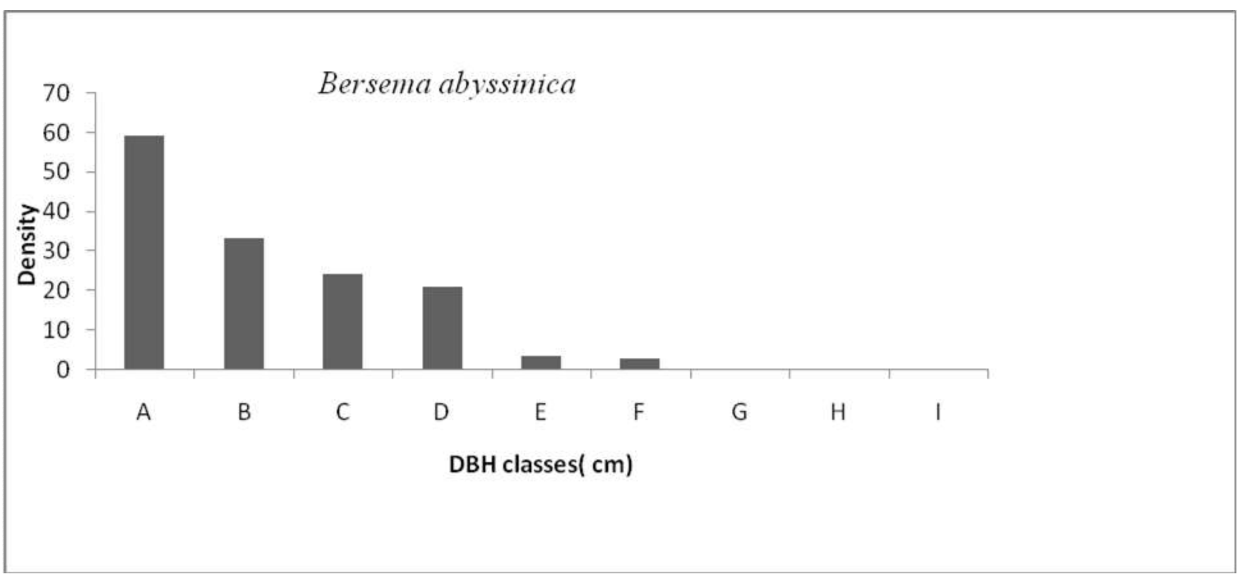


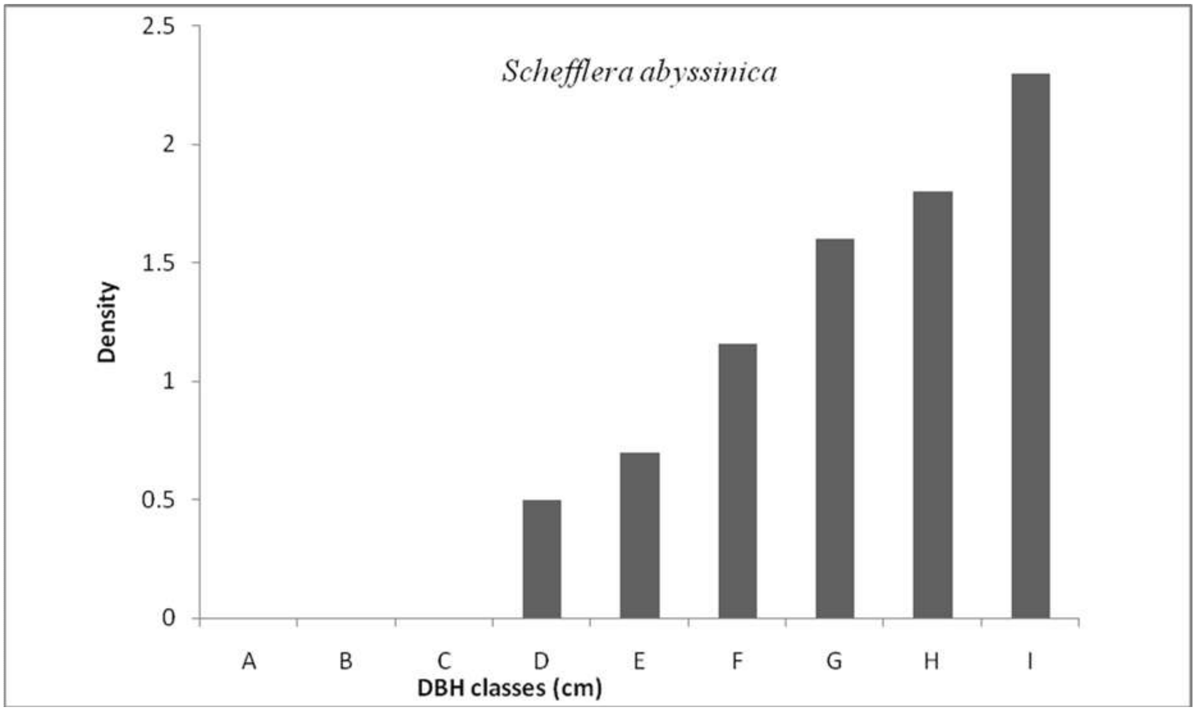
Figure 10. Basal area of forest patches

4.2.3 Population structure of woody species

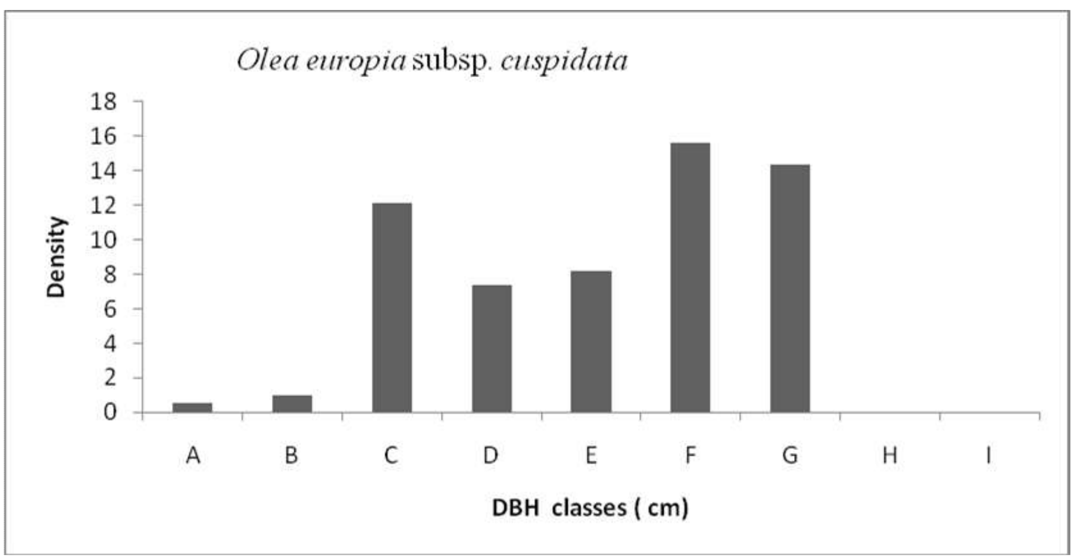
The population structure of selected representative woody species showed in three diameter class distribution patterns (Figure 11a-c). The first pattern was an inverted J-shaped distribution formed by species with the high-frequency distribution of individuals in the lower DBH classes followed by a gradual decrease towards the higher DBH classes (Figure11a). The species *Bersama abyssinica* showed this type of pattern. The second pattern was J-shape, which showed that a larger proportion of woody plant individuals are found in the higher DBH classes and decreased towards the lower diameter classes. This pattern was represented by *Schefflera abyssinica.* The third pattern was represented by species having an irregular distribution over DBH classes where some DBH classes had a small number of individuals while other DBH classes had a large number of individuals (Figure 11 c). *Olea europia* subsp.*cuspidata* show this type of pattern.



(a)



(b)



(c)

Figure 11. Population structure of a, *Bersama abyssinica, b,Shefelira Abyssinia, c, Olea europia* subsp. *cuspidata*in the study area (A=2.5-10 cm, B=10.1-20 cm, C=20.1-30 cm, D=30.1-40 cm, E=40.1-50 cm, F=50.1-60 cm, G=60.1-80cm, H=80.1-100, I=>100 cm)

4.3 Plant community types

Five plant community types were identified from the hierarchical cluster analysis in the study area (Figure12). The community is named after one or two dominant indicator tree or shrub species selected by the relative magnitude of their indicator values (Table 11). In this study, a species is considered as an indicator of a group when its indicator value is significantly higher at $p < 0.05$. Consequently, the identified communities were *Erica arborea-Osyris quadripartita*, *Discopodium penninervium-Echinops pappii*, *Olea europaea* subsp. *cuspidata-Scolopia theifolia*, *Euphorbia abyssinica-Prunus africana*, *Dodonaea anguistifolia-Acokanthera schimperi* community types.

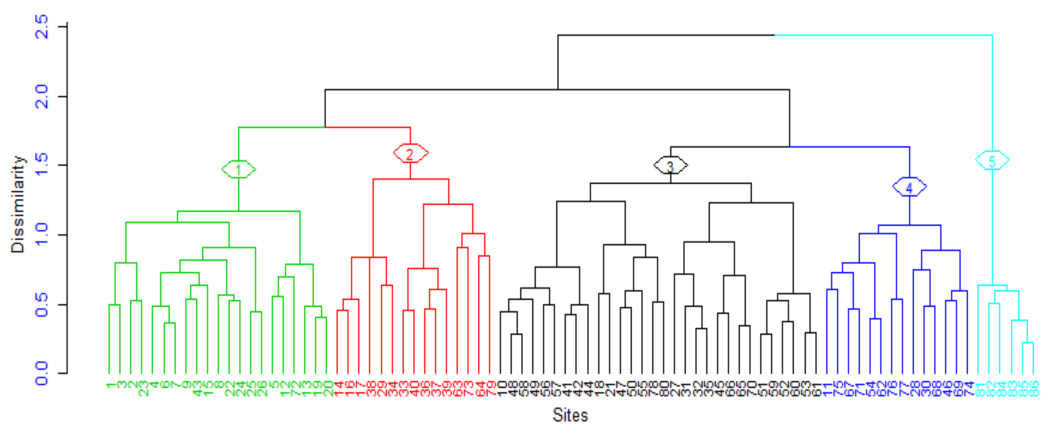


Figure 12. Dendrogram of the vegetation data obtained from hierarchical cluster analysis of the study area (1= Community type 1, 2= Community type 2, 3= Community type 3, 4= Community type 4 and 5= Community type 5)

Table 11.Indicator values of species in each community type (C1 - C5) and their significance ($P < 0.05$).

Indicator Species	Indicator values (%)					
	1	2	3	4	5	P value
Erica arborea	**51.8**	0	12.8	0	0	0.001
Osyris quadripartita	**39**	6.5	15.4	3.9	0	0.001
Bersama abyssinica	37.5	13.9	8.6	18.2	0	0.001
Buddleja polystachya	34	4.8	2.4	7.4	0	0.01
Rosa abyssinica	33.2	15.5	11.4	3.1	0	0.007
Maesa lanceolata	23.1	1.4	3.4	1.6	2.2	0.033
Discopodiumpenninervium	0.4	**40.6**	3.3	0	0	0.004
Echinops pappii	3	**36.2**	1.5	0.4	0	0.01
Laggera tomentosa	5	32.2	1.3	0	0	0.01
Olea europaea	2.2	4.4	**47.2**	0.5	0	0.001
Scolopia theifolia	0	0	**43.7**	11.1	0	0.001
Olinia rochetiana	19.7	1.5	42.1	15	0	0.001
Myrsine africana	23.2	0	28.7	2.5	0	0.028
Clutia abyssinica	9.9	17.9	28	0.2	0	0.046

Pittosporium viridiflorum	5.2	0.5	24.2	0.4	0	0.035
Euphorbia abyssinica	0	0.4	10.2	**45.7**	0	0.001
Prunus africana	3.8	0.3	13.5	**30.5**	0	0.019
Solanecio gigas	0.9	5.7	6.7	27.9	0	0.028
Embelia schimperi	1.1	0	0	27.8	0	0.005
Dodonaea anguistifolia	0.6	0.1	0.9	0	**91.3**	0.001
Acokanthera schimperi	0	0	0	0	**83.3**	0.001
Croton macrostachyus	1.5	2.4	0.4	0.2	56.7	0.001
Euclea schimperi	0	0	0	0	50	0.001
Acacia seyal	0	0	0	0	50	0.002
Combretum molle	0	0	0	0	50	0.001
Rhus vulgaris	0	0	0	0.7	45.2	0.001
Premna schimperi	0	0	0	0	33.3	0.008
Senna singueana	0	0	0	0	33.3	0.003

***Erica arborea-Osyris quadripartita* community type (C1)**

This community is found in the Shangi Derkie forest patch, which has a very steep slope. The altitudinal range of this community type lies between 2516 and 2947 ma.s.l. The community has six indicator species with significant indicator values, namely; *Erica arborea, Osyris quadripartita, Bersama abyssinica*, *Buddleja polystachya*, *Maesa lanceolata* and *Rosa abyssinica.* The tree layer was dominated by *Ekebergia capensis* and *Lepidotrichiliavolkensii.* The shrub layer was dominated by *Lippia adoensis.* The most dominant species in the herb layer include *Kniphofia foliosa, Kalanchoe petitiana, Verbascum sinaiticum* and *Trifolium decorum.* This community type is represented by 108 species, being the richest in a number of species among the five community types.

***Discopodium penninervium-Echinops pappii* community type (C2)**

The altitudinal range of this community type lies between 2375 and 2916 ma.s.l and located in Shangi Derkie, Aradie, Bunise and Masikana Medhanyalm forest patches. The indicator species are *Discopodiumpenninervium, Echinops pappii* and *Laggera tomentosa*. The most dominant shrub species were *Solanecio gigas, Maytenus arbutifolia, Solanum incanum, Rumex nervosus*, *Gnidia glauca*and*Acanthus sennii.* The tree layer was dominated by *Arundinaria alpina*. The liana such as *Asparagus africanus* and *Phytolacca dodecandra* were dominant. The herb layer was dominated by *Plectranthus assurgens, Helichrysum nudifolium* and *Carduus schimperi*. This community is comprised of 104 species.

Olea europaea **subsp.** ***cuspidata-Scolopia theifolia*** **Community type (C3)**

This community lies between altitudes 2475 and 2906 m above sea level. Similar to community 1 and 2, *Olea europaea* subsp. *cuspidata* - *Scolopia theifolia* Community type is also found in Bunise, Shangi Derkie, Aradie and Masikana Medihanyalm forest patches. The indicator tree and shrub species of this community are *Olea europaea* subsp*. cuspidata, Scolopia theifolia, Olinia rochetiana, Myrsineafricana, Clutia abyssinica* and *Pittosporum viridiflorum.*The dominant species in the tree layer include *Apodytes dimidiata.* The shrub species such as *Rhus glutinosa*. subsp. *glutinosa*, *Dovyalis verrucosa* and *Catha edulis* were highly dominant. The herb layer comprised of *Oplismenus hirtellus, Impatiens hochstetteri, Impatiens rothii* and *Justicia heterocarpa.* This community is comprised of 73 species.

Euphorbia abyssinica-Prunus africana **community type (C4)**

This community type is located between altitudes 2455 and 2733 masl, and which is found in 3 forest patches: Bunise, Shangi Derkie, Aradie and Masikana Medihanyalm. The indicator species are *Euphorbia abyssinica* and *Prunus africana.* The shrub layer includes *Solanecio gigas* and liana species *Embelia schimperi* were also dominant. The herb layer was dominated by *Hypoestes forskaolii.* It consists of 84 species.

Dodonaea anguistifolia-Acokanthera schimperi **community type (C5)**

Community 5 found in the Samana forest patch. This community is established at lower elevations (1881–2110 ma.s.l.). *Dodonaea anguistifolia* and *Acokanthera schimperi* are the characteristic species of the shrub, and tree layers, respectively. Other dominant tree species include *Croton macrostachyus, Acacia seyal,* and *combretum molle.* The shrub layer was dominated by *Euclea schimperi*. Dominant species of the herb layer were *Bidens macroptera* and *Satureja abyssinica.*

Table 12: Location of plant community in the forest patches

Plant community types	Location of forest patch
Community 1	Shangi Derkie
Community 2	Shangi Derkie, Aradie, Bunise and Masikana Medhanyalm
Community 3	Bunise, Shangi Derkie, Aradie and Masikana Medihanyalm
Community 4	Bunise, Shangi Derkie, Aradie and Masikana Medihanyalm
Community 5	Samana forest patch

4.3.1 Diversity and evenness of plant communities

Shannon`s diversity indices showed that community 1 had the highest species diversity and richness followed by community 2, while community 5 had the lowest species diversity and richness. On the other hand, community 4 had the highest evenness value followed by communities 3 and 5. Community 1 and 2 had the least evenness value (Table 13).

Table 13. Diversity and evenness of plant communities

Plant community types	Richness	Shannon_Evenness (J)	Shannon Diversity (H)
Comminty 1	108	0.837764	3.922522
Comminty 2	104	0.83718	3.888192
Comminty 3	73	0.863749	3.705881
Comminty 4	84	0.878393	3.891999
Comminty 5	31	0.840046	2.884706

One way ANOVA showed that there was a statistically significant difference among plant communities in species richness, evenness, and species diversity (Table 14). The comparison of plant communities based on the mean of species richness and species diversity showed that community type 5 is significantly different from community types 1, 2, 3 and 4.

Table 14. Post-hoc comparison of means between, richness, diversity, evenness and plant community

	Plant community types				
Variable	C1	C2	C3	C4	C5
Richness	21.762a	16.000ab	22.100a	18.286a	10.833b
Diversity	2.9248a	2.5073bc	2.8663ab	2.7779ab	2.1967c
Evenness	0.959048a	0.946667ab	0.950667ab	0.961429a	0.938333b

Note: Values in a row with different letters are significantly different ($P< 0.05$).

4.3.2 Similarities between plant communities

Results of plant community similarity indicated that communities 2 and 3, the similarity index values and communities 1 and 2, communities 1 and 3 have the same similarity index values. The least similarity was between community 1 and 5, community 3 and 5, community 4 and 5 (Table 15).

Table 15. Similarity indices of plant communities (C1 - C5) in the study area

	Plant community types				
	C1	C2	C3	C4	C5
C1	-				
C2	0.72	-			
C3	0.72	0.74	-		
C4	0.60	0.64	0.68	-	
C5	0.20	0.25	0.20	0.20	-

Note: C1: *Erica arborea-Osyris quadripartita,* C2: *Discopodium penninervium-Echinops pappii,* C3: *Olea europaeasubsp. cuspidata - Scolopia theifolia,* C4: *Euphorbia abyssinica - Prunus africana,* C5: *Dodonaea anguistifolia - Acokanthera schimperi* plant community types.

4.4 Correlation of environmental variables

Pearson's correlation matrix of the environmental factors is shown in Table 16. Altitude was positively correlated with moisture content, nitrogen and sand and negatively correlated with pH and bulk density. Nitrogen and phosphorus are positively correlated with soil moisture content and organic matter. CEC is positively correlated with organic matter, nitrogen and phosphorus. Soil pH shows a positive correlation with phosphorus while EC shows a positive correlation with organic matter (see Table 16).

Table 16. Pearson correlation coefficients between environmental variables in Dega Damot District, Northwestern Ethiopia

-	Slo	Elev	MOc	BD	Clay	PH	EC	OM	CEC	N	P
Slo	1										
Elev	-0.08	1									
MOc	0.18	0.26*	1								
BD	0.01	-0.22*	-0.22*	1							
Clay	0.264*	0.35**	0.48**	-0.37**	1						
pH	0.28*	-0.4**	0.03	0.11	-0.96*	1					
EC	0.04	-0.06	0.17	-0.15	0.23*	0.09	1				
OM	0.26	0.18**	0.67**	-0.3**	0.71**	0.14	0.28*	1			
CEC	0.01	0.01	0.56**	-0.21*	0.27*	0.191	0.17	0.58**	1		
N	0.06	0.40**	0.52**	-0.25*	0.40**	-0.01	0.08	0.65**	0.51**	1	
P	-0.19	-0.06	0.38**	-0.04	0.19**	0.38**	0.15	0.44**	0.47**	0.25*	1

*. Correlation is significance at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed), Slo, slope; Elev, elevation; Moc, Moisture content; BD, Bulk density.

4.5 Relationship between plant community types and environment variables

4.5.1 RDA Ordination

Out of the 10 environmental variables included in ordination analysis (slope, bulk density, moisture content, elevation, clay, pH, P, EC, OM and CEC), only elevation, moisture content, OM, slope, pH, EC, clay and phosphorus had significant ($p < 0.05$) correlated on species compositions of communities and their distributions as shown in Table 17 and Figure 13. The RDA diagram indicated that the first axis was primarily correlated with elevation, clay, and moisture content, while the second axis was correlated with P, OM and moisture content (Figure13, Table 18). The eigenvalue for the first and second axis were 0.54 and 0.19, respectively. The first axis eigenvalue which closer to 1 and show distribution of the plant communities along the axis is good. The cumulative proportion variance explained by the first six RDA axis of the joint biplot was 92%. The variation in patterns of plant species distribution and plant community formation for the first and second axis were 46%, and 16%, respectively. This showed that 62% of the variation in patterns of plant species distribution and plant community formation was explained by axis one and two.

Consequently, the first two axes are sufficient to reflect the relationship between species and environmental factors. In the first RDA axis, elevation was the most important variable and separated communities at high elevation (communities 1, 2, 3, and 4) from communities distributed at lower elevation (communities 5) on the ordination axis (Figure 13). On the other hand, in the second axis, communities 2 and 3 were located on sites with higher organic matter and moisture content.

Table 17. Result of function donis test of environmental variables (significant environmental variables are indicated by Asterix at their p-value) the study area

Environmental variables	Df	Sums of Sqs.	Mean Sqs	F. Model	R^2	Pr(>F)
Slope (%)	1	0.5315	0.53153	2.4132	0.02232	0.007 **
Altitude(ma.s.l)	1	2.6735	2.67347	12.1376	0.11225	0.001***
MOC(%)	1	0.9862	0.98618	4.4773	0.04141	0.001 ***
Bulk Density	1	0.3151	0.31505	1.4303	0.01323	0.137
Clay	1	0.3822	0.38217	1.7351	0.01605	0.042*
pH	1	0.5543	0.55432	2.547	0.02327	0.002 ***
EC	1	0.6313	0.63132	2.7876	0.02651	0.002 **
OM	1	0.4122	0.51573	1.8716	0.01731	0.028*
CEC	1	0.3469	0.2462	1.5748	0.01034	0.086
P	1	0.4745	0.4745	2.1544	0.0199	0.010 *
Residuals	75	16.5197	0.22026		0.69361	
Total	85	23.8170			1.00000	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘’ 1

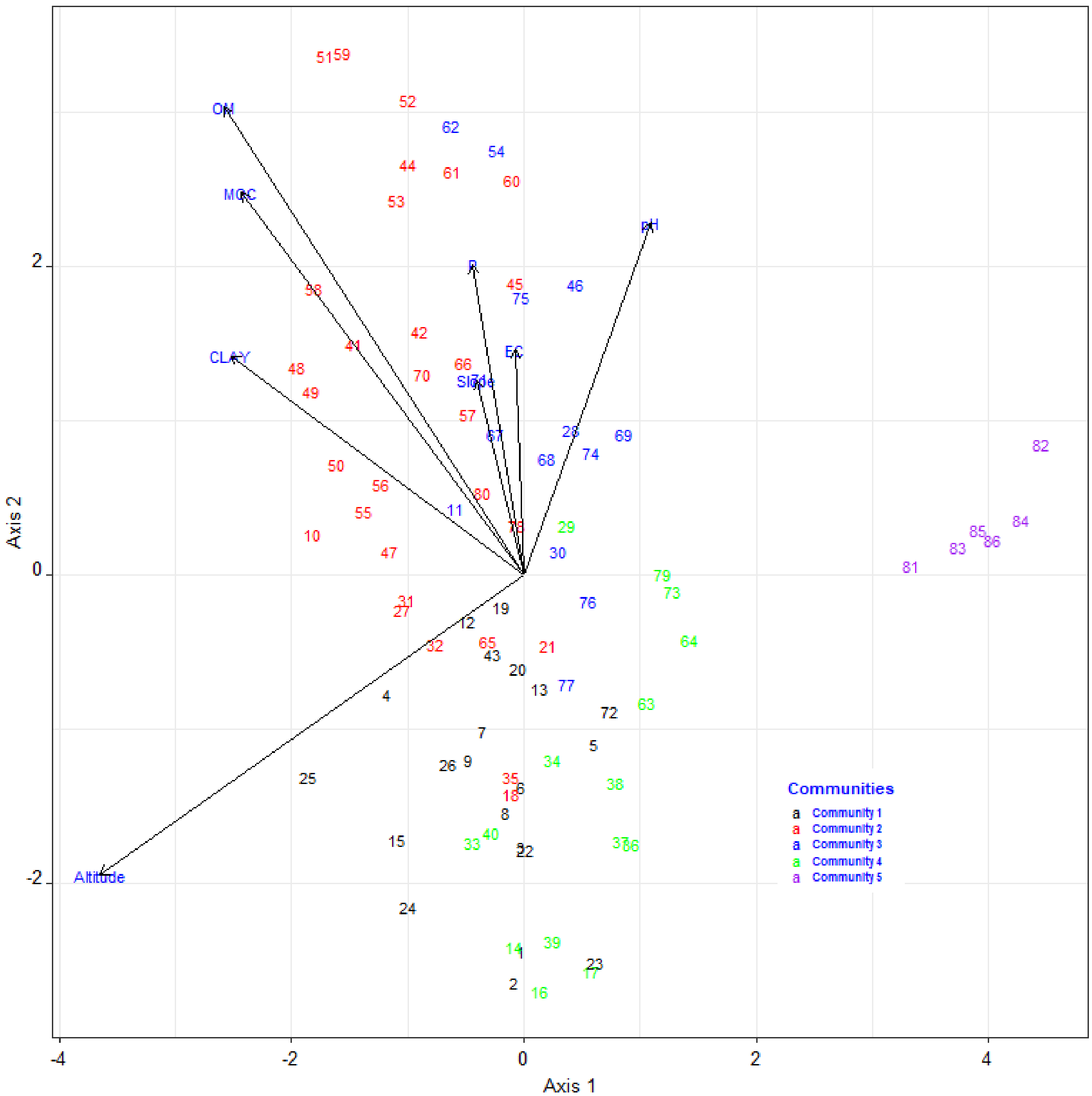


Figure 13. Redundancy analysis (RDA) ordination graph significant environmental variables (p < 0.05 and the plant community in the study area. The arrows in the diagram stand for the environmental factors, the length of each arrow indicates the contribution of the factor to ordination axes, The numbers refer to quadrat number, and the angle between the arrows and the axes indicates the correlation between the variable and the ordination axes.

Table 18. Biplot scores for constraining variables

Variables	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Slope	0.0025	0.13	-0.5861	0.496	-0.4817	0.045
Altitude	-0.9492	-0.29	0.0079	0.082	0.044	-0.049
Moisture content	-0.3664	0.67	-0.217	0.072	0.092	0.172
Clay	-0.4319	0.53	-0.2948	0.084	0.0086	-0.633
PH	0.2330	0.30	-0.3008	-0.594	-0.52	0.283
EC	-0.0504	0.42	-0.2941	-0.098	0.654	0.206
OM	-0.3424	0.86	-0.2748	0.144	- 0.008	-0.068
P	-0.1120	0.74	0.4181	-0.322	-0.16	0.217
Eigenvalue	0.5392	0.1887	0.1238	0.0933	0.062	0.0634
Proportion Explained	0.4612	0.1614	0.1059	0.077	0.05829	0.053
Cumulative Proportion	0.4612	0.6226	0.7285	0.80	0.920	0.920

The values of the different environmental variables average for each plant community type are presented in Table 19.

Table19. Post-hoc comparison of means between environmental variables and plant communities

	Plant community types				
Environmental variable	C1	C2	C3	C4	C5
Elevation	2762.67^{a}	2783.60^{a}	2727.17^{a}	2593.64^{b}	2021.33^{c}
Moisture content	10.363^{b}	10.710b^{a}	14.782^{a}	13.908b^{a}	4.697^{c}
Clay	21.143^{bc}	27.533^{ab}	20.867^{bc}	19.000^{c}	33.000^{a}
PH	6.3419^{b}	6.39733^{ab}	6.44500^{ab}	6.60357^{a}	6.63000^{a}
Organic matter	7.561^{ab}	6.551^{b}	10.244^{a}	10.332^{a}	3.485^{c}
CEC	63.111^{ab}	58.069^{cb}	66.780^{ab}	72.433^{a}	51.088^{c}
N	0.38205^{ab}	0.32040^{b}	0.42547^{a}	0.41150^{a}	0.15967^{c}
P	9.048^{b}	18.000^{ab}	17.367^{ab}	24.071^{a}	6.167^{b}

Note: Values in a row with different letters are significantly different ($P<0.05$).

4.6 Floristic composition and seedling density of seed bank

4.6.1 Floristic composition of the seed bank

A total of 2133 seedling species belonging to 27 families germinated and were identified in the greenhouse experiment from soil samples collected in the 46 plots (Appendix 4). The richest families were Asteraceae (9 species) followed by Solanaceae (3 species), Euphorbiaceae, Fabaceae, Geraniaceae, Lamiaceae, Poaceae, Polygonaceae, and Rosaceae (2 species for each). For growth forms, 29 were herbs (65.9%), 12 shrubs (27.27%), 2 trees (4.54%) and one liana (2.27%) species germinated (Figure 14).

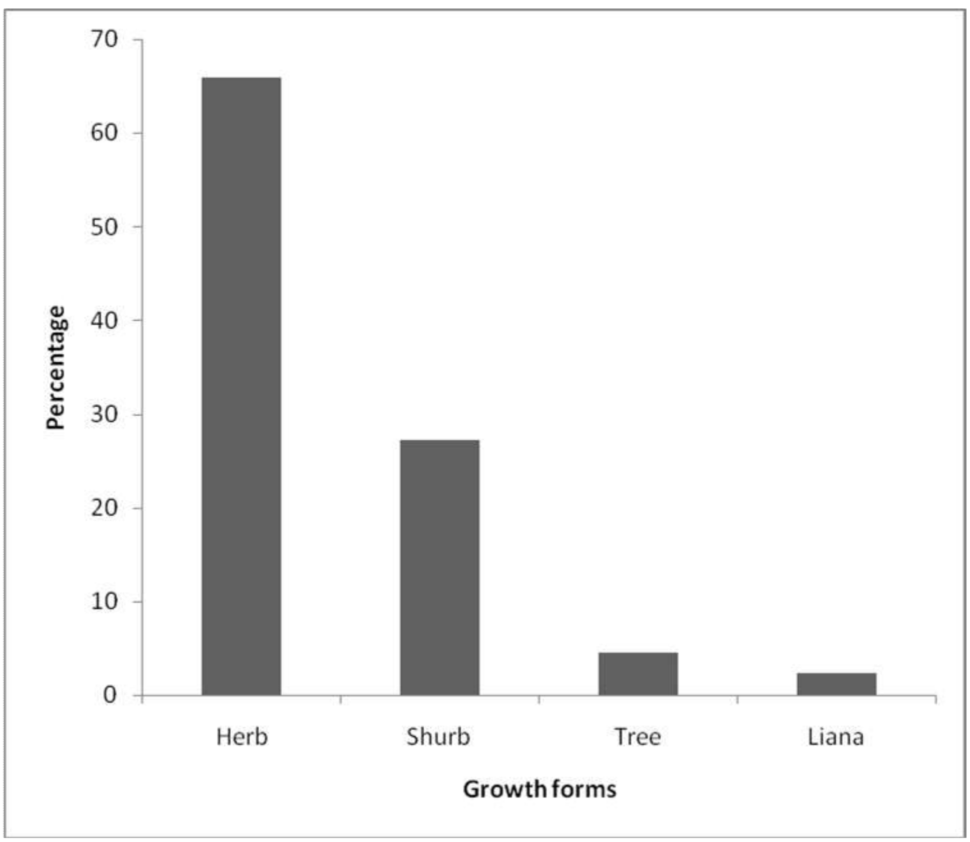


Figure 14. Growth forms of the soil seed bank flora

4.6.2 Seedling density in the soil seed banks

The total seedling density of species in the seed bank was 4637 seeds/m^2. The density of viable seeds from the seed bank ranged between 2.17 and 989.13 seeds/m^2. The seven species with the highest seedling densities included, *Eragrostis* sp.(989 seeds/m^2) followed by *Drymaria cordata* (576 seeds/m^2), *Trifolium rueppellianum* (545.7 seeds/m^2), *Polygonium nepalensis* (356.5 seeds/m^2), *Geranium arabicum* (252 seeds/m^2), *Dichondra repens*, *Erica arborea* (232.7 seeds/m^2) (Appendix 5). The highest seed bank density was recorded in the litter layer and the upper 3 cm layer (0-3 cm depth) and then gradually decreased with increasing depth (Figure 15).

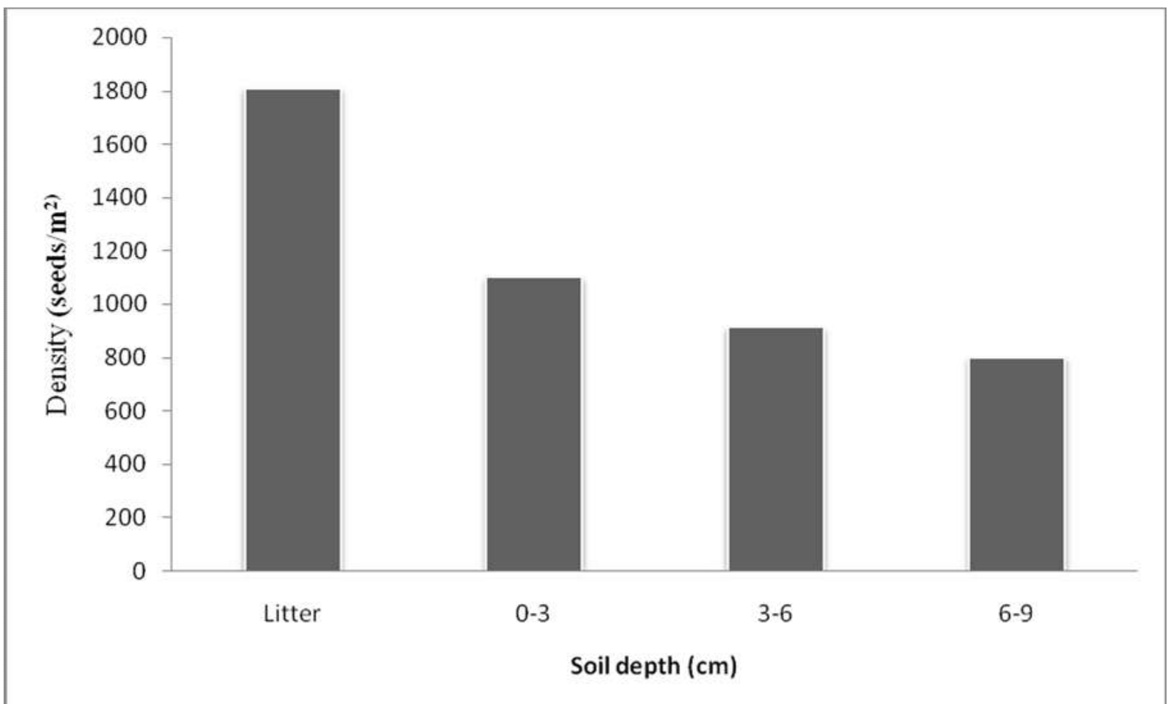


Figure 15. The density of seeds (number of seeds/$m^{2)}$) along with soil depth

4.6.3 The relationship between aboveground vegetation and seed bank

Of the total 44 species germinated from the seed bank, only 22 species were present the aboveground vegetation. The Jaccard's coefficient of similarity between seedlings that emerged from the soil seed bank and the above-ground vegetation was very low (Ss=0.11). Consequently, a low value indicates that very few aboveground vegetation species were represented in the soil seed bank.

4.7 Accuracy assessment of the classified images

The overall accuracy of the land use land cover classification for the year 2017 was 0.8133 (81.33%) with a 0.77 **(77.6%)** kappa coefficient (Table 20).

Table 20. Accuracy assessment of 2017

L/U type	Farmland	Grazing land	Settlement	Forest	Shrubland	Bareland	Total
Farmland	**46**	2	0	0	2	0	50
Grazingland	6	**44**	0	0	0	0	50
Settlement	3	3	**38**	0	0	6	50
Forest	4	0	0	**33**	13	0	50
Shurbland	5	0	0	4	**41**	0	50
Bareland	6	0	2	0	0	**42**	50
Total	70	49	40	37	56	48	300

4.8 Land Use/ land cover classification

Six major land use/ land cover types were classified for the years of 1986, 2003 and 2017 (Figure 16,17, 18). The results of the image classification showed that the total land area of Dega Damot district was 83,124 ha of land area. The individual LU/LC class area and their percentage for 1986, 2003 and 2017 are summarized in Table 21.

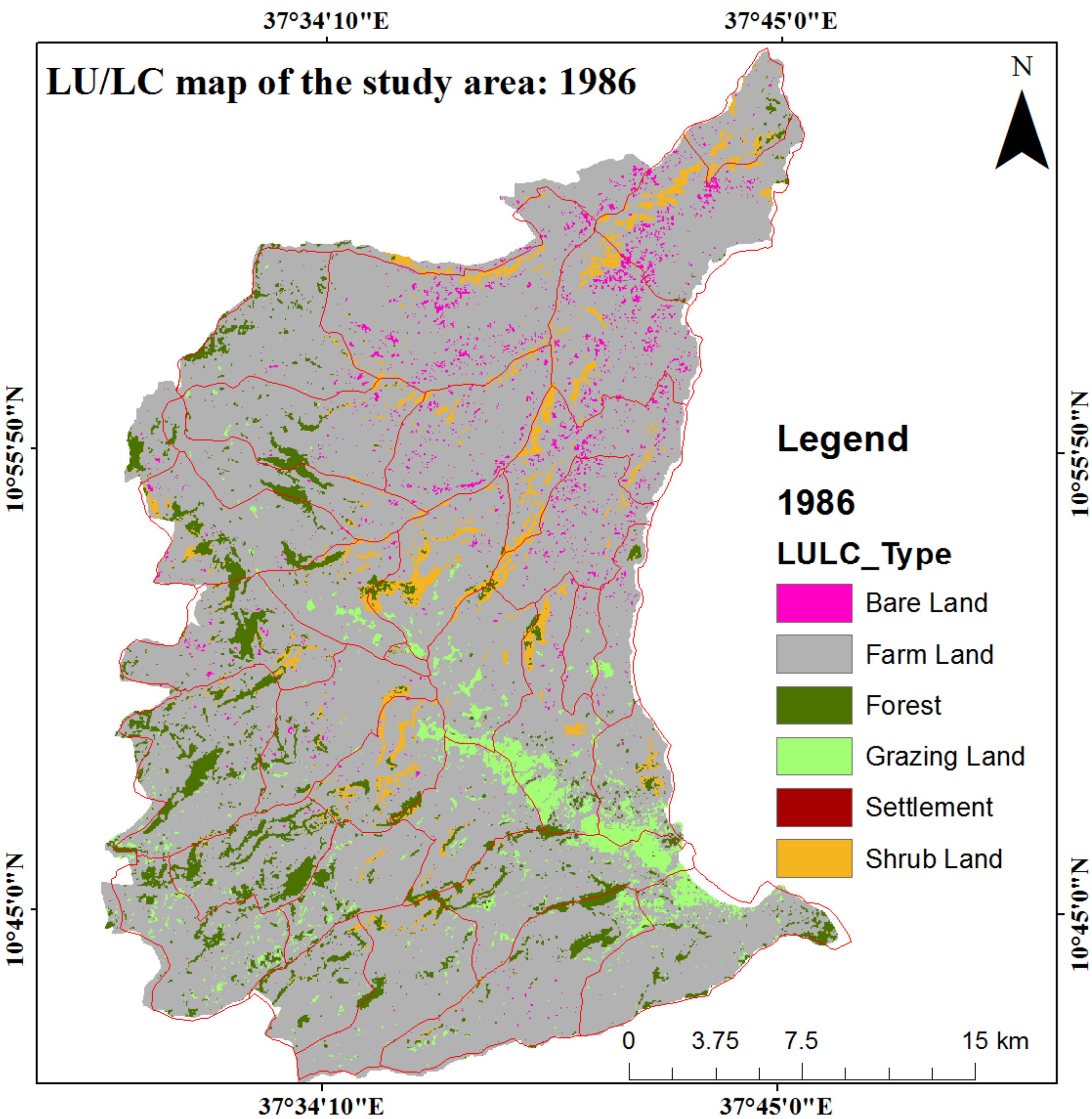


Figure 16. Land use/land cover map of the study area for the year 1986

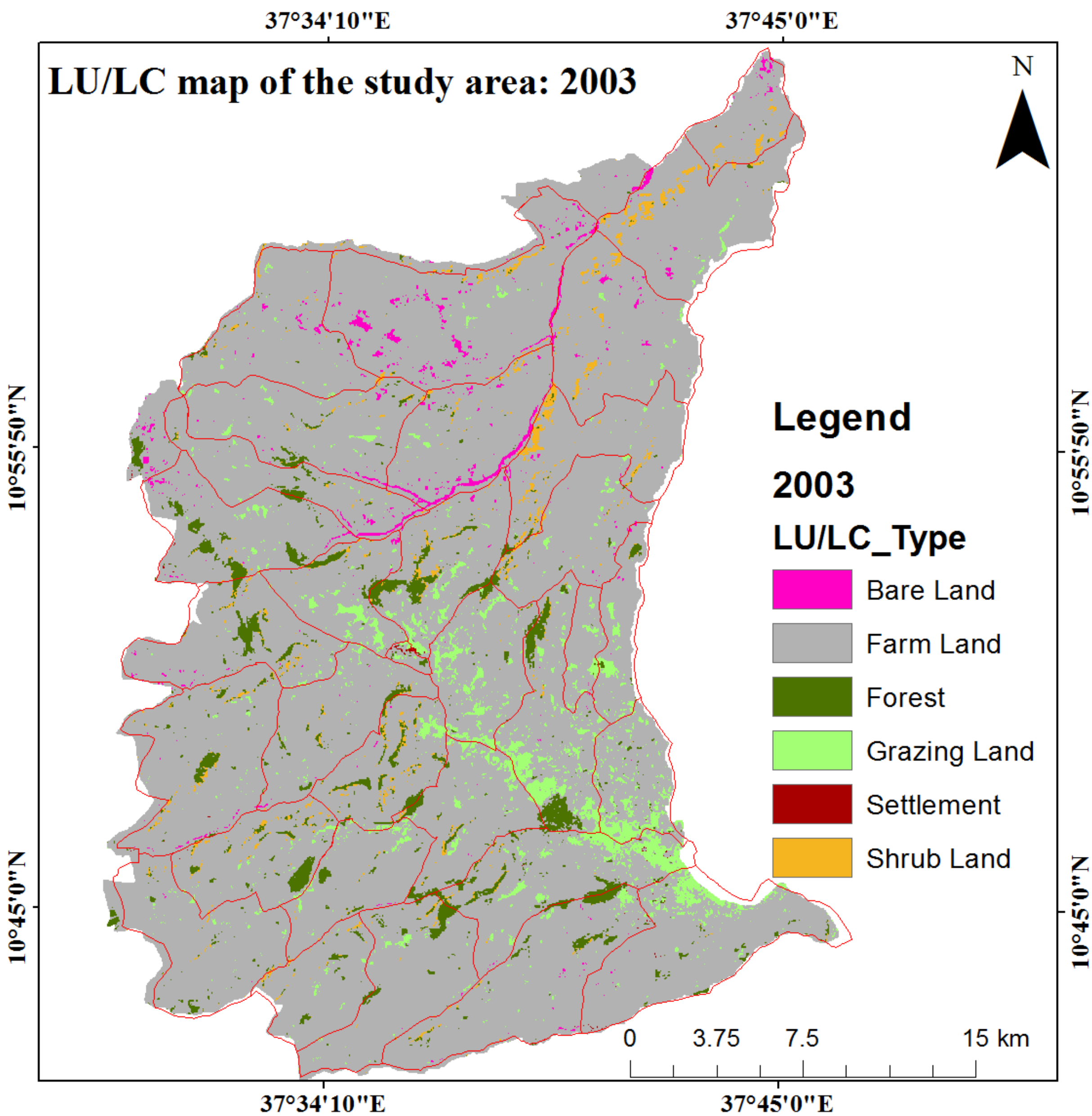


Figure 17. Land use/land cover map of the study area for the year 2003

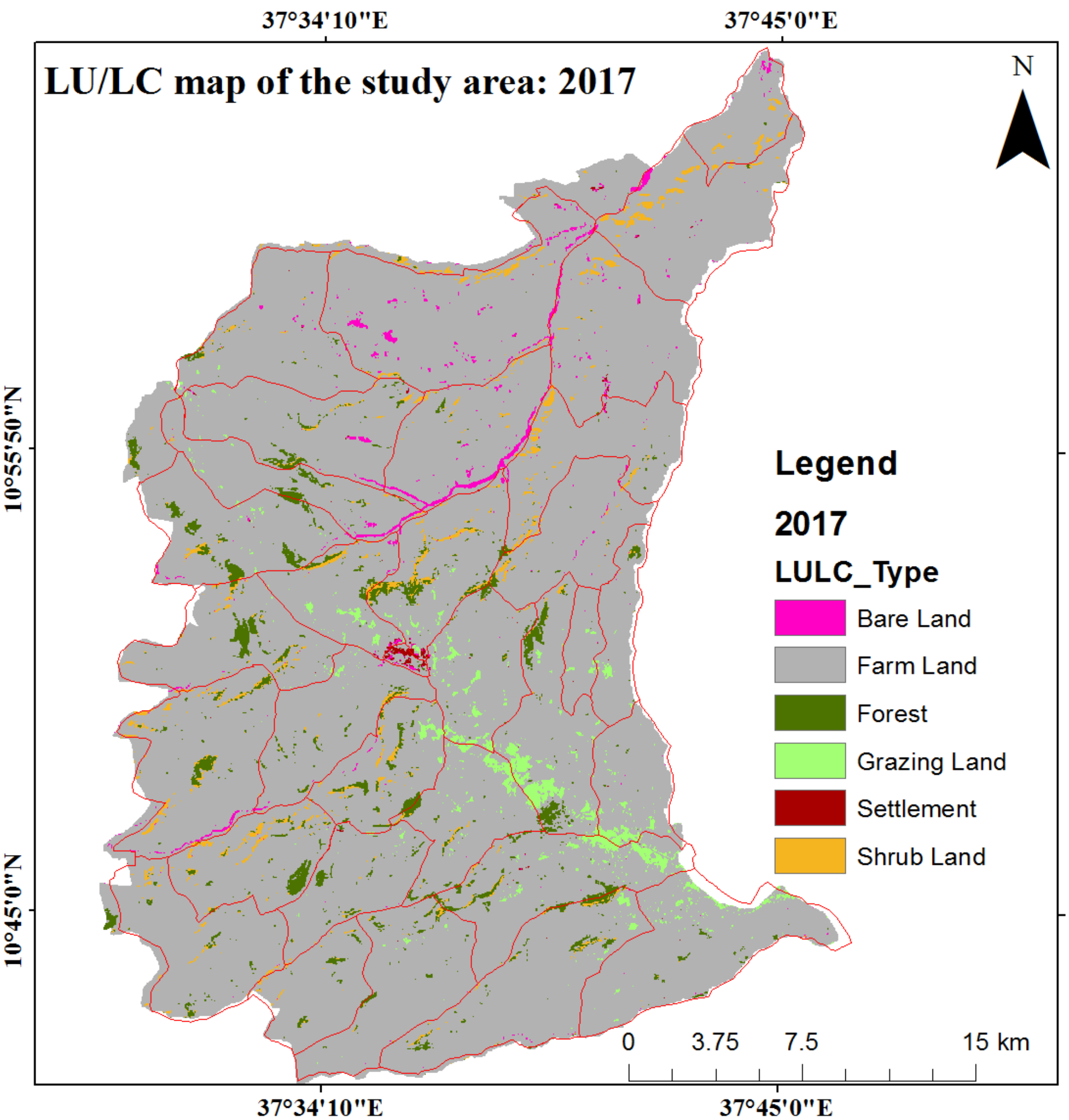


Figure 18. Land use/land cover map of the study area for the year 2017

Table 21. Land use/ Land cover classes and area coverage

LU type	1986		2003		2017	
	Area (ha)	%	Area (ha)	%	Area	%
Farmland	71011	85.43	75367	90.67	77540	93.28
Grazing land	2821	3.39	3101	3.73	1265	1.52
Settlement	0	0	29	0.03	95	0.11
Forest	5088	6.12	2729	3.28	2168	2.60
Shrubland	2899	3.49	1128	1.36	1421	1.71
Bareland	1305	1.57	770	0.93	635	0.76
Total	83124	100	83124	100	83124	100

4.9 Land use/land cover change and in relation to elevation and slope

From 1986 to 2003, farmland and grazing land areas increased by 4356 (6.13%) and 280 (9.99%) hectare of the total area, respectively. In contrast, forest, shrubland and bare land decreased by 2359 (46.36%), 1771 (61.09%) and 535 (40.99%) hectare of the total area respectively. Between 2003 and 2017, the area of farmland, shrubland and settlement increased by 2173 ha (2.88%), 293 ha (25.97%) and 66 ha (227.58%) respectively, while the area of grazing land, forest and bare land declined by 1836 ha (59.20%), 561 ha (20.55%), 135 ha (17.53%) respectively (Table 22).

Table 22. Land use/land cover change during (1986-2003 and 2003-2017)

LU type	1986-2003		2003-2017	
	Area (ha)	%	Area (ha)	%
Farmland	4356	6.13	2173	2.88
Grazingland	280	9.99	-1,836	-59.2
Settlement	29	-	66	227.58
Forest	-2,359	-46.36	-561	-20.55
Shrubland	-1,771	-61.09	293	25.97
Bareland	-535	-40.99	-135	-17.53

Note: *Percent of change was calculated using e.q 13, the positive and the negative signs revealed the position of influence.

The LU/LC change matrix analysis (Table 23) shows that forest, the main conversion areas, has been largely converted to farmland (2994 ha) and shrubland (554 ha). The diagonal cells of the matrix (bold) represent the area that has remained the same in both periods. For instance, 1523 ha of the forest remains unchanged during the study periods (1986-2017). Other cell values represent the area that has changed from one class to another class.

Table 23. Land use/land cover change matrix from 1986 to 2017 (in hectare)

		2017 (Final year)						
	LU type	Farmland	Grazing land	Settlement	Forest	Shrubland	Bare land	Total
1986(initial year)	Farmland	**69726**	340	76	212	124	533	71011
	Grazing land	1830	**920**	14	52	0	5	2821
	Settlement	0	0	0	0	0	0	0
	Forest	2994	3	1	**1523**	554	13	5088
	Shrubland	1754	2	4	381	**743**	15	2899
	Bareland	1236	0	0	0	0	**69**	1305
	Total	77540	1265	95	2168	1421	635	83124

The elevation distribution of each land-use type is shown in Table 24. For the years of 1986, 2003, 2017, in the area where altitude was lower than 2000 m, mainly bare land and shrubland were dominant along the district. On the other hand, Grazing land areas were densely located at 3000-3500 m of altitude. During 1986-2017, the dominant land-use types in the study area were bare land, farmland, and shrubland between the elevations of 2000 and 2500 m. Likewise, most forest areas were distributed at an elevation of 2500-3000 m. Land use/land cover changes were also different along the elevation gradient. Farmland increased while forest reduced regardless of the elevation. For example, from 1986 to 2003, farmland has increased by 2261 ha between 2000 and 2500 m altitudinal range. In contrast, the forest decreased by 1151 ha in the same altitudinal range.

Table 24. LU/LC distribution and change across the elevation

LU type	Elevation(m)	1986		2003		2017		1986-2003	2003-2017
		Area(ha)	%	Area(ha)	%	Area(ha)	%	Change	Change
	< 2000	126	7	148	19.2	161	25.4	22	13
Bare land	2000-2500	855	65.5	500	64.9	392	61.7	-355	-108
	2500-3000	319	24.4	117	15.2	63	9.9	-202	-54
	3000-3586	5	0.4	5	0.6	19	3.0	0	14
Farmland	< 2000	3368	4.7	3575	4.7	3586	4.6	207	11
	2000-2500	30534	43	32795	43.5	33034	42.6	2261	239
	2500-3000	29280	41.2	30568	40.6	31645	40.8	1288	1077
	3000-3586	7829	11	8429	11.2	9275	12.0	600	846
Forest	< 2000	76	1.5	15	0.5	3	0.1	-61	-12
	2000-2500	1678	33	527	19.3	434	20	-1151	-93

	2500-3000	2776	54.6	1905	69.8	1590	73.3	-871	-315
	3000-3586	558	11	282	10.3	141	6.5	-276	-141
Grazing land	<2000	56	2	11	0.4	0	0	-45	-11
	2000-2500	266	9.4	214	6.9	3	0.2	-52	-211
	2500-3000	506	17.9	1128	36.4	268	21.2	622	-860
	3000-3586	1993	70.6	1748	56.4	994	78.6	-245	-754
Settlement	<2000	0	0	1	3.4	5	5.3	1	4
	2000-2500	0	0	7	24.1	14	14.7	7	7
	2500-3000	0	0	8	27.6	32	33.7	8	24
	3000-3586	0	0	13	44.8	44	46.3	13	31
Shrubland	<2000	188	6.5	64	5.7	59	4.2	-124	-5
	2000-2500	1383	47.7	673	59.7	839	59	-710	166
	2500-3000	1220	42.1	375	33.2	503	35.4	-845	128
	3000-3586	108	3.7	16	1.4	20	1.4	-92	4

Distribution and changes of LU/LC were different along the slope gradient. Grazing land and settlement were dominant LU/LC types at slopes less than 11°, while forest had their dominant occurrence at slopes between 11 and 30 degrees. For instance, farmland was mainly found at slopes less than 31 degrees. During 1986-2003, the changes in land use/land cover mainly occurred in the area with a slope of between 11 and 30 degrees. Farmland increased by 1858 ha while forest decreased by 899 ha with a slope between 21 and 30 degrees. The change variation occurred on slope gradients from 1986 to 2003 and from 2003 to 2017 (Table 25).

Table 25. LU/LC distribution and change across a slope

Land use	Slope(°)	1986		2003		2017		1986-2003	2003-2017
		Area(ha)	%	Area(ha)	%	Area(ha)	%	Change	Change
Bareland	0-5	252	19.3	210	27.3	229	36.1	-42	19
	6-10	546	41.8	290	37.7	226	35.6	-256	-64
	11-20	446	34.2	241	31.3	148	23.3	-205	-93
	21-30	56	4.3	26	3.4	20	3.1	-30	-6
	31-40	2	0.2	0	0	8	1.3	-2	8
Farmland	0-5	9910	14.2	9886	13.1	10555	13.6	-24	669
	6-10	21276	30	21659	28.7	22620	29.2	383	961
	11-20	28303	39.9	29727	39.4	30272	39	1424	545
	21-30	9878	13.9	11736	15.6	11812	15.2	1858	76
	31-40	1413	2	2080	2.8	2012	2.6	667	-68
	41-50	231	0.3	279	0.4	269	0.3	48	-10
Forest	0-5	154	3	86	3.2	32	1.5	-68	-54
	6-10	480	9.4	206	7.5	112	5.2	-274	-94
	11-20	1575	31	773	28.3	629	29	-802	-144
	21-30	1898	37.3	999	36.6	920	42.4	-899	-79
	31-40	910	17.9	600	2.2	450	20.8	-310	-150
	41-50	71	1.4	65	2.4	25	1.2	-6	-40
Grazing land	0-5	1074	38.1	1268	40.9	603	47.7	194	-665
	6-10	1048	37.1	1311	42.3	481	38.0	263	-830
	11-20	415	14.7	447	14.4	135	10.7	32	-312

	21-30	216	7.7	61	2	35	2.8	-155	-26
	31-40	59	2.1	6	0.2	6	0.5	-53	0
	41-50	9	0.3	8	0.3	5	0.4	-1	-3
Settlement	0-5	76	2.6	11	37.9	43	45.3	-65	32
	6-10	147	5.1	13	44.8	43	45.3	-134	30
	11-20	618	21.3	4	13.8	6	6.3	-614	2
	21-30	1406	48.5	0	0	3	3.2	-1406	3
	31-40	600	20.7	1	3.4	0	0	-600	-1
	41-50	52	1.8	0	0	0	0	-52	0
Shrubland	0-5	11466	252	5	0.1	4	0.3	-11461	-1
	6-10	23497	546	18	1.6	15	1.1	-23479	-3
	11-20	31357	446	165	14.6	167	11.8	-31192	2
	21-30	13454	56	632	56	664	46.7	-12822	32
	31-40	2984	2	297	26	508	35.7	-2687	211
	41-50	366	3	11	1	63	4.4	-355	52

5. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Floristic composition and diversity

It is not reasonable to compare the species richness and diversity of one forest with others directly as there might be a difference in forest size, habitat heterogeneity, and edaphic factors (Murphy and Lugo, 1986). However, to give a general picture of the species richness of Dega Damot district forest patches, the results of the present study are compared with results from other dry evergreen Afromontane forests in Ethiopia. Accordingly, the total number of woody species recorded in this study (106 species) was higher than other similar studies conducted in the dry evergreen Afromontane forest in Ethiopia. For instance, Zengena forest *(*Desalegn Tadele *et al*., 2014) recorded 50 species, Kuandisha forest (Abiyot Berhanu *et al.,* 2017) recorded 66 species, and Amoro forest (Liyew Birhanu *et al.,* 2018) recorded 57 woody species. On the other hand, Haileab Zegeye *et al.* (2011) recorded a much higher species richness of 143 species in the Tara Gedam and Abebaye forests. Besides, the number of woody species recorded in this study is more or less similar to that of the Zege Peninsula forest with 113 species (Alemnew Alelign *et al.,* 2007). The difference in species composition among the different areas is due to the number of plots sampled and its size can somehow explain this heterogeneity of the species richness. Urban *et al*., (2000) reported that forests with a high degree of human interference and disturbances show relatively lower species richness than others. According to Chen *et al*. (2004), environmental heterogeneity, regeneration success, and competition are also important factors that shape the species composition of forests.Thus, the present study suggests that the Dega

Damot district had relatively high species composition, compared to other similar vegetation types in Ethiopia.

The dominance of Asteraceae was reported from other studies in dry evergreen Afromontane forests vegetation type (Haile Yineger *et al.*, 2008; Abiyou Tilahun *et al.,* 2011; Ermias Lulekal, 2014). Mesfin Tadesse (2004) also reported that Asteraceae was the richest family in terms of species numbers for the flora of Ethiopia and Eretria. The dominance of Asteraceae in the present study may indicate that the forest patches might have been under a certain level of disturbances. As reported by Friis (1992) and Mesfin Tadess (2004), Asteraceae usually have a preference for open and disturbed lands to grow. Herbaceous species were the most dominant growth forms in the study area when compared to other growth forms. This could be the opened canopy cover of the forest patches in the study area.

According to Friis and Sebsebe Demissew (2001), the proportion of endemic plant species in the montane forests of Ethiopia is high, between 11-15% of the total number of species. Similarly, the results from the study area showed that relatively high endemicity (10.6%). Ethiopia is one of the centers of plant endemism in East Africa (Vivero *et al.* ,2005). This study is in line with the typical feature of Afromontane forests that house numerous endemic species (White, 1983). However, the Ethiopian Afromontane forests are one of the most degraded forests and continuously shrinking mainly due to anthropogenic disturbances (Feyera Senbeta, 2006). In the study area, 18 species were endemic to Ethiopia and Eritrea and of the 9 species were included in the IUCN Red List Categories of Ethiopia and Eritrea (Vivero *et al*., 2005). The IUCN vulnerable species *Rhus glutinosa subsp.glutinosa,* near threatened species *such as Acanthus sennii, Crotalaria rosenii and Inula confertiflora;* least concern species *Solanecio* *gigas, Bothriocline schimperi, Erythrina brucei*a and *Lippia adoensis* are also found in study forest patches. Therefore, conservation measures in Dega damot district forest patches by policymakers, natural resources managers or stakeholders need to take into account special protection and monitoring of the endemic and threatened species of the forest patches.

The overall Shannon diversity index for the study area forest patches was 2.79, a higher number of species resulted in higher Shannon diversity. As a result, the higher species richness at Dega Damot district gave higher Shannon diversity index when it is compared with that of Zengena forest (H' = 2.74) (Desalegn Tadele*et al*., 2014) and Abebaye forest (H' = 1.31) (Haileab Zegeye *et al.,* 2011). On the other hand, it is lower than other dry evergreen Afromontane forests such as the Afromontane forest patches of Awi zone (H' = 3.7) (Abiyot Berhanu, 2017); Zege forest (H' = 3.72) (Alemu Alelign *et al.*, 2007), Tara Gedam forest (H' = 2.98) (Haileab Zegeye *et al.*, 2011). This variation might be due to the altitudinal ranges, size of the forests, the degree of disturbance and habitat diversity. Maguran (1988) noted that a low diversity and evenness index is usually related to the high disturbance. The same author also reported that the presence of high evenness and species richness in an area result increased Shannon diversity. Kent and Coker (1992) reported that the Shannon-Wiener diversity index normally varies between 1.5 and 3.5, and rarely exceeds 4.5. Thus, the overall diversity of the forest patches of the study area falls within the normal range of Shannon-Wiener diversity. Shangi Derkie and Bunise forest patches had higher diversity than Aradie, Masikanaand Samana forest. This could be attributed to the size difference, altitudinal difference and degree of disturbance.

The middle altitude comprised more plant species than the lower and higher elevation in the study area. Elevation as a key factor affecting species diversity in mountainous areas has been demonstrated by many researchers (e.g., Tamrat Bekele, 1994; Ermias Aynekulu, 2011, Meng *et al.,* 2012). The species richness and diversity along an elevational gradient in the study area also show a similar pattern with other studies (e.g., Ermias Aynekulu, 2011, Virtanen *et al.,* 2010). The higher diversity of plants recorded at the mid-elevation may be attributed to the favorable mild environmental conditions for plant growth (Oommen and Shanker, 2005; Hemp, 2006).

5.1.1.1 Floristic similarities between the forest patches

The similarity of the forest patches was generally strong (Ss >= 0.5) with exceptions of Samana forest at elevations between 1881m and 2110 m. The four forest patches (Shangi Derkie, Aradie, Bunise and Masikana Medihanyalm) have relatively similar elevational ranges, which may have contributed to the highest similarity between them (Friis *et al.,* 2010; Schmitt *et al.,* 2013). This might be also due to similarities in temperature and rainfall. Moreover, the Samana forest patches are found near disconnected by agricultural land and grazing areas.

Compared to other forest patches in the study area, the Samana forest patch is relatively far away in its location from the four forest patches with relative similar environmental factors (soil and altitudinal range). As a result, the Samana forest patch may have created different environmental conditions and species compositions. For instance, the Samana forest patch is located at the lowest elevation with low content of organic matter, moisture, and total nitrogen. By contrast, it appeared that the four forest patches (Shangi Derkie, Aradie, Bunise and Masikana Medihanyalm) are located at similar elevational ranges (with high values of moisture content, organic matter, and total nitrogen) and which may have a high floristic similarity. As reported by Pyke *et al*. (2001) environmental variables change with the geographical distance which leads to the floristic dissimilarity. Therefore, the lower organic matter, moisture, and total nitrogen in

Samana forest patch might be due to the reduction in vegetation coverage. Soil organic matter increased with increased vegetation coverage (Mulugeta Sebhatleab, 2014). The soil organic matter also influences the total nitrogen, available phosphorus and moisture content of the soil.

5.1.2 Vegetation structure

The total density of woody species recorded in the study forest patches has shown differences from other areas. For example, the density was low when compared to other dry evergreen Afromontane forests such as Tara Gedam and Abebaye*,* Zegie peninsula*,* Kundasha, Amoro forests. On the other hand, the density was greater than other forests, for example, Dense and Zengena forests (Table 26).

The species of *Dodonaea anguistifolia, Myrsine africana, Vernonia myriantha* and *Oliniarochetiana* accounted for the highest density values in the study area. These could be the small size of species, contributing to higher total count within a given plot size and relatively good regeneration capacity under shaded conditions in dry environments. In contrast, the low-density species might be related to high grazing and cutting of trees and shrubs for firewood and charcoal production. Topographic variation, species habitat preferences of species forming the forest and the degree of anthropogenic disturbances, therefore, appears to lead to the density of woody species variation within the forest (Whittaker *et al.,*2003).

Table 26. Comparison of the density in the forest patches with other 7 dray evergreen Afromontane forests in Ethiopia

Forest	Density individuals ha^{-1}	References
Tara Gedam	3001	Haileab Zegeye *et al.*(2011)
Abebaye forests	2850	Haileab Zegeye *et al*. (2011)
Zegie peninsula	3318	Alemnew Alelign *et al*.(2007)
Kundasha forest	3086	Abiyot Berhanu *et al*.(2017)
Amoro forest	2860	Liyew Birhanu *et al*. (2018)
Dense forest	1,138	Ermias Lulekal (2014)
Zengena forest	2202	Desalegn Tadele *et al*.(2014)
Dega Damot district*	2679.33	The present study

According to Lamprecht (1989), frequency is the number of sampling plots in which a given species occurred in the study area and it indicates homogeneity and heterogeneity of given vegetation. The high value of frequency in lower frequency class and low-frequency value in the higher frequency class show the floristic heterogeneity whereas high value in higher frequency class and low value in lower frequency class indicates homogenous nature of forest (Simon Shibiru and Girma Balcha, 2004; Aye *et al.,* 2014). The present study reveals the distribution of most woody species found in lower frequency classes. Thus, the result showed floristic heterogeneity of Dega Damot district forest patches. However, *Bersama abyssinica*, *Olinia rochetiana* and *Vernonia myriantha* were found the most frequent species in the study forest patches. Simon Shibru and Girma Balcha (2004) reported that the variation in frequency among species indicates differences in site conditions, species characteristics, seed dispersal mechanisms of species and disturbance. Likewise, the high frequency of a species depends on factors that share to the degree of exploitation, habitat preferences, adaptation and availability of suitable conditions for regeneration of the species (Rey *et al*., 2000). The species *Bersama abyssinica* is common in *Juniperus - Podocarpus* forests and their degraded remnants, growing in a wide altitudinal range extending from 1,700 to 2,715 m a.s.l (Verdcourt, 1989). Besides, the species *Bersama abyssinica* is also the most frequent in Tara Gedam and Abebaye forests (Haileab Zegeye *et al.*, 2011).

Tamrat Bekele (1993) reported that the basal area provides a better measure of the relative importance of species than simple stem counts. The total basal area of woody species in the study area with DBH $\geq$ 2.5 cm was 51.05m^2 ha^{-1}. The total basal area of the study area was comparable to that of the Abebaye forests. But the basal area of this forest is small compared to other dry evergreen Afromontane forests like Tara Gedam and Wof-washa forests (See Table 27).

The variation of the basal area may be due to the size of species. The most important woody species having the largest basal area were *Ficus sur, Prunus africana, Schefflera abyssinica, Rhusglutinosa* subsp. *glutinosa*, *Olea europaea* subsp. *cuspidata* and *Oliniarochetiana.* The first three species namely, *Ficus sur, Prunus africana, Schefflera abyssinica* had high basal area due to its large size, even though it had low density. This finding is consistent with that of Tamrat Bekele (1994), who reported that species with the highest basal area do not necessarily have the highest density but indicative of size differences between species.

Table 27. Comparison of the basal area in the forest patches with other 11 dray evergreen Afromontane forests in Ethiopia

Forest	Basal area m^2ha^{-1}	Reference
Kuandisha Afromontane forest	15.3	Abiyot Berhanu*et al*. (2017)
Zengena forest	22.3	Desalegn Tadele *et al*. (2014)
Tara Gedam forest	115.36	Haileab Zegeye *et al*. (2011)
Abebaye forests	49.45	Haileab Zegeye *et al*. (2011)
Wof-washa forest	101.8	Tamrat Bekele (1994)
Adelle forest	26	Haile Yineger *et al*. (2008)
Boditi forest	23	Haile Yineger *et al*. (2008)
Chilimo forest	30.1	Tamrat Bekele (1994)
Menagesha forest	36.1	Tamrat Bekele (1994)
Amoro forest	18.5	Liyew Birhanu *et al*. (2018)
Denkoro forest	45	Abate Ayalew *et al*. (2006)
Dega Damot district forest patches*	51.05	The present study

The Importance value index (IVI) which determine the ecological significance of species in a given area (Lamprecht, 1989). It is obtained from combined data from three parameters which include Relative density, Relative dominance and Relative frequency (Kent and Coker, 1992). Species with high Importance value index are considered more important than those with low Importance value index. Those species with low IVI value need high conservation priority (Simon Shibru and Girma Balcha, 2002). *Prunus africana, Schefflera abyssinica, Ficus sur* accounted for about 48.07% of the total IVI value mainly due to their high dominance/basal area, though they had low density. On the other hand, the highest IVI value of *Olinia rochetiana, Rhus glutinosa* subsp. *glutinosa* and *Vernonia myriantha* were due to their high relative density and relative frequency although they had low relative dominance or basal area.

5.1.3 Population structure of woody species

The population structure of species can help in understanding the regeneration patterns of species and the history of past disturbance of this species and its environment (Tamrat Bekele, 1994; Demel Teketay,1997). The population structure of woody species is often estimated by size class distribution. Thus, based on the assessment of diameter class distributions, the population structure patterns of the woody species recorded from the study area were categorized into three groups. The first groups show an inverted J-shaped distribution pattern where the number of individuals is low at the higher diameter class, an indication of a stable population structure or a good reproduction and healthy regeneration potential of the species in the forest (Tamrat Bekele, 1993; Demel Teketay, 1997a).

The second groups show a J shaped distribution pattern where the number of individuals is low in the first and second DBH classes but increases toward the higher classes. Such a pattern shows poor reproduction patterns (Tamrat Bekele, 1993). *Schefflera abyssinica* followed a J-shape distribution pattern, reflecting severe limitation on regeneration (Peters, 1996) (Figure15 c). In the study area, *Schefflera abyssinica* is required for farm and hand tools at its lower and medium-size (Personal observation and communication with the local people). This could be one reason for tree species to have a J-shape population structure in the study area.

The third group showed an irregular distribution type distribution pattern. *Oleaeuropia* subsp.*cuspidata* showed an irregular shape with complete absence from diameter classes 8 and 9. This kind of distribution is observed might be due to the multipurpose uses of *Oleaeuropia* subsp.*cuspidata* by local people (for example, for fencing, farm tools, fuelwood, timber extraction, and charcoal burning) (Mekdes Ourge *et al*., 2018). During field observation, the local people did not have any special size preference regarding the species used for fuelwood. Therefore, This could be one reason for the species to have an irregular shape population structure in the forest.

5.1.4 Plant communities

Based on the hierarchical cluster analysis result, 5 plant communities were identified in the study area. However, the location of the 3 community types (community 2, 3, and 4) had overlapping ranges of elevation. Elevation represents a complex gradient combination of many different environmental factors such as topography, soil, moisture and climate (Feyera Senbeta *et al*., 2014). So that it is difficult to separate other environmental factors (Korner, 2000).

The vegetation of the area is classified as dry evergreen Afromontane forest and grassland complex (DAF) (Friis *et al.,* 2010) and dominated by the species *Olea europaea* subsp. *cuspidata, Juniperus procera, Discopodium penninervium, Pittosporum viridiflorum, Erica arborea, Hypericum revolutum*, *Dodonaea angustifolia*, *Acacia abyssinica*, *Bersama abyssinica,* and *Prunus africana.* The *Olea europaea* subsp. *cuspidata,* indicator species was also mentioned to form the upper canopies of different dry Afromontane forests in Ethiopia (Tamrat Bekele, 1993; Demel Teketay and Tamrat Bekele, 1995).

The identified plant communities are characterized by their different floristic composition. This could be attributed to variations in environmental factors. According to Whittaker *et al.* (2003), the variation species composition among plant communities probably associated with the effects of environmental factors. Nevertheless, species diversity and richness were not the same among plant communities. For instance, the highest species richness and diversity were recorded in community 1. On the contrary, community 5 had the least species richness and diversity than the remaining community types. The reason for high species diversity and richness of community 1 may be due to the highest altitudinal ranges in which this community is found (2516-2947 m). Also, community 5 type is the most disturbed community due to settlement, agricultural expansion, overgrazing by livestock and crossing road.

Anthropogenic land-use change is one of the most important factors contributing to global change (Sala *et al.,* 2000), and changes in landscape structure and agricultural land-use intensity are likely to influence plant community composition and species richness. Changes in land-use practice may result in continuously or more abruptly deteriorating environmental conditions for some plant species, causing their decline in abundance and distribution (Naeem. *et al.*, 2009). For instance, over the last 31 years, the forest cover of Dega Damot district has decreased while areas under farmland, grazing, and settlements have increased (Liyew Birhanu *et al,* 2019). Therefore, these anthropogenic land-use changes might influence the plant community formation of the present study in a different plant species richness and diversity.

The result of the pairwise comparison of Sorensen's similarity coefficient index in species composition between the 3 plant communities (Community 1, 2 and 3) showed high similarity. This due to the location of these community have relatively similar environmental factors (soil and altitudinal range). Community 5 located at the lowest elevation with low content of organic matter, soil moisture content and which may have a less floristic similarity from the remaining plant community types (Community 1, 2 and 3).

5.1.5 Environmental factors and plant community relationship

The distribution of plant communities in the study area reflects the combined influence of altitude and soil factors. Based on the results of RDA, elevation was the major environmental variable in explaining variations in plant species distribution and patterns of plant community formation although there are overlaps among some community types. This might be associated with a continuous change in environmental variables along the elevational gradient (Lovett and Wasser, 1993). Other studies conducted in Ethiopia (see Zerihun Woldu *et al*., 1989; Kumelachew Yeshitila and Tamrat Bekele, 2002; Haile Yeneger *et al.*, 2008) also noted that altitude is the most important environmental variable for the determinant of vegetation variation. Moreover, Zhang and Dong (2010) reported that vegetation distribution influenced by elevation. Besides, elevation is a vital environmental factor that affects the atmospheric pressure, moisture, and temperature which have a strong influence on the growth and development of plants and the distribution of vegetation (Hedberg, 1964).

Moreover, organic matter was also the most important constraining variable in plant community formation of the study area. Research in the Jibat forest, Ethiopia, by Tamrat Bekele (1993) reported that plant distributions were affected by the organic matter at a higher elevation. SOM, its role in soil structure and moisture retention capability are well known (Schaetzl and Anderson, 2005); these effects may account for its relevance for determining plant species distribution and community formation in the study area, besides its role as a source of soil nutrients to plants. The mineralization of organic matter is a contributing factor in supplying available mineral nutrients for plant use and through decomposition process the available nitrogen.

Similar to the present findings, P was also attributed to have significant effects on species compositions of plant communities in remnant Afromontane forests on the central plateau of Shewa (Tamrat Bekele, 1994). Phosphorus plays a fundamental role in plant nutrition and its concentration and availability determine to a great extent the soil fertility and site productivity as it is required in relatively large amounts by plants. Kumelachew Yeshitila and Tamrat Bekele (2002) observed a direct correlation between P and the distribution of plant species in Afromontane and transitional rainforest vegetation of southwestern Ethiopia. Furthermore, a study conducted in Brazil by Amorim and Batalha (2007), P was the main factor that distinct plant communities

Topographic features associated with soil properties are strongly correlated with species distribution and plant community structure on a local scale (Cui *et al*., 2009). For instance, the *Dodonaea anguistifolia-Acokanthera schimperi* community, with a low content of organic matter, soil moisture content, and N, is differentiated from the other community types in the study area. The anthropogenic disturbances are higher at the lower altitudes (selective cutting of trees, grazing by livestock and expanding of farmlands) and the temperature is also higher at these altitudes. Generally, in the study area, the soil organic matter is higher at higher altitudes. This might be due to the decreased decomposition of organic matter and the long-term accumulation of organic matter (Bolstad and Vose, 2001). Much of the soil nitrogen is obtained from organic matter (Thompson and Troeh, 1979) and hence is bound in higher quantities at higher elevations.

Also, the moisture content is higher at higher altitudes and decreases the rate of mineralization of the organic matter by low temperature and acidic pH and thus leads to the accumulation of organic matter. When the soil pH is lower the rate of organic matter decomposition decreases, this is due to the effect of soil pH on the activity of soil microorganisms that are involved in the decomposition of organic matter. The correlation of organic matter with electrical conductivity could be explained by its capacity to supply replaceable cations to the soil solution which increases the conductivity. Thus, altitude and organic matter were the most significant environmental variable, determining the general occurrence and distribution patterns of plant communities in Dega Damot district.

5.1.6 Soil seed bank

The composition and density of soil seed banks obtained from the forest indicate disturbance and history of the standing vegetation (Demel Teketay and Granstrom, 1995; Alemayehu Wassie and Demel Teketay, 2006) and may also be linked to prolonged dry seasons experienced in forests, which necessitates accumulation of dormant seeds in the soil (Demel Teketay and Granstrom, 1995; Alemayehu Wasse, 2005). Garwood (1989) and Barnes *et al* (1998) reported that the forest vegetation maintains and increases its populations through the process of regeneration involving soil seed banks and vegetative sprouts.

In the study area, the soil seed bank results show that there were large quantities of seeds of herbaceous species, but a low proportion of woody species in the seed bank. The dominance of herbaceous species might be they produce numerous small, persistent seeds, have a better chance of natural recovery than woody species, easily incorporated into the soil to form seed banks (Alemayehu Wassie and Demel Teketay, 2006; Belay Assefa *et al.,*2014). Moreover, Whitemore (1991) reported that herbaceous species have greater success in establishing after disturbance due to the production of a large number of seeds in a short time and possessing means of long-distance dispersal. On the other hand, the absence of tree species in the seed bank is probably due to short viability and no dormancy (Demel Teketay, 1996). The present study result is consistent with findings of other soil seed bank studies in Ethiopia (for example, Demel Teketay and Granstrom, 1995; Demel Teketay, 1996, 1998; Kebrom Tekle and Tesfaye Bekele, 2000; Feyera Senbeta and Demel Teketay, 2001; Alemayehu Wassie *et al.,* 2006; Mulugeta Lemenih and Demel Teketay, 2006 and Belay Assefa *et al.,* 2014,).

Seed density was highest in the upper soil layers of the forest (Litter and 0-3 cm soil layer) and gradually decreased with increasing depth. These might be due to the availability of environmental conditions such as oxygen and light (Mulugeta Lemenih and Demel Teketay, 2005 and Eyob Tenkir, 2006). Closed canopy covers prevent germination of some seed (Kruk *et al.,* 2006) whereas open canopy promotes the germination of seeds. Most of the time, seeds from parent plants fall on the soil surface and therefore, remain close to it, with only a few having the opportunity to enter the deeper soil layers. For instance, the formation of cracks in habitat allows the incorporation of seeds into deeper layers (Belay Assefa *et al.,* 2014). As well, if the upper soil layer is degraded by soil erosion or other factors, there may be variation in soil seed bank down to depth. The seeds to move deeper in the soil by rodents, birds, ants and ground-dwelling arthropods (Saatkamp *et al*., 2014).

The variation of seed density with depth also might be explained by deference in seed longevity, seed predation, and mode of seed dispersal (Demel Teketay, 1998). The results of the present study in agreement with several previous studies conducted in Ethiopia (Demel Teketay, 1996; Mekuria Argaw *et al.*, 1999; Kebrom Tekle and Tesfaye Bekele, 2000; Feyera Senbeta and Demel Teketay, 2001; Tefera Mengistu *et.al*., 2005; and AlemayehuWassie and Demel Teketay, 2006).

The low similarity in species composition between the soil seed banks and aboveground vegetation might be due to anthropogenic disturbances present in the study forest patches. Disturbed habitats have less similarity in species composition between the seed bank and above-ground vegetation (Tessema Zewdu *et al.*, 2012). The other probable reason for the difference between above-ground vegetation and soil seed bank flora is seeds of the woody plant species which are found in the above-ground flora germinate immediately within a few days after dispersal. Most of the woody species do not accumulate seeds in the soil and germinate within a few days or weeks (Demel Teketay, 1996). This result is also in agreement with past similar works in Ethiopia (Mulugeta Lemenih and Demel Teketay, 2005, AlemayehuWassie and Demel Teketay, 2006). Furthermore, the seedling emergence method may decrease the density of the seed bank due to errors associated with seed dormancy and specific environmental requirements for germination (Wright and Clarke, 2009).

Seed bank studies provide basic information on seed densities and species composition as well as an indication of the restoration process (Welling *et al*., 1988). The soil seed banks of the forest in the present study contain relatively few woody species and are dominated by herbaceous species. The implication, in the long run, is that herbaceous species will have better chances of recovery than woody species after disturbance (AlemayehuWassie and Demel Teketay, 2006). In the study area, only two viable seeds of tree species (*Dombeya torrida and Ficus sur*) are identified in the seed bank study. These results indicated that most of the dominant tree species do not accumulate seeds in the soil and their regeneration from seed banks would delay by the anthropogenic disturbance in the study area. Therefore, to accelerate vegetation restoration, seed banks may require supplementation by planting tree seedlings.

5.1.7 Land use/ land cover change

In the study area, the area of farmland consistently increased while forest decreased in varying proportions over the study periods. As to the information gathered from elder peoples, the major reason for the expansion of farmlands and the decrement of forest lands was population pressure which caused much of the forest land used for cultivation and also fall off the Derg Government in 1991 that led to the illegal destruction of protected forests for agriculture by farmers (personal communication). The continuous increase of the human population has resulted in the clearing and conversion of forests into farmlands (Girmay Gebresamuel*et al*., 2010). The present result is consistent with the findings of other LU/LC change studies in Ethiopia.

In Dembecha area of northwestern Ethiopia, Gete Zeleke and Hurni (2001) reported that farmland increased from 39% in 1952 to 70% in 1982 and 77% in 1995 while the natural forest cover declined from 27% to 2% and 0.3% throughout these periods. In the same manner, cultivated land in the Andassa watershed of the Blue Nile basin which accounted for 62.7% in 1985 were increased to 73.1% and 76.8% in 2000 and 2015 periods, respectively. Conversely, the forest was reduced from 3.5 to 1.9%, between 1986 and 2015 (Temesgen Gashaw *et al.,* 2017).

However, the increase of forest cover was also reported in Chemoga watershed from the 1957-1998 periods (Woldeamlak Bewket, 2002). The reason for the forest cover improvement in Chemoga watershed was mainly because of the community aforestation. The change matrix in the study area from 1986 to 2017 shows the majority of forest land was converted to farmland (Table 23). The conversions from forest to farmland had a high proportion, and it coincided with the increasing trend of farmland areas. It could be viewed as the result of the destruction of forest attributed to the rapid human population growth and increasing demand farmland in the study area. Grazing land and shrubland had great changes and mainly converted into farmland. The decreased grazing land in the study periods may be due to the 1997 land redistribution in Amhara Regional State, which allocated much of the grazing lands to landless peasants for cultivation(Yigremew Adal, 1997).

Farmlands were mostly located in the study area at 2000-2500 m of elevation (Table 28). These might be the best zone for growing diverse crops (Gete Zeleke and Hurni, 2001). Similarly, the highest shrubland coverage was located at 2000-2500 m of elevation, which could be due to the logging of big size trees for different purposes. Contrary, the area of grassland too decreased in the study period at lower elevations; however, a concurrent increase in grasslands at higher elevations was recorded. These might be due to population pressure pushed more people into higher areas for collecting fuelwood, which depleted forests and increased grassland at higher elevations. Additionally, it is indicating that the effects of returning steep farmland to grassland and converting from forest to grassland were significant. Generally, forest decreased while farmland increased despite the elevation gradient, which was possibly caused by the conversion from forest to farmland.

The highest farmland coverage was located in the slope less than 30 degrees, implying that the human beings preferred working on areas with gentler slopes than areas with steep ones. On the other hand, steeper topographic features are not suitable for crop production and grazing due to the inaccessibility and fragility of the land. Along with steep slope areas, soils had low fertility and poor water holding capacity, farmers had relatively lower agricultural input, which may cause farmland to decline as slope increases while in a gentle slope, water is not draining fast and it is wet throughout the rainy period so that it is favorable crop production. A steep slope will cause more runoff and will enhance the soil erosion in the absence of vegetation cover (Gete Zeleke and Hurni, 2001; Tsehaye Gebrelibanos and Mohammed Assen, 2013). The fact that agricultural activities were found to prevail in mostly flat areas may be due to the ease of agricultural practices, such as plowing, the better quality of soils, and proximity to human settlements. A similar trend was also reported by Gete Zeleke and Hurni (2001) in which deforestation may be widespread in areas where slopes are relatively gentle and thus better suited for agriculture.

5.2 Conclusions

In this study, floristic composition, vegetation structure and species diversity were described for the forest patches of Dega Damot district. Accordingly, a total of 176 plant species belongs to 80 families were identified. Asteraceae was the dominant family followed by Fabaceae. Herbs and shrubs were the dominant growth forms, while trees were least represented. The forest patches of Dega Damot district comprises high endemic plant species. Therefore, it is one of the most important forest areas for biodiversity conservation. The vegetation of Dega Damot district forest patches exhibited the characteristics of the dry evergreen Afromontane forest and grassland complex vegetation type. The results of the study showed that the high density and dominance of small-sized individuals in the lower DBH classes with a gradual decline towards the higher classes. This indicating a high regeneration potential of the forest patches.

Five plant communities were identified from this study. Among all of the investigated environmental factors, elevation, moisture content, slope, pH, EC, clay, OM, and phosphorus were found to significantly explain variation in species composition and community formation in the study area. Elevation was the most important environmental factor influencing species distribution and community formation. The lower elevation resulted in a decline in species richness, diversity, organic matter, moisture content , especially in the community 5 in the forest. The anthropogenic disturbances present in this community type may also contribute to the low species richness and diversity recorded. Also, *Dodonaea anguistifolia-Acokanthera schimper*i community type is not correlated to all the measured environmental variables. Therefore, it can be concluded that other environmental factors may influence the plant community formation, which is required to be additionally studied.

Species composition and seed density of the soil seed banks are dominated by herbaceous species. On the other hand, tree species except for *Dombey torrida and Ficus sur* have no viable seeds in the soil. Furthermore, seed density decreased with increasing soil depth. The result showed a low similarity between the standing vegetation and soil seed bank in species composition, which could be the effect of anthropogenic disturbances in the study area. This had also indicated that the potential for forest regeneration from seed banks is limited.

In the last 31 years, land use/ land cover changes have undergone considerable change in the study area. The dominant land use/land cover types of the study area were farmland. The land use/ land cover changes observations showed the expansion of farmland while forest declined through 1986–2017 periods. This is due to the increase of the human population has resulted in the clearing and conversion of forests into farmlands. Moreover, Land use/ land cover change proportion varied with both slope and elevation range gradient. Agriculture land expansion, forest resources extraction, increasing human and livestock population and other human interferences led to the continuous reduction of forest area and influences species richness and diversity. Overall, the observed changes are associated with increasing human and expanding agricultural activities in the Degadamot district of northwestern highland Ethiopia. These changes aggravate soil erosion, biodiversity loss and disturbance of hydrological cycle.

5. 3 Recommendations

Based on the present study results and conclusions the following recommendations are forwarded:

- Out of the 18 endemic species found in the forest, 9 of them: *Acanthus sennii, Crotalaria rosenii, Inula confertiflora, Solanecio gigas, Rhus glutinosa* subsp. *glutinosa, Bothriocline schimperi, Erythrina brucei* and *Lippiaadoensis* are registered in the IUCN Red List Categories. Thus, these species need close attention and immediate intervention for all stakeholders: local government offices, the community, Ethiopian Biodiversity Institute (EBI), Amhara Regional State forest enterprise, researchers, NGOs, to take action towards the conservation, and management of the endemic and threatened species.

- Among the plant community types in the forest patches, community type 5 (Samana forest patch) is a highly disturbed area and declines species diversity. Thus, rehabilitation, conservation and management actions for protecting the reaming of this forest patch is a necessity.

- The presence of dominance of herbaceous species and the absence of tree species in the seed bank requires in-depth study to understand why this is so.

- The soil seed bank study indicates that the potential for forest regeneration from seed banks is limited, and it is recommended to transplant indigenous tree species into the forests to accelerate restoration of the forest. Further, conservation and sustainable utilization of the reaming of forest patches is a necessity.

- The present land use/land cover change result should be used as the main contribution through land-use planning for sustainable land use management in the study area. Therefore, conservation and sustainable land use, natural forest should be practiced to maintain the ecosystem, biodiversity in the study area.

- In the present study, only the topographic variables such as slope and elevation were used to study LU/LC change. However, the driving forces of LU/LC change are complex, thus further research should be conducted on LULC change processes and the interactions of the drivers such as economic, policy, technology and institution, which will help to identify the driver's LU/LC change in the study area.

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LIST OF APPENDICES

Appendix 1. Floristic composition of the aboveground vegetation

No	Species	Family	Habit	Local name
1	*Abutilon figarianum* Webb	Malvaceae	Herb	Nacha
2	*Acacia abyssinica* Hochst. ex Benth.	Fabaceae	Tree	Girar
3	*Acaciaetbaica*Schweinf.	Fabaceae	Tree	Korara girar
4	*Acacia seyal* Del.	Fabaceae	Tree	Nech Girar
5	*Acanthus sennii*Chiov.	Acanthaceae	Shrub	Kosheshila
6	*Achyranthes aspera*L.	Amaranthaceae	Herb	-
7	*Achyrospermum schimperi*(Hochst. ex Briq.)Perkins	Lamiaceae	Herb	-
8	*Acokanthera schimperi* (A.DC.) Schweinf	Apocynaceae	Tree	Merenz
9	*Albizia schimperiana*Oliv.	Fabaceae	Tree	-
10	*Allophylus abyssinicus*(Hochst.) Radlk.	Sapindaceae	Tree	Embis
11	*Aloe pulcherrima* Gilbert & Sebsebe	Aloaceae	Shrub	Eret
12	*Andropogon abyssinicus*Fresen.	Poaceae	Herb	Gaja Sar
13	*Anthospermum herbaceum*L.f.	Rubiaceae	Herb	-
14	*Apodytes* dimidiata E. Mey. ex Arn.acutifolia (Hochst. ex A. Rich.) Boutique	Icacinaceae	Tree	Dong
15	*Arisaema enneaphyllum*Hochst. ex A.Rich.	Araceae	Herb	Amoch
16	*Arundinaria alpina*K. Schum.	Poaceae	Tree	Kerkeha
17	*Arundo donax* L.	Poaceae	Shrub	Shembeqo
18	*Asparagus africanus* Lam.	Asparagaceae	Liana	-

19	*Bersama abyssinica* Fresen. subsp. *abyssinica*	Melianthaceae	Shrub	Azamara
20	*Berula erecta* (Hudson) Coville	Apiaceae	Herb	-
21	*Bidens macroptera* (Sch. Bip. ex Chiov.) Mesfin	Asteraceae	Herb	AdeyAbaba
22	*Bothriocline schimperi*Sch. Bip. ex Walp.	Asteraceae	Shrub	-
23	*Bruceaantidysenterica* J. F. Mill	Simaroubaceae	Shrub	Abalo
24	*Buddleja davidii* Franch.	Loganiaceae	Shrub	Tikuir Anfar
25	*Buddleja polystachya* Fresen.	Loganiaceae	Shrub	Nech anfar
26	*Calpurnia aurea*(Ait.) Benth.	Fabaceae	Shrub	Ligita
27	*Carduus nyassanus* (S. Moore) R.E. Fr.	Asteraceae	Herb	-
28	*Carduus schimperi* Sch. Bip.	Asteraceae	Herb	Yemidir eshoh
29	*Carissa spinarum* L.	Apocynaceae	Shrub	Agam
30	*Cassipourea malosana* (Baker) Alston	Rhizophoraceae	Tree	Tikur Enchet
31	*Catha edulis* (Vahl) Forssk. ex Endl.	Celastraceae	Shrub	chat
32	*Clausena anisata*(Willd.) Benth.	Rutaceae	Shrub	Limich
33	*Clematis simensis* Fresen.	Ranunculaceae	Liana	Azo hareg
34	*Clerodendrum myricoides* (Hochst.) Vatke	Lamiaceae	Shrub	-
35	*Clutia abyssinica* Jaub. & Spach.	Euphorbiaceae	Shrub	Fiyelfej
36	*Combretum collinum* Fresen.	Combretaceae	Tree	Wonde Abalo
37	*Combretum molle* R. Br. ex G. Don	Combretaceae	Tree	Sete Abalo
38	*Commelina benghalensis* L.	Commelinaceae	Herb	Eregna kolw
39	*Convolvulus kilimandschari* Engl.	Convolvulaceae	Liana	-

40	*Crassocephalum macropappum* (Sch. Bip. ex A. Rich.) S. Moore	Asteraceae	Herb	-
41	*Crotalaria rosenii* (Pax) Milne-Redh. ex Polhill	Fabaceae	Shrub	-
42	*Croton macrostachyus* Del.	Euphorbiaceae	Tree	Bisana
43	*Cynoglossum coeruleum* Hochst. ex A.DC.	Boraginaceae	Herb	Shingug
44	*Cyperus dereilema* Steud.	Cyperaceae	Herb	Giramita
45	*Cyperus squarrosus* L.	Cyperaceae	Herb	Ketema sar
46	*Cyphostemma cyphopetalum* (Fresen.) Desc. ex Wild& Drummond	Vitaceae	Herb	-
47	*Datura stramonium* L.	Solanaceae	Herb	Astenagir
48	*Delphinium* wellbyi Hemsl.	Ranunculaceae	Herb	Gedel Amuk
49	*Desmodium velutinum*(Willd.) DC.	Fabaceae	Herb	-
50	*Dicranopteris linearis* (Burm. f.) Underw.	Gleicheniaceae	Herb	Fern
51	*Dipsacus pinnatifidus* Steud. ex A. Rich.	Dipsacaceae	Herb	Enkelekey
52	*Discopodium penninervium* Hochst.	Solanaceae	Tree	Aluma
53	*Dodonaea angustifolia*L. f	Sapindaceae	Shrub	Kitkita
54	*Dombeyatorrida* (J.F.Gmel.) P.Bamps	Sterculiaceae	Tree	Wilkifa
55	*Dovyalis verrucosa* (Hochst.) Warb.	Flacourtiaceae	Shrub	Koshim
56	*Drynaria volkensii* Hieron.	Polypodiacie	Herb	Fern spp
57	*Echinops pappii Chiov.*	Asteraceae	Shrub	Ahiya eshoh
58	*Ekebergia capensis*Sparrm.	Meliaceae	Tree	Lol
59	*Embelia schimperi* Vatke	Myrsinaceae	Liana	Enkoko
60	*Ensete ventricosum* (Welw.) Cheesman	Musaceae	Herb	Enset

61	*Entada abyssinica* Steud. ex A. Rich.	Fabaceae	Tree	-
62	*Epilobium hirsutum* L.	Onagraceae	Herb	-
63	*Erica arborea* L.	Ericaceae	Shrub	Asta
64	*Erythrina brucei* Schweinf.	Fabaceae	Tree	Korch
65	*Eucalyptus globulus* Labill	Myrtaceae	Tree	Bahirzaf
66	*Euclea schimperi*(A. DC.) Dandy	Ebenaceae	Shrub	Dedeho
67	*Euphorbia abyssinica* Gmel.	Euphorbiaceae	Tree	Kulkual
68	*Euphorbia schimperiana* Scheele	Euphorbiaceae	Herb	Yegede wetet
69	*Euphorbia tirucalli* L.	Euphorbiaceae	Shrub	kinchib
70	*Ferula communis* L.	Apiaceae	Herb	-
71	*Festuca macrophylla*Hochst. ex A.Rich.	Poaceae	Herb	-
72	*Ficus ingens* (Miq.) Miq.	Moraceae	Tree	-
73	*Ficus sur* Forssk.	Moraceae	Tree	Shola
74	*Ficus thonningii*Blume	Moraceae	Tree	chebeha
75	*Ficus vasta* Forssk	Moraceae	Tree	Warka
76	*Galiniera saxifraga*(Hochst.) Bridson	Rubiaceae	Tree	Yetotakolet
77	*Galium simense* Fresen.	Rubiaceae	Herb	Ashekit
78	*Geranium ocellatum* Cambess	Geraniaceae	Herb	-
79	*Girardinia bullosa*(Stedudel) Wedd.	Lamiaceae	Herb	-
80	*Gladiolus a byssinieus* (Brongn. ex Lemaire) Goldblatt &de Vos	Iridaceae	Herb	yejib Ageda
81	*Gnidia glauca*(Fresen.)Gilg	Thymelaeaceae	Shrub	Awra
82	*Grewia ferruginea*Hochst. ex A. Rich.	Tiliaceae	Shrub	Kawt

83	*Guizotia scabra* (Vis.) Chiov.	Asteraceae	Herb	Mech
84	*Gymnema sylvestre* (Retz.) R. Br. ex Schult.	Asclepiadaceae	Liana	Yedega medir
85	*Hagenia abyssinica* (Bruce) J.F. Gmel.	Rosaceae	Tree	Koso
86	*Helichrysum citrispinum* Del.	Asteraceae	Shrub	Chifrg
87	*Helichrysum nudifolium*(L.) Less.	Asteraceae	Herb	-
88	*Helichrysum schimperi* (Sch. Bip. ex A. Rich.) Moeser	Asteraceae	Herb	-
89	*Helichrysum splendidum* (Thunb.) Less.	Asteraceae	Herb	-
90	*Hymenodictyon floribundum* (Hochst. & Steud.) Robinson	Rubiaceae	Tree	Gedel Amuk
91	*Hypericum quartinianum*A. Rich.	Hypericaceae	Shrub	Amija
92	*Hypericum revolutum*Vahl.	Hypericaceae	Shrub	Amija
93	*Hypoestes forskaolii*(Vahl) R. Br.	Acanthaceae	Herb	Yebrbere kitel
94	*Impatiens hochstetteri* Warb. subsp. *hochstetteri*	Balsaminaceae	Herb	Gishirt
95	*Impatiens rothii* Hook. f.	Balsaminaceae	Herb	Gishirt
96	*Inula confertiflora*A. Rich.	Asteraceae	Herb	-
97	*Jasminum abyssinicum* Hochst. ex DC.	Oleaceae	Liana	Abita hareg
98	*Juniperus procera* L.	Cupressaceae	Tree	Tsid
99	*Justicia heterocarpa*T.	Acanthaceae	Herb	-
100	*Kalanchoe petitiana*A. Rich.	Crassulaceae	Herb	Andawila
101	*Kniphofia foliosa* Hochst.	Asphodelaceae	Herb	Ashegidye
102	*Lactuca inermis* Forssk.	Asteraceae	Herb	-
103	*Laggera tomentosa* Sch.-Bip.	Asteraceae	Shrub	Gimane

104	*Leonotis ocymifolia* (Burm.f.) Iwarsson	Lamiaceae	Shrub	Ras kimir
105	*Lepidotrichiliavolkensii*(Gurke) Leroy	Meliaceae	Tree	Abalat
106	*Lippia adoensis* Hochst. ex Walp. var. *adoensis*	Verbenaceae	Shrub	Kesy
107	*Lobelia giberroa* Hemsl.	Lobeliaceae	Shrub	Gibira
108	*Lunathyrium boryanum* (Willd.) H. Ohba	Woodsiaceae	herb	-
109	*Maesa lanceolata* Forssk.	Myrsinaceae	Shrub	Kilaba
110	*Malva verticillata* L.	Malvaceae	Herb	Tulit
111	*Maytenus arbutifolia* (A.Rich.) Wilczek	Myrsinaceae	Shrub	Atat
112	*Maytenus obscura* (A.Rich.) Cuf.	Celastraceae	Tree	Qoba
113	*Mimusops kummel* A. DC.	Sapotaceae	Tree	Ishe
114	*Momordica foetida* Schumach.	Cucurbitaceae	Herb	-
115	*Myrica salicifolia*A.Rich	Myricaceae	Tree	Shi**n**et
116	*Myrsine africana* L.	Myrsinaceae	Shrub	Kechemo
117	*Olea capensis*L.subsp. *macrocarpa* (C.H. Wright) Verdc.	Oleaceae	Tree	wegeda
118	*Olea europaea* L. subsp. *cuspidata* (Wall. ex G.Don) Cif.	Oleaceae	Tree	woyra
119	*Olinia rochetiana* A. Juss	Oliniaceae	Tree	Tife
120	*Oplismenus hirtellus* (L.) P. Beauv.	Poaceae	Herb	Yekok Sar
121	*Osyris quadripartita* Decn.	Santalaceae	Shrub	Qeret
122	*Otostegia integrifolia* Benth	Lamiaceae	Shrub	Tunjit
123	*Pennisetum sphacelatum*(Nees) Th. Dur. &	Poaceae	Herb	Sebez

	Schinz			
124	*Peperomia abyssinica* Miq.	Piperaceae	Herb	-
125	*Periploca linearifolia* Quaart.-Dill. & A. Rich.	Asclepiadaceae	Liana	Yekola medir
126	*Phragmanthera regularis* (Sprague) M. Gilbert.	Loranthaceae	Liana	Teketila
127	*Phytolacca dodecandra*L 'Herit.	Phytolaccaceae	Liana	Endod
128	*Pittosporium viridiflorum* Sims	Pittosporaceae	Tree	weylwiha
129	*Plectranthus assurgens* (Baker) J.K. Morton	Lamiaceae	Herb	-
130	*Plectranthus longipes*Baker	Lamiaceae	Herb	yedimet Ayn
131	*Pleopeltis macrocarpa* (Willd.) Kaulf	Polypodiaceae	Herb	
132	*Premna schimperi* Engl.	Lamiaceae	Shrub	Chafie
133	*Prunus africana* (Hook. f.) Kalkm.	Rosaceae	Tree	Koma
134	*Rhamnus prinoides* L'Herit.	Rhamnaceae	Shrub	Gesho
135	*Rhus glutinosa*A. Rich. subsp. *glutinosa*	Anacardiaceae	Shrub	Qamo
136	*Rhus vulgaris*Meikle	Anacardiaceae	Tree	Ashkamo
137	*Ricinus communis* L.	Euphorbiaceae	Shrub	Chakima
138	*Rosa abyssinica* Lindley	Rosaceae	Shrub	Qega
139	*Rubus steudneri*Schwienf.	Rosaceae	Liana	Enjori
140	*Rumex nepalensis* Spreng.	Polygonaceae	Herb	Wisha milas
141	*Rumex nervosus* Vahl	Polygonaceae	Shrub	Ambacho
142	*Rytigynia neglecta* (Hiern) Robyns	Rubiaceae	Shrub	Dingayseber
143	*Salix subserrata*Willd.	Salicaceae	Tree	Kiya

144	*Satureja abyssinica*(Benth.) Briq. subsp.*abyssinica*	Lamiaceae	Herb	Tosegn
145	*Satureja paradoxa* (Vatke) Engl. ex Seybold	Lamiaceae	Herb	Zikakibe like
146	*Scabiosa columbaria* L.	Dipsacaceae	Herb	-
147	*Scadoxus multiflorus*(Martyn) Raf.	Amaryllidaceae	Herb	-
148	*Schefflera abyssinica* (Hochst. ex A. Rich.) Harms	Araliaceae	Tree	Getem
149	*Scolopia theifolia* Gilg.	Flacourtiaceae	Tree	Erkudie
150	*Selaginella goudotiana* (Spring) Bizzarri	Selaginellaceae	Herb	fern
151	*Senecio* sp.	Asteraceae	Herb	-
152	*Senna singueana* (Del.) Lock	Fabaceae	Tree	Gofa
153	*Snowdenia polystachya* (Fresen.) Pilg.	Poaceae	Herb	Yekok sar
154	*Solanecio gigas* (Vatke) C. Jeffrey	Asteraceae	Shrub	Boz
155	*Solanum giganteum* Jacq	Solanaceae	Shrub	Tikuir Enbuay
156	*Solanum incanum*L.	Solanaceae	Shrub	Zerche Enbuy
157	*Sparmannia ricinocarpa* (Eckl. & Zeyh.) O. Ktze.	Tiliaceae	Shrub	Nechachiye
158	*Sporobolus africanus* (Poir.) Robyns & Tournay	Poaceae	Herb	Murig
159	*Stephania abyssinica* (Dillon & A. Rich.) Walp.	Menispermaceae	Herb	Ayt hareg
160	*Swertia abyssinica* Hochst.	Gentianaceae	Herb	Abish like
161	*Syzygium guineense*(Willd.) DC. subsp. *guineense*	Myrtaceae	Tree	Dokima
162	*Tapinanthus globiferus*(A. Rich.) Tieghem	Loranthaceae	Liana	Teketila

163	*Teclea nobilis*Del.	Rutaceae	Tree	Yenebir Tifir
164	*Tephrosla obbladensis* Chiov.	Fabaceae	Shrub	-
165	*Thalictrum rhynchocarpum* Dill. & A. Rich.	Ranunculaceae	Herb	Sire Bizu
166	*Torilis arevensis*(Hudson) Link	Apiaceae	Herb	like Dinbilal
167	*Trifolium* sp.	Fabaceae	Herb	Maget/oxalis
168	*Trifolium decorum* Chiov.	Fabaceae	Herb	Maget
169	*Urera hypselodendron* (A. Rich) Wedd.	Urticaceae	Liana	Lankuso
170	*Urtica simensis* L.	Urticaceae	Herb	Kusha
171	*Verbascum sinaiticum* Benth. in DC.	Scrophulariaceae	Herb	Yeahya Joro
172	*Vernonia amygdalina* Del.	Asteraceae	Shrub	Girawa
173	*Vernonia leopoldi*(Sch. Bip. ex Walp.) Vatke	Asteraceae	Shrub	-
174	*Vernonia myriantha* Hook.f.	Asteraceae	Shrub	Dengorita
175	*Ximenia americana* L.	Olacaceae	Shrub	Enkoy
176	*Zehneria scabra* (Linn.f.) Sond.	Cucurbitaceae	Liana	Nech harg

Appendix 2. Floristic richness and Shannon diversity and evenness indices of plots in the study area. Plot codes: Shangi Derkie, 1-29; Aradie, 30-39; Bunsie, 40-71; Masikana medhanyalm, 72-80; Samana, 81-86

Plot	Richness	Diversity/H	Eveness/J
1	27	3.18	0.97
2	23	2.95	0.94
3	20	2.92	0.98
4	27	3.15	0.95
5	17	2.79	0.98
6	19	2.80	0.95
7	12	2.38	0.96
8	26	3.12	0.96
9	19	2.86	0.97
10	26	3.17	0.97
11	21	2.94	0.96
12	20	2.90	0.97
13	21	2.97	0.98
14	29	3.21	0.95
15	30	3.22	0.95
16	27	3.08	0.93
17	23	3.03	0.97
18	22	3.03	0.98
19	24	3.07	0.96
20	21	2.94	0.97

21	14	2.57	0.97
22	13	2.38	0.93
23	18	2.73	0.95
24	20	2.86	0.96
25	25	3.08	0.96
26	28	3.19	0.96
27	28	3.20	0.96
28	16	2.63	0.95
29	18	2.75	0.95
30	20	2.92	0.98
31	23	2.97	0.95
32	13	2.38	0.93
33	14	2.51	0.95
34	15	2.57	0.95
35	12	2.24	0.90
36	7	1.79	0.92
37	5	1.42	0.88
38	17	2.71	0.96
39	19	2.76	0.94
40	22	2.92	0.95
41	33	3.33	0.95
42	29	3.16	0.94
43	28	3.17	0.95

44	24	2.96	0.93
45	22	2.87	0.93
46	21	2.92	0.96
47	33	3.36	0.96
48	40	3.54	0.96
49	31	3.29	0.96
50	38	3.49	0.96
51	27	3.09	0.94
52	24	2.98	0.94
53	16	2.65	0.96
54	21	2.91	0.96
55	19	2.80	0.95
56	17	2.72	0.96
57	18	2.78	0.96
58	31	3.28	0.95
59	22	2.92	0.95
60	20	2.79	0.93
61	14	2.50	0.95
62	18	2.81	0.97
63	10	2.18	0.95
64	13	2.51	0.98
65	16	2.58	0.93
66	21	2.86	0.94

67	18	2.73	0.95
68	24	3.06	0.96
69	19	2.80	0.95
70	15	2.63	0.97
71	16	2.68	0.97
72	19	2.76	0.94
73	16	2.57	0.93
74	17	2.77	0.98
75	18	2.81	0.97
76	11	2.25	0.94
77	16	2.66	0.96
78	9	2.12	0.97
79	5	1.60	0.99
80	6	1.73	0.97
81	12	2.30	0.93
82	16	2.69	0.97
83	10	2.13	0.93
84	10	2.17	0.94
85	6	1.70	0.95
86	11	2.19	0.91

Appendix 3. Vegetation structure values (frequency, density, basal area, and importance value index) of woody species in the study area (pooled data from the five forest patches)

NO	Species	Density (ha^{-1})	Frequency	Basal Area ($m^2 ha^{-1}$)	Relative Density	Relative Frequency	Relative Dominance	IVI
1	*Acacia abyssinica*	9.95	2.33	0.46	0.37	0.15	0.9	1.42
2	*Acacia seyal*	3.75	4.65	0.15	0.14	0.3	0.3	0.74
3	*Acanthus sennii*	34.75	13.95	-	1.3	0.9	0	2.2
4	*Acokanthera schimperi*	78.17	5.81	0.07	2.91	0.38	0.13	3.42
5	*Albizia shimperiana*	3.23	9.3	2.24	0.12	0.6	4.36	5.09
6	*Allophylus abyssinicus*	15.63	32.56	1.07	0.58	2.11	2.07	4.76
7	*Aloe pulcherrima*	2.58	1.16	-	0.1	0.08	0	0.17
8	*Apodytes dimidiata*	9.95	20.93	1.61	0.37	1.35	3.13	4.86
9	*Arundinaria alpina*	1.29	1.16	0	0.05	0.08	0.01	0.13
10	*Asparagus africanus*	10.21	12.79	0	0.38	0.83	0	1.21
11	*Bersama abyssinica*	100.9	66.28	0.67	3.76	4.29	1.3	9.34
12	*Brucea antidysenterica*	30.75	31.4	0.29	1.15	2.03	0.57	3.74
13	*Buddleja davidii*	24.81	36.05	1.55	0.92	2.33	3.01	6.27
14	*Buddleja polystachya*	22.87	34.88	0.89	0.85	2.26	1.74	4.85
15	*Calpurnia aurea*	55.17	36.05	0.29	2.06	2.33	0.57	4.95
16	*Carissa spinarum*	56.72	6.98	0.08	2.11	0.45	0.16	2.73
17	*Catha edulis*	15.89	13.95	0.03	0.59	0.9	0.06	1.56
18	*Clausena anisata*	26.74	19.77	-	1	1.28	0	2.27
19	*Clematis simensis*	9.82	16.28	-	0.37	1.05	0	1.42
20	*Clerodendrum*	3.88	1.16	-	0.14	0.08	0	0.22

	myricoides							
21	*Clutia abyssinica*	80.23	44.19	-	2.99	2.86	0	5.85
22	*Combretum collinum*	0.39	1.16	0.08	0.01	0.08	0.16	0.25
23	*Combretum molle*	1.94	3.49	0.08	0.07	0.23	0.15	0.44
24	*Croton macrostachyus*	22.87	16.28	0.03	0.85	1.05	0.07	1.97
25	*Discopodium penninervium*	35.92	17.44	0.11	1.34	1.13	0.21	2.68
26	*Dodonaea anguistifolia*	225.32	19.77	0.08	8.4	1.28	0.15	9.83
27	*Dombeya torrida*	18.73	31.4	0.72	0.7	2.03	1.4	4.13
28	*Dovyalis verrucosa*	35.53	51.16	0.49	1.32	3.31	0.96	5.59
29	*Echinops pappii*	136.3	19.77	-	5.08	1.28	0	6.36
30	*Ekebergia capensis*	4.01	15.12	0.3	0.15	0.98	0.59	1.72
31	*Embelia schimperi*	4.65	6.98	-	0.17	0.45	0	0.62
32	*Erica arborea*	73.39	32.56	0.22	2.73	2.11	0.43	5.27
33	*Erythrina brucei*	0.26	2.33	0.27	0.01	0.15	0.53	0.69
34	*Eucalyptus globulus*	6.07	4.65	0.59	0.23	0.3	1.14	1.67
35	*Euclea schimperi*	2.33	3.49	0	0.09	0.23	0	0.32
36	*Euphorbia abyssinica*	67.7	24.42	1.86	2.52	1.58	3.62	7.72
37	*Euphorbia schimperiana*	1.81	3.49	-	0.07	0.23	0	0.29
38	*Ficus sur Forssk.*	1.68	5.81	7.47	0.06	0.38	14.53	14.96
39	*Ficus thonningii*	0.78	1.16	0.01	0.03	0.08	0.02	0.12
40	*Ficus vasta*	0.13	1.16	1.77	0	0.08	3.44	3.52
41	*Galiniera saxifraga*	4.39	4.65	-	0.16	0.3	0	0.46

42	*Gnidia glauca*	32.43	9.3	0.03	1.21	0.6	0.05	1.86
43	*Gymnema sylvestre*	1.94	5.81	-	0.07	0.38	0	0.45
44	*Hagenia abyssinica*	0.78	5.81	0.12	0.03	0.38	0.23	0.63
45	*Hymenodictyon floribundum*	0.39	1.16	0.06	0.01	0.08	0.12	0.21
46	*Hypericum quartinianum*	1.94	1.16	-	0.07	0.08	0	0.15
47	*Hypericum revolutum*	2.58	3.49	-	0.1	0.23	0	0.32
48	*Jasminum grandiflorum*	16.54	11.63	-	0.62	0.75	0	1.37
49	*Juniperus procera*	0.52	4.65	0.21	0.02	0.3	0.41	0.73
50	*Laggera tomentosa*	51.94	17.44	-	1.94	1.13	0	3.06
51	*Lippia adoensis*	87.21	6.98	-	3.25	0.45	0	3.7
52	*Lobelia giberroa*	9.3	5.81	-	0.35	0.38	0	0.72
53	*Maesa lanceolata*	14.08	24.42	0.07	0.52	1.58	0.13	2.23
54	*Maytenus arbutifolia*	118.6	54.65	0.22	4.42	3.53	0.42	8.37
55	*Maytenus obscura*	9.43	11.63	0.36	0.35	0.75	0.7	1.8
56	*Mimusops kummel*	0.39	1.16	0	0.01	0.08	0.01	0.1
57	*Myrica salicifolia*	4.78	10.47	0.77	0.18	0.68	1.5	2.35
58	*Myrsine africana*	186.95	39.53	-	6.97	2.56	0	9.52
59	*Olea capensis*	2.97	6.98	0.36	0.11	0.45	0.71	1.27
60	*Olea europaea*	54.39	38.37	2.71	2.03	2.48	5.26	9.77
61	*Olinia rochetiana*	144.96	66.28	2.36	5.4	4.29	4.59	14.28
62	*Osyris quadripartita*	58.53	53.49	0.62	2.18	3.46	1.21	6.85

63	*Otostegia integrifolia*	3.88	4.65	-	0.14	0.3	0	0.45
64	*Periploca linearifolia*	14.08	2.33	-	0.52	0.15	0	0.68
65	*Phragmanthera regularis*	0.78	1.16	-	0.03	0.08	0	0.1
66	*Phytolacca dodecandra*	5.81	11.63	-	0.22	0.75	0	0.97
67	*Pittosporium viridiflorum*	16.67	20.93	0.51	0.62	1.35	0.99	2.96
68	*Premna schimperi*	10.98	2.33	-	0.41	0.15	0	0.56
69	*Prunus africana*	33.72	36.05	7.4	1.26	2.33	14.38	17.97
70	*Rhamnus prinoides*	0.13	1.16	0	0	0.08	0	0.08
71	*Rhus glutinosa*	67.44	55.81	3.7	2.51	3.61	7.19	13.31
72	*Rhus vulgaris*	9.43	4.65	0.07	0.35	0.3	0.13	0.78
73	*Ricinus communis*	0.26	1.16	0	0.01	0.08	0	0.09
74	*Rosa abyssinica*	50.52	53.49	0.32	1.88	3.46	0.62	5.96
75	*Rubus steudneri*	29.33	22.09	-	1.09	1.43	0	2.52
76	*Rumex nervosus*	40.18	18.6	0.02	1.5	1.2	0.03	2.73
77	*Rytigynia neglecta*	33.2	41.86	0.09	1.24	2.71	0.17	4.11
78	*Schefflera abyssinica*	8.14	24.42	6.82	0.3	1.58	13.26	15.14
79	*Scolopia theifolia*	65.63	27.91	0.49	2.45	1.8	0.95	5.2
80	*Senna singueana*	3.62	2.33	0.05	0.13	0.15	0.1	0.38
81	*Solanecio gigas*	50.52	27.91	0.03	1.88	1.8	0.07	3.75
82	*Solanum giganteum*	4.78	4.65	-	0.18	0.3	0	0.48
83	*Solanum incanum L.*	5.17	5.81	-	0.19	0.38	0	0.57
84	*Sparmannia*	2.07	2.33	-	0.08	0.15	0	0.23

	ricinocarpa							
85	*Syzygium guineense*	0.65	1.16	0.01	0.02	0.08	0.02	0.11
86	*Tapinanthus globiferus*	0.13	1.16	-	0	0.08	0	0.08
87	*Teclea nobilis*	1.16	4.65	0.13	0.04	0.3	0.25	0.6
88	*Urera hypselodendron*	29.72	29.07	-	1.11	1.88	0	2.99
89	*Vernonia amygdalina*	0.39	2.33	0.08	0.01	0.15	0.16	0.33
90	*Vernonia myriantha*	145.61	66.28	0.32	5.43	4.29	0.62	10.33
91	*Ximenia americana*	0.26	1.16	0.01	0.01	0.08	0.02	0.11
	Total	2679.33	1537.21	51.42	100	100	100	300

Appendix 4. List of species and emerged seed density (number of seedlings /m^2) in the soil seed banks in the study area

No	Scientific name	Family	Localname	Habit	No indi	Seed density
1	*Achyranthes aspera*	Amaranthaceae	Telenj	Herb	1	2.17
2	*Ageratum conyzoides*	Asteraceae	-	Herb	12	26.09
3	*Alchemilla abyssinica*	Rosaceae	-	Herb	17	36.96
4	*Botbrioclline* schimperi	Asteraceae	-	Shrub	2	4.35
5	*Chenopodium album*	Chenopodiaceae	-	Herb	3	6.52
6	*Chrysanthemum indicum*	Asteraceae	-	Herb	3	6.52
7	*Crotalaria rosenii*	Fabaceae	-	Shurb	16	34.78
8	*Cyperus squarrosus*	Cyperaceae	-	Herb	22	47.83
9	*Dichondra repens*	Convolovolacie	-	Herb	107	232.61
10	*Dicrocephala chrysanthemifolia*	Asteraceae	-	Herb	78	169.57
11	*Dicrocephala integrifolia*	Asteraceae	-	Herb	1	2.17
12	*Discopodium penninervium*	Solanaceae	Aluma	Shurb	1	2.17
13	*Dodonaea angustifolia*	Sapindaceae	Kitkita	Shurb	8	17.39
14	*Dombeyatorrida*	Sterculiaceae	Wulkifa	Tree	58	126.09
15	*Drymaria cordata*	Caryophyllaceae	-	Herb	265	576.09
16	*Erica arborea*	Ericaceae	Asta	Shurb	107	232.61
17	*Euphorbia schimperiana*	Euphorbiaceae	Yegede wetet	Herb	2	4.35

18	*Ficus sur*	Moraceae	Shola	Tree	1	2.17
19	*Galinsoga parviflora*	Asteraceae	-	Herb	46	100.00
20	*Galium simense*	Rubiaceae	Ashekit	Herb	25	54.35
21	*Geranium arabicum*	Geraniaceae	-	Herb	116	252.17
22	*Geranium ocellatum*	Geraniaceae	-	Herb	69	150.00
23	*Eragrostis* sp.	Poaceae	-	Herb	455	989.13
24	*Helichrysum schimperi*	Asteraceae	-	Herb	9	19.57
25	*Helichrysum* sp.	Asteraceae	-	Herb	5	10.87
26	*Hypericum peplidifolium*	Hypericaceae	Amija	Herb	4	8.70
27	*Impatiens hochstetteri* subsp. *hochstetteri*	Balsaminaceae	Ensosila	Herb	2	4.35
28	*Laggera crispata*	Asteraceae		Herb	5	10.87
29	*Leonotis ocymifolia*	Lamiaceae	Ras Kimir	Shurb	2	4.35
30	*Lippia adoensis*	Verbenaceae	Kosert kitel	Shurb	10	21.74
31	*Maesa lanceolata*	Myrsinaceae	Kilaba	Shurb	3	6.52
32	*Oplismenus hirtellus*	Poaceae	-	Herb	61	132.61
33	*Polygonium nepalensis*	Polygonaceae	-	Herb	164	356.52
34	*Phyllanthus ovalifolius*	Euphorbiaceae	-	Lianna	3	6.52
35	*Pilea tetraphylla*	Urticaceae	-	Herb	80	173.91
36	*Plantago lanciolata*	Plantaginaceae	Gortb	Herb	4	8.70
37	*Plectranthus longipes*	Lamiaceae	-	Herb	16	34.78

38	*Polygonum aviculare*	Polygonaceae	yelam chew	Herb	3	6.52
39	*Rosa abyssinica*	Rosaceae	Kega	Shurb	7	15.22
40	*Solanum anguivi*	Solanaceae	Enbuy	Shurb	8	17.39
41	*Solanum nigrum*	Solanaceae	Enbuy	Shurb	49	106.52
42	*Sparmannia ricinocarpa*	Tiliaceae	-	Shurb	20	43.48
43	*Trifolium rueppellianum*	Fabaceae	-	Herb	251	545.65
44	*Veronica abyssinica*	Scrophulariaceae	-	Herb	12	26.09
Total					2133	4636.95

Appendix 5. Families with the number of species in the seed bank

Family	No. of sp.	**%**
Amaranthaceae	1	2.3
Asteraceae	9	20.5
Balsaminaceae	1	2.27
Caryophyllaceae	1	2.27
Chenopodiaceae	1	2.27
Convolovolacie	1	2.27
Cyperaceae	1	2.27
Ericaceae	1	2.27
Euphorbiaceae	2	4.54
Fabaceae	2	4.54

Geraniaceae	2	4.54
Hypericaceae	1	2.27
Lamiaceae	2	4.54
Moraceae	1	2.27
Myrsinaceae	1	2.27
Plantaginaceae	1	2.27
Poaceae	2	4.54
Polygonaceae	2	4.54
Rosaceae	2	4.54
Rubiaceae	1	2.27
Sapindaceae	1	2.27
Scrophulariaceae	1	2.27
Solanaceae	3	6.82
Sterculiaceae	1	2.27
Tiliaceae	1	2.27
Urticaceae	1	2.27
Verbenaceae	1	2.27

Appendix 6. Sample plots together with the corresponding altitude and location

Plot	Altitude	Latitude	Longitude
1	2947	10°52.688′	037°36.669′
2	2896	10°52.727′	037°36.647′
3	2840	10°52.748′	037°36.617′
4	2752	10°52.803′	037°36.570′
5	2695	10°52.785′	037°36.409′
6	2763	10°52.748′	037°36.443′
7	2800	10°52.711′	037°36.444′
8	2874	10°52.645′	037°36.512′
9	2855	10°52.514′	037°36.43′
10	2798	10°52.541′	037°36.398′
11	2733	10°52.561′	037°36.371′
12	2676	10°52.594′	037°36.317′
13	2609	10°52.601′	037°36.269′
14	2904	10°52.315′	037°36.083′
15	2850	10°52.366′	037°36.143′
16	2916	10°52.421′	037°35.952′

17	2801	10°52.461′	037°36.059′
18	2716	10°52.551′	037°36.066′
19	2654	10°52.555′	037°36.109′
20	2548	10°52.601′	037°36.128′
21	2475	10°52.772′	037°35.942′
22	2706	10°52.638′	037°35.961′
23	2783	10°52.588′	037°35.956′
24	2857	10°52.554′	037°35.896′
25	2880	10°52.503′	037°35.554′
26	2797	10°52.550′	037°35.571′
27	2742	10°52.577′	037°35.594′
28	2692	10°52.593′	037°35.656′
29	2637	10°52.629′	037°35.640′
30	2688	10°52.513′	037°35.280′
31	2773	10°52.471′	037°35.313′
32	2825	10°52.416′	037°35.349′

33	2912	10°52.371′	037°35.428′
34	2905	10°52.279′	037°35.471′
35	2836	10°52.264′	037°35.401′
36	2889	10°52.137′	037°35.068′
37	2846	10°52.217′	037°35.179′
38	2884	10°52.070′	037°35.302′
39	2848	10°52.131′	037°35.307′
40	2906	10°51.670′	037°32.078′
41	2852	10°51.689′	037°32.130′
42	2774	10°51.699′	037°32.178′
43	2718	10°51.700′	037°32.243′
44	2656	10°51.699′	037°32.301′
45	2591	10°51.718′	037°32.333′
46	2546	10°51.715′	037°32.360′
47	2906	10°51.566′	037°32.050′
48	2857	10°51.556′	037°32.092′

49	2807	10°51.557′	037°32.126′
50	2749	10°51.558′	037°32.172′
51	2698	10°51.550′	037°32.242′
52	2650	10°51.545′	037°32.284′
53	2594	10°51.537′	037°32.328′
54	2536	10°51.517′	037°32.381′
55	2901	10°51.457′	037°32.051′
56	2838	10°51.444′	037°32.104′
57	2792	10°51.429′	037°32.133′
58	2735	10°51.439′	037°32.170′
59	2684	10°51.439′	037°32.235′
60	2631	10°51.371′	037°32.273′
61	2577	10°51.344′	037°32.303′
62	2517	10°51.307′	037°32.341′
63	2641	10°51.064′	037°32.065′
64	2608	10°51.050′	037°32.043′

65	2735	10°51.812′	037°32.549′
66	2677	10°51.795′	037°32.513′
67	2625	10°51.781′	037°32.485′
68	2572	10°51.774′	037°32.425′
69	2529	10°51.620′	037°32.424′
70	2579	10°51.639′	037°32.493′
71	2646	10°51.672′	037°32.551′
72	2516	10°53.579′	037°38.290′
73	2375	10°53.565′	037°38.397′
74	2455	10°52.944′	037°38.183′
75	2521	10°52.868′	037°38.240′
76	2595	10°52.798′	037°38.248′
77	2656	10°52.765′	037°38.299′
78	2732	10°52.69′	037°38.302′
79	2682	10°52.605′	037°38.315′
80	2635	10°52.710′	037°38.155′

81	2110	UTM1220849	37P0362540
82	2060	UTM1220888	37P0362499
83	2010	UTM1220806	37P0362051
84	1881	UTM1220893	37P0361978
85	2013	UTM1220998	37P0361821
86	2054	UTM1220763	37P0361759

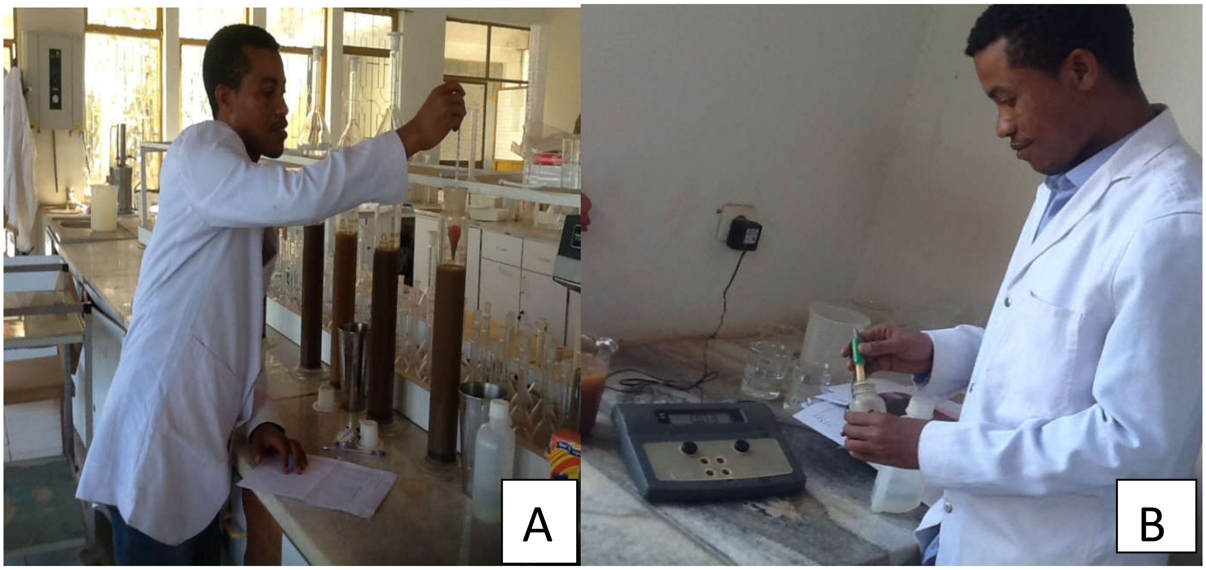
Appendix 7. Photograph illustrating some aspects of anthropogenic disturbance in the study area

A. *Prunes africana* mature tree cutting and ready for charcoal production

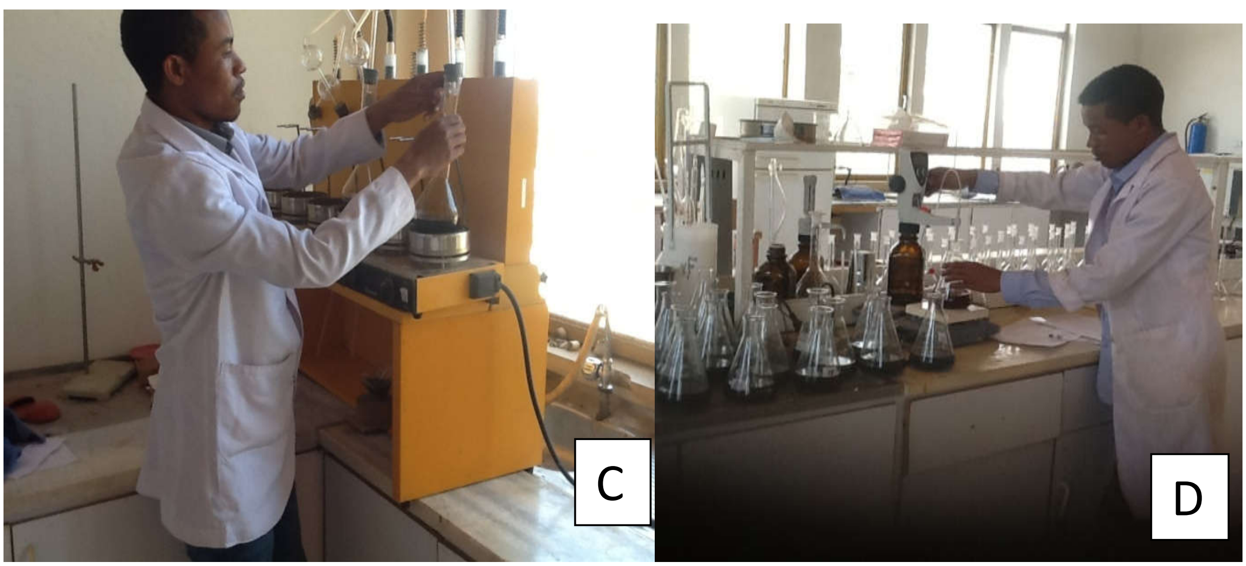
B. Site for charcoal production in the forest

C. Falling of tree

Appendix 8. Photograph demonstrating soil testing in progress at the laboratory of Debremarkos soil research and fertility improvement center



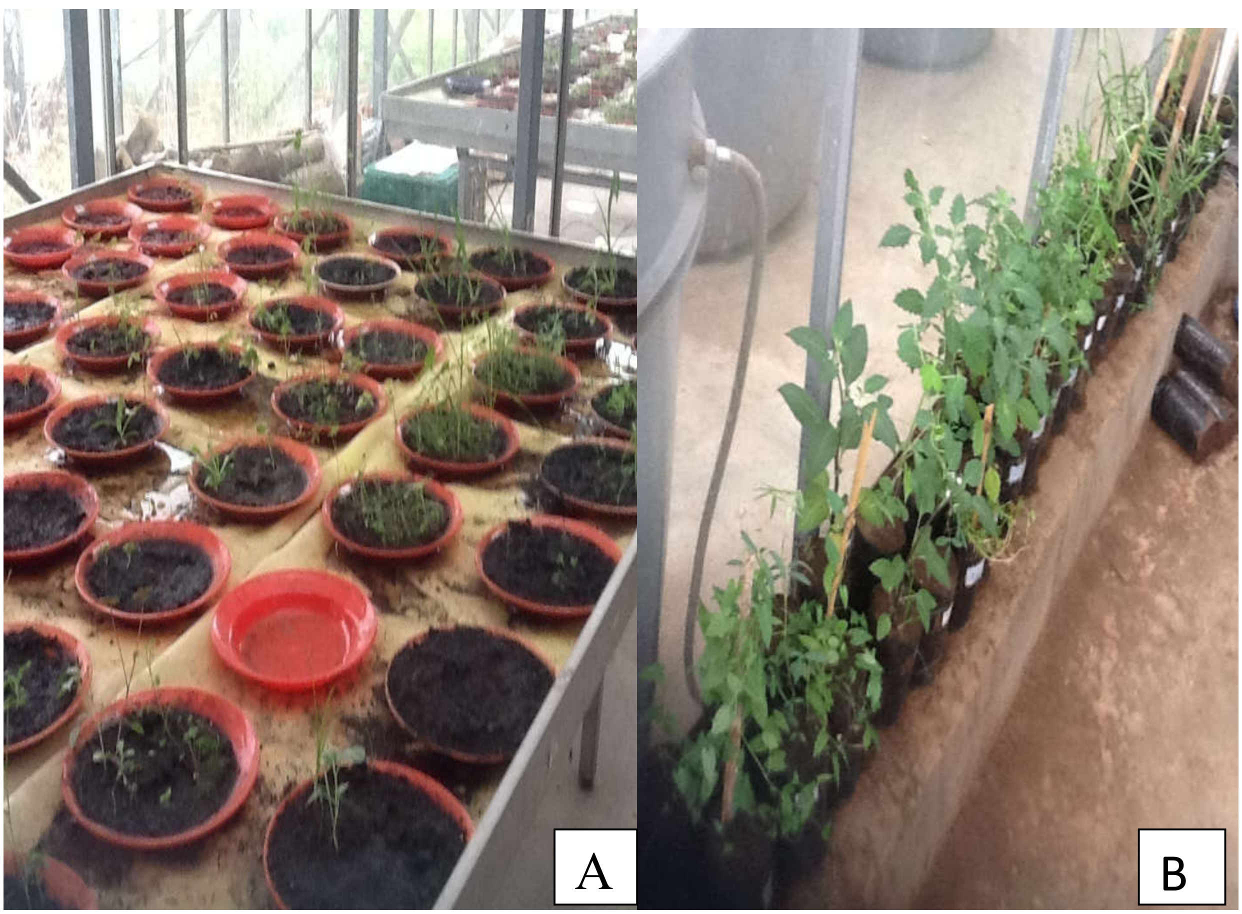
A.Testing of soil texture, B. Testing of electrical conductivity



C. Testing of total nitrigen, D. Testing of organic carbon

E. Testing of cation exchange reaction

Appendix 9. Photograph showing soil seed bank germination experiment at FRC



A.Emerging seedlings, B. Transplanted of seedlings